ARTICLE

Do Changes in Body Mass Index Percentile Reflect Changes in Body Composition in Children? Data From the Fels Longitudinal Study

Ellen W. Demerath, PhD[a], Christine M. Schubert, PhD[a], L. Michele Maynard, PhD[b], Shumei S. Sun, PhD[a], W. Cameron Chumlea, PhD[a], Arthur Pickoff, MD[c], Stefan A. Czerwinski, PhD[a], Bradford Towne, PhD[a], Roger M. Siervogel, PhD[a]

[a]Lifespan Health Research Center, Wright State University School of Medicine, Dayton, Ohio; [b]National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Atlanta, Georgia; [c]Department of Pediatrics, Children's Medical Center, Dayton, Ohio

The authors have indicated they have no financial relationships relevant to this article to disclose.

ABSTRACT

OBJECTIVE. Our aim was to examine the degree to which changes in BMI percentile reflect changes in body fat and lean body mass during childhood and how age and gender affect these relationships.

METHODS. This analysis used serial data on 494 white boys and girls who were aged 8 to 18 years and participating in the Fels Longitudinal Study (total 2319 observations). Total body fat (TBF), total body fat-free mass (FFM), and percentage of body fat (%BF) were determined by hydrodensitometry, and then BMI was partitioned into its fat and fat-free components: fat mass index (FMI) and FFM index (FFMI). We calculated predicted changes (Δ) in FMI, FFMI, and %BF for each 10-unit increase in BMI percentile using mixed-effects models.

RESULTS. FFMI had a linear relationship with BMI percentile, whereas FMI and %BF tended to increase dramatically only at higher BMI percentiles. Gender and age had significant effects on the relationship between BMI percentile and FFMI, FMI, and %BF. Predicted Δ%BF for boys 13 to 18 years of age was negative, suggesting loss of relative fatness for each 10-unit increase in BMI percentile.

CONCLUSIONS. In this longitudinal study of white children, FFMI consistently increased with BMI percentile, whereas FMI and %BF had more complicated relationships with BMI percentile depending on gender, age, and whether BMI percentile was high or low. Our results suggest that BMI percentile changes may not accurately reflect changes in adiposity in children over time, particularly among male adolescents and children of lower BMI.

www.pediatrics.org/cgi/doi/10.1542/peds.2005-0572

doi:10.1542/peds.2005-0572

Key Words
BMI, fat-free mass, body composition, total body fat, obesity, percentage of body fat, longitudinal study, childhood, adolescence, gender differences

Abbreviations
TBF—total body fat
%BF—percentage of body fat
FFM—fat-free mass
FMI—fat mass index
FFMI—fat-free mass index

Accepted for publication Aug 18, 2005

Address correspondence to Ellen W. Demerath, PhD, Lifespan Health Research Center, Wright State University School of Medicine, 3171 Research Blvd, Kettering, OH 45420-4014. E-mail: ellen.demerath@wright.edu

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

CURRENT RECOMMENDATIONS SPECIFY the 85th and 95th percentiles of the Centers for Disease Control and Prevention reference values of BMI to identify children who are aged 2 to 20 years and "at risk for overweight" and "overweight" and who may require additional testing and/or monitoring.[1–10] These percentiles were chosen as clinical action points for obesity prevention in children because they correspond to adult BMI values (eg, 25 kg/m^2) at which the risk for morbidity and mortality are significantly elevated.[3,6,11,12] Evidence also indicates that at or above these BMI percentiles, childhood cardiovascular health status is negatively affected,[13–16] future risk for overweight and obesity is elevated,[17] and future health is compromised.[18–20] Given that BMI percentiles and their recommended cutoff points are more easily interpretable than other BMI metrics and can be compared with nationally representative reference data, they provide a useful clinical tool for screening and prevention of obesity for children.[10] Accordingly, experts recommend that BMI percentile changes be monitored during annual well-child visits for the purpose of obesity prevention.[1]

Although high correlations have been reported between BMI and both total body fat (TBF) and percentage of body fat (%BF) during childhood[21–26] and although BMI above the 85th percentile is predictive of elevated fat mass and %BF in children, BMI is not a precise indicator of the underlying proportion of fat and lean tissue.[3,4] At any particular BMI, body composition varies greatly in children depending on gender, age, maturity, race, height, and body fat distribution.[13,27–29] The extent to which BMI percentile changes may or may not reflect corresponding changes in body fatness (or leanness) in children is not known.

In a previous study,[30] we found that the average incremental changes in BMI over single-year periods were associated with a variety of body composition changes in children, depending on gender and age. The aim of the present investigation was to determine the degree to which longer term serial changes in BMI percentile reflect changes in body composition across a broader span of childhood and adolescence (8–18 years), to assess the impact of gender and age on these relationships, and to provide estimates of the expected changes in body composition that occur in boys and girls across a wide range of BMI percentile shifts.

METHODS

Sample

Data for this study were derived from a subset of participants in the Fels Longitudinal Study, a long-term serial study of human growth, development, and aging.[31] The subset included all of those with body composition data measured at least once between the ages of 8 and 18 years. Participants in the Fels Longitudinal Study typically are enrolled near the time of their birth and represent a cohort of generally healthy individuals.[31] Most are white, resided in southwestern Ohio at the time of their enrollment, and were selected for enrollment on the basis of their parents' willingness to allow them to participate in a long-term serial study. For the present analyses, there were 254 white boys and 240 white girls (494 total individuals) measured between 1976 and 2003, when hydrodensitometry (underwater weighing) was being conducted. From the 494 children, there were 2319 total observations, with an average of 4.7 examinations per participant and a range of between 1 and 11 observations per individual. A proportion of participants ($n = 100$) had a single body composition observation in this age range. Mixed-effects statistical modeling procedures (see below) allowed their data, which improved parameter estimation, to be used in the analyses. The Wright State University Institutional Review Board approved all data-collection procedures, and all participants and their parents or guardians gave informed consent to be involved in this research.

Weight and height were measured for each participant according to standard practice, and BMI was calculated.[32] A BMI percentile then was assigned to each BMI value using the formulas for the appropriate age- and gender-specific percentile value according to the US growth charts for BMI-for-age.[7] Body density was determined through the use of hydrodensitometry.[33] The body composition measures of TBF, fat-free mass (FFM), and %BF from hydrodensitometry were calculated using a multicomponent model over a wide age range.[34]

We detected a small effect of birth year on BMI in this study. Therefore, we included in our models a 2-level categorical term ("birth cohort") whereby subjects were assigned a value of 1 (born 1960–1979) or 2 (born 1980–1995). The proportion of girls who were at risk for overweight (ie, BMI percentile ≥85th) increased from 25.0% in birth cohort 1 to 33.3% in birth cohort 2 ($P <$ .05); the proportion of boys who were at risk for overweight increased from 19.7% in birth cohort 1 to 31.3% in birth cohort 2 ($P <$ .05). A more thorough discussion of these trends is provided elsewhere.[35]

Analytical Methods

The body-composition measures of TBF and FFM were used to separate BMI into a fat mass index (FMI) and a FFM index (FFMI):

$$\mathrm{BMI} = \frac{\text{weight}}{\text{height}^2} = \frac{\text{TBF}}{\text{height}^2} + \frac{\text{FFM}}{\text{height}^2} = \mathrm{FMI} + \mathrm{FFMI}$$

We expressed body-composition data as FMI and FFMI, as first suggested by Van Itallie et al.[36] In this approach, BMI is understood as a simple sum of fat and fat-free components of body weight (FMI + FFMI), each of which is adjusted for (divided by) height^2. These height-adjusted indices may have advantages over both unadjusted measures of lean mass and fat mass (FFM and TBF) and weight-adjusted measures of fat mass (%BF) for the tracking of nutritional status in children.[37–39] However, because there may be residual correlations between the BMI components and height, we also examined TBF and FFM as outcome variables and added height to our regression models as a continuous covariate. This method of height adjustment yielded similar results to the analysis that we present and did not provide the interpretive advantage of the BMI components (data not shown).

Gender- and age-specific means and SDs for BMI, BMI percentile, TBF, FFM, %BF, FMI, and FFMI were computed to describe the study sample. Age groups were defined on whole-year intervals; for example, "8-year-olds" range from 8.00 to 8.99 years, and "9-year-olds" range from 9.00 to 9.99 years. *T* tests were used to test gender differences for each of these variables at each chronological age.

We examined the concurrent serial data on BMI percentile and body composition using gender-specific mixed-effects models (SAS PROC MIXED; SAS Institute, Cary, NC). Mixed-effects models allow for the analysis of longitudinal and other multilevel data in which there are correlations between observations. In this analysis, the span of data (age 8–18 years for some, a shorter range for others) and the frequency of missing data were unbalanced (ie, varied by individual). Mixed-effects models are robust with respect to the effects of such common variation on parameter estimation. BMI percentile, BMI percentile^2, age, age^2, and an age-by-BMI percentile interaction term (age $\times$ BMI percentile) were entered into the models as fixed effects; that is, we chose those variables because we were interested in determining the effects of variations in the level of change in those factors on the level of change in the outcome variables: FMI, FFMI, and %BF. The serial observations for a single person were identified, and the unique subject identification number was considered a random effect, in that we were not interested in testing differences between particular individual children (ie, the "effect" of subject identification number) but wanted to adjust properly for the impact of individual differences in the relationship between BMI percentile and age on body composition (eg, individual differences in slope). The subject (random) effect allowed for a correlation structure to be specified for the serial measures within individuals. In this case, the model specifying an unstructured covariance of the repeated measures correlations was chosen as the best, on the basis of Akaike's Information Criterion and Schwarz's Bayesian Information Criterion.[40,41]

Significance of fixed effects was assessed in a maximum likelihood framework, in which the log-likelihood of each reduced model was compared against the fully parameterized, general model. Terms were reviewed for significance ($P < .05$), and using Akaike's Information Criterion and Bayesian Information Criterion, models that had a log-likelihood that was not significantly different from the general model but had the fewest parameters (ie, were the most parsimonious) were chosen as the best models. Because of the serial nature of the data, the interpretation of the mixed-effects model parameters are in terms of change; if the parameter estimate for the effect of BMI percentile on FMI is 0.05, then we may say that a 1 percentile change in BMI in individuals of a given age corresponds to a 0.05-kg/m^2 change in FMI. A detailed description of the mixed-effects models that we used is provided by Guo et al.[42] To illustrate better the expected changes in body composition with changes in BMI percentile, we used the parameter estimates from the mixed models to calculate predicted changes in FFMI, FMI, and %BF across 2 age ranges, split at the median age of 13 (ie, 8–13 and 13–18 years), for girls and boys at a number of specified 10-unit BMI percentile increments (15th–25th, 25th–35th, etc). All analyses were conducted using SAS, version 9.1 (SAS, Inc, Cary, NC).

RESULTS

Age- and gender-specific means and SDs for the study variables are provided in Table 1. The average BMI of children in this study fell close to the national median,[7] with BMI percentiles ranging from the 42nd to the 58th percentiles at all ages. Although BMI itself tended to be similar in boys and girls, the components of BMI (FFMI and FMI) differed greatly between the genders, particularly in later adolescence. In both genders, BMI was composed predominantly of fat-free tissue (ie, FFMI was ~3–5 times greater than FMI). In boys, the age-related increase in BMI was composed of a large increase in the FFMI, accompanied by relatively small changes in the FMI, whereas in girls, the age-related increase in BMI occurred via a doubling in FMI and smaller increases in FFMI (Table 1).

We found that upward changes in BMI percentile were accompanied by linear increases in FFMI in both genders across all BMI percentiles (BMI percentile^2 term was not significant; Table 2). In contrast, BMI percentile exhibited a quadratic relationship with FMI and %BF (BMI percentile^2 term was significant). These relationships are illustrated in Figs 1 and 2 at 3 selected ages (age 8, 13, and 18 years). It can be seen that children at the upper BMI percentiles tended to have higher FMI and %BF than children at the 50th BMI percentile, for example, whereas the adiposity of children at the 10th and the 50th BMI percentiles tended to differ to a much lesser extent.

There were age and gender differences in the relationship between BMI percentile and body composition as well. Older children generally had higher FFMI for a given BMI percentile than younger children, and older

TABLE 1 Age- and Gender-Specific Means (SDs) of Study Variables

Age, y	N^a	BMI, kg/m²	BMI Percentile	TBF, kg	FFM, kg	FMI, kg/m²	FFMI, kg/m²	%BF
Boys								
8	60	16.18 (1.83)	48.00 (28.18)	4.22 (3.34)[b]	23.72 (3.22)	2.41 (1.86)[b]	13.77 (1.55)[b]	14.36 (9.85)[b]
9	87	17.00 (2.93)	48.59 (31.52)	6.16 (4.92)	26.75 (4.04)[b]	3.16 (2.49)	13.84 (1.56)	17.34 (10.91)[b]
10	101	17.63 (3.63)	46.74 (33.20)	7.24 (6.14)	28.96 (4.28)	3.48 (2.83)	14.15 (1.50)[b]	18.02 (10.57)[b]
11	140	17.61 (2.98)[b]	42.98 (31.49)[b]	7.78 (5.43)[b]	31.21 (4.77)	3.47 (2.28)[b]	14.15 (1.37)	18.52 (8.97)[b]
12	134	18.82 (3.50)	49.21 (33.00)[b]	9.41 (6.71)[b]	35.79 (6.62)	3.90 (2.68)[b]	14.92 (1.65)	19.41 (9.23)[b]
13	120	19.02 (3.36)[b]	44.43 (31.33)[b]	9.73 (6.38)[b]	40.62 (8.23)	3.66 (2.26)[b]	15.36 (1.95)	18.30 (8.07)[b]
14	132	20.25 (3.89)	49.35 (30.66)[b]	10.44 (8.36)[b]	47.52 (8.63)[b]	3.65 (2.88)[b]	16.60 (2.11)[b]	16.77 (9.64)[b]
15	120	20.72 (4.21)	45.00 (30.10)[b]	9.66 (9.23)[b]	53.99 (8.98)[b]	3.14 (2.98)[b]	17.58 (2.18)[b]	13.80 (8.95)[b]
16	122	21.01 (3.60)[b]	44.85 (31.60)[b]	8.61 (6.47)[b]	57.65 (9.33)[b]	2.73 (2.06)[b]	18.28 (2.39)[b]	12.28 (6.93)[b]
17	118	21.71 (3.64)	45.33 (29.86)[b]	8.97 (7.53)[b]	60.46 (7.64)[b]	2.81 (2.35)[b]	18.90 (2.04)[b]	12.02 (7.33)[b]
18	81	21.95 (3.65)	43.36 (30.84)[b]	10.05 (7.61)[b]	60.27 (8.53)[b]	3.14 (2.38)[b]	18.82 (2.19)[b]	13.44 (7.71)[b]
Girls								
8	67	16.33 (2.11)	48.25 (27.77)	5.47 (3.23)	22.78 (3.62)	3.14 (1.76)	13.19 (1.63)	18.70 (9.07)
9	80	17.01 (2.66)	49.32 (30.62)	6.88 (4.09)	25.03 (4.11)	3.64 (1.99)	13.38 (1.64)	20.59 (8.71)
10	110	17.73 (2.76)	50.86 (28.18)	8.65 (4.73)	28.45 (4.86)	4.12 (2.10)	13.61 (1.67)	22.45 (8.65)
11	108	18.51 (2.95)	52.02 (29.42)	9.92 (5.06)	31.35(6.09)	4.45 (2.15)	14.06 (1.86)	23.31 (8.37)
12	114	19.59 (3.16)	57.17 (29.01)	12.37 (5.55)	36.21(6.15)	4.97 (2.09)	14.62 (1.78)	24.67 (6.88)
13	118	20.14 (3.43)	55.65 (28.60)	12.57 (6.28)	39.20 (6.40)	4.88 (2.32)	15.27 (1.88)	23.39 (7.52)
14	122	21.00 (3.43)	57.33 (26.52)	13.77 (6.87)	42.09 (5.91)	5.18 (2.52)	15.83 (1.81)	23.80 (7.72)
15	101	21.58 (3.20)	58.65 (24.82)	15.02 (6.12)	43.43 (5.29)	5.55 (2.21)	16.03 (1.68)	25.06 (6.57)
16	109	21.97 (3.49)	56.05 (24.99)	15.80 (7.53)	43.81 (5.47)	5.83 (2.74)	16.14 (1.70)	25.65 (8.08)
17	108	22.12 (3.48)	53.65 (26.24)	15.88 (6.98)	44.72 (5.82)	5.82 (2.56)	16.30 (1.65)	25.47 (7.50)
18	67	22.01 (2.75)	52.23 (23.74)	16.26 (6.68)	44.30 (5.16)	5.93 (2.44)	16.09 (1.37)	26.24 (7.83)

[a] Data are from 494 children (254 boys and 240 girls) having a total of 2319 observations at ages 8 to 18 years.
[b] Significantly different from girls of the same age (*t* test, $P < .05$).

TABLE 2 Relationships Between Serial BMI Percentile and Body Composition Measures in Boys and Girls

Variable	FFMI, β (SE)	FMI, β (SE)	%BF, β (SE)
Boys			
BMI percentile	0.005 (0.007)	−0.06 (0.011)	−0.12 (0.03)
BMI percentile²	—	0.001 (0.0001)	0.003 (0.0003)
Age	−0.45 (0.03)	0.57 (0.14)	−3.18 (0.65)
Age²	0.034 (0.0046)	−0.023 (0.0051)	−0.14 (0.024)
BMI percentile × age	0.003 (0.0005)	0.002 (0.001)	—
Birth cohort (2 vs 1)	—	—	—
Girls			
BMI percentile	0.04 (0.002)	−0.08 (0.011)	−0.12 (0.05)
BMI percentile²	—	0.0009 (0.0001)	0.002 (0.0003)
Age	0.67 (0.12)	0.06 (0.03)	0.28 (0.16)
Age²	−0.012 (0.004)	—	—
BMI percentile × age	—	0.004 (0.0006)	0.007 (0.003)
Birth cohort (2 vs 1)	−0.31 (0.12)	—	1.34 (0.63)

Estimates are from mixed-effects models in which serial observations of BMI percentile, FFMI, FMI, and %BF are analyzed to determine the relationship in individuals between a change in BMI percentile and the corresponding changes in FFMI, FMI, and %BF, adjusting for the other variables in the models. Em dashes indicate the variable was not significant in the maximum likelihood model comparisons.

girls also had higher FMI and %BF than younger girls for a given BMI percentile. However, in boys, there was a rise and then a fall of %BF with age (highlighted in Fig 1 B); ie, the age 8 curve fell between the age 13 and age 18 curves.

In addition, there were significant age × BMI percentile interactions for FFMI and FMI in boys and for FMI and %BF in girls. This effect is mostly easily seen in the figures, in which an increasing divergence in FMI between older and younger children is observed in both genders (as well as in %BF in girls and FFMI in boys) as BMI percentile increased. In other words, as relatively heavy girls grew older, they had a greater increase in adiposity for the same increase in BMI percentile than did lighter girls. As relatively heavy boys grew older, they had greater increases in both the fat and the lean components of BMI than did lighter boys for a given change in BMI percentile. Another outcome of the age × BMI percentile interaction effect was a "crossing over" of the FMI plots for 8- and 18-year-old boys; at low BMI percentiles, FMI was lower in 18-year-olds than in either 8- or 13-year-olds, whereas at higher BMI percentiles,

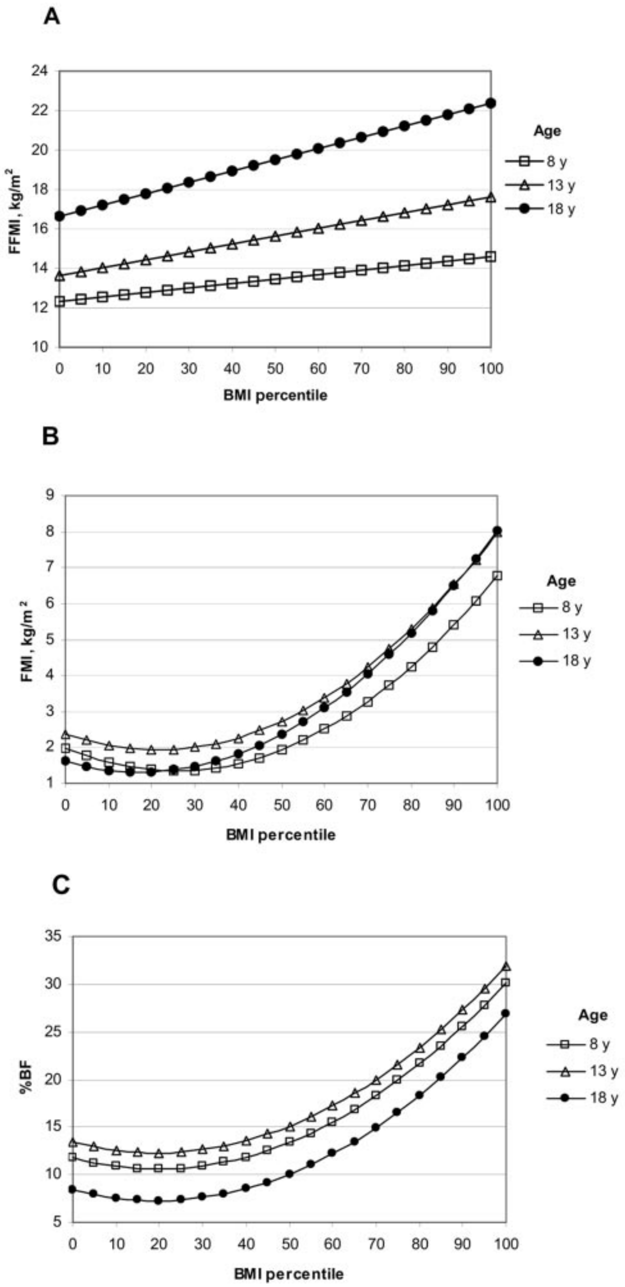

FIGURE 1
Predicted values for FFMI (A), FMI (B), and %BF (C) by BMI percentile and age in boys 8, 13, and 18 years of age.

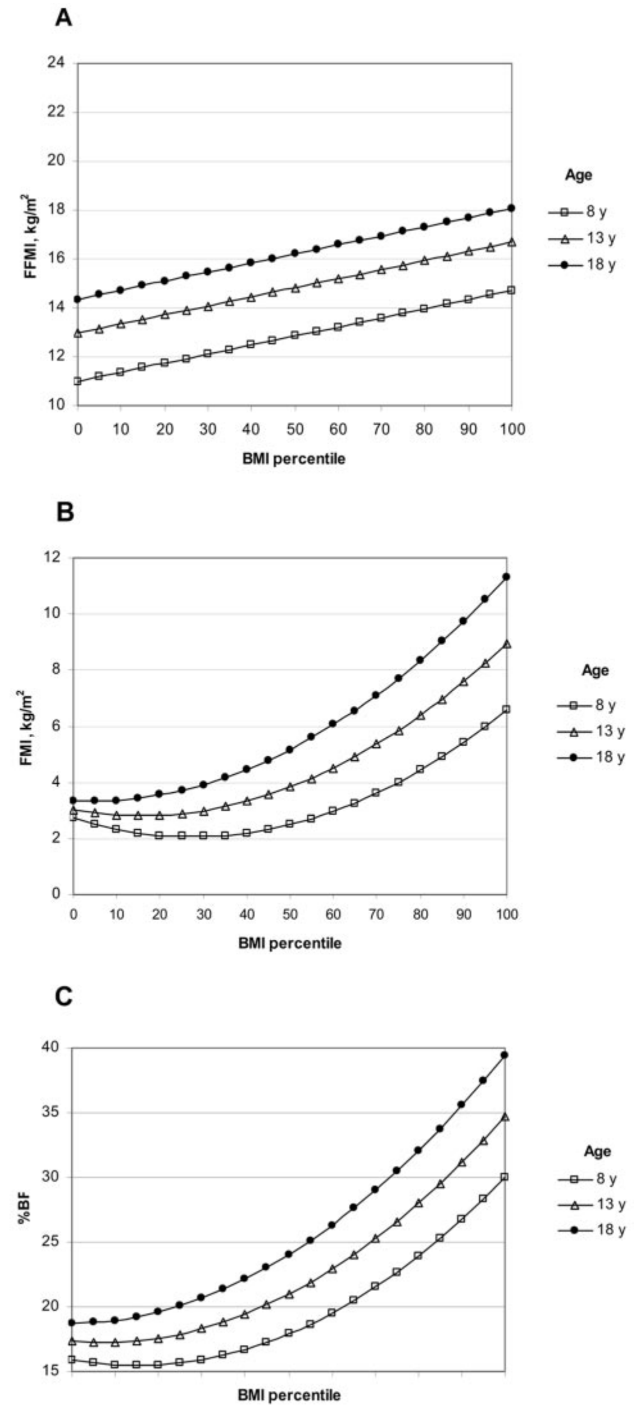

FIGURE 2
Predicted values for FFMI (A), FMI (B), and %BF (C) by BMI percentile and age in girls 8, 13, and 18 years of age.

FMI was higher in 18-year-olds than in 8- or 13-year-olds (Fig 1 B). For a given age and BMI percentile, we also found that FFMI was marginally higher (0.3 kg/m²) and %BF was marginally lower (−1.3%) in girls from birth cohort 2 versus birth cohort 1; no significant cohort effects were found for boys. Exclusion of the birth cohort term from our analyses did not substantially change the parameter estimates for the other terms in the models. We therefore conclude that although there may be a small secular change in body composition in the girls in this analysis (including an increase in the lean body mass component of BMI), it did not have an impact on the relationship between BMI percentile and body composition, which was the major focus of this analysis.

Because observed changes in BMI and body composition occur naturally over time (chronological age), Table 2 and Figs 1 and 2 do not describe accurately the expected changes in body composition for individual children. To illustrate properly the predicted concurrent changes in BMI percentile, FFMI, FMI, and %BF in children, we calculated predicted (model-derived) changes in body composition for each 10-unit increase in BMI percentile using the estimates provided in Table 2 (Table 3). Using this approach, we found that ΔFFMI (ie, the change in FFMI for each 10-unit increase in BMI percentile) was similar in younger (8- to 13-year-old) boys and girls, whereas adolescent boys (age 13–18 years) had a greater ΔFFMI than adolescent girls (~4.0 vs 1.89 kg/m^2). As expected, the opposite was the case for FMI, in that ΔFMI was 2 to 8 times higher in girls than in boys across both age spans and for all tested BMI percentile increments. It is interesting that ΔFFMI was higher than ΔFMI in boys, even as boys passed into the overweight range (85th–95th percentile), and this was particularly true for boys who were 13 to 18 years of age. Δ%BF was positive in younger girls, younger boys, and older girls, and its magnitude increased approximately three- to fivefold from the 15th to the 95th percentiles. However, in boys between the ages of 13 and 18 years, we noted that Δ%BF was consistently negative despite increasing BMI percentile, even when BMI percentile was high (eg, 85th–95th percentile). That is, adolescent boys who increased in BMI percentile were predicted nonetheless to decline in %BF.

DISCUSSION

The American Academy of Pediatrics recommends that clinicians identify children who are at risk for developing obesity by plotting BMI for all children and adolescents on the Centers for Disease Control and Prevention BMI-for-age percentile grids once a year and then use the change in BMI to identify children with excessive weight gain relative to linear growth.[1] In this way, "significant changes on growth patterns (eg, upward crossing of weight-for-age or BMI percentiles) can be recognized and addressed before children are severely overweight"[1] (p 426). Similar statements appear in the recommendations made by the US Department of Health and Human Services.[2] To help clinicians understand the meaning of a change in BMI percentile, we believe that it is important to examine how the BMI percentile performs as a measure of body composition in children. The longitudinal data presented in this analysis, collected from seemingly healthy children at annual study visits over a 4- to 5-year period on average (and 11 years for some), approximate the recommended conditions of yearly pediatric office visits in the community.

The curvilinear relationship between BMI percentile and both %BF and FMI indicates that at any given age, the difference in adiposity between children who are at the low to middle range of the BMI percentile curve is minimal, whereas the difference in adiposity between children in the normal weight to overweight range may be high. These observations suggest that BMI percentile tends to reflect adiposity differences predominantly at higher BMI percentiles and therefore support to some extent the use of high BMI percentile cutoff points (eg, 85th or 95th percentile) to identify children who are at risk for obesity at a given time. It also suggests that changes in BMI percentile in children of lower BMI percentile may occur without appreciable change in adiposity.

In accordance with previous reports, there were significant age and gender effects on the relationship between BMI percentile and both FMI and %BF in children.[13,23–25,29,30] To illustrate this, we can consider a commonly used definition of overfatness. Although no consensus has been reached yet on the definition of excess adiposity in children, it has been suggested that percentage of body fat above 25% in boys and 30% to 35% in girls constitutes obesity during childhood.[43] We

TABLE 3 Changes (Δ) in FFMI, FMI, and %BF for Given Changes in BMI Percentile and Age According to Gender

Δ in Age, y	Δ in BMI Percentile	Boys			Girls		
		ΔFFMI, kg/m^2	ΔFMI, kg/m^2	Δ%BF	ΔFFMI, kg/m^2[a]	ΔFMI, kg/m^2	Δ%BF
8–13	15th–25th	1.89	0.65	1.20	2.49	3.73	2.44
8–13	25th–35th	2.04	0.95	1.80	2.49	4.11	3.19
8–13	35th–45th	2.19	1.25	2.40	2.49	4.49	3.94
8–13	45th–55th	2.34	1.55	3.00	2.49	4.87	4.69
8–13	55th–65th	2.49	1.85	3.60	2.49	5.25	5.44
8–13	65th–75th	2.64	2.15	4.20	2.49	5.63	6.19
8–13	75th–85th	2.79	2.45	4.80	2.49	6.01	6.94
8–13	85th–95th	2.94	2.75	5.40	2.49	6.39	7.69
13–18	15th–25th	3.74	−0.40	−5.80	1.89	3.93	2.79
13–18	25th–35th	3.89	−0.10	−5.20	1.89	4.31	3.54
13–18	35th–45th	4.04	0.20	−4.60	1.89	4.69	4.29
13–18	45th–55th	4.19	0.50	−4.00	1.89	5.07	5.04
13–18	55th–65th	4.34	0.80	−3.40	1.89	5.45	5.79
13–18	65th–75th	4.49	1.10	−2.80	1.89	5.83	6.54
13–18	75th–85th	4.64	1.40	−2.20	1.89	6.21	7.29
13–18	85th–95th	4.79	1.70	−1.60	1.89	6.59	8.04

[a] The predicted change in FFMI in girls was constant within each age range regardless of BMI percentile.

found that boys reached this critical threshold of body fat at different BMI percentiles, depending on their age: at the 90th BMI percentile at 8 years of age, at the 85th BMI percentile at 13 years of age, and at the 95th percentile at 18 years of age (Fig 1 C). On average, the 30% body fat threshold for girls was not attained at any BMI percentile by 8-year-olds and was attained at the 85th percentile for 13-year-olds and at the 75th percentile for 18-year-olds (Fig 2 C). Even in the overweight range, therefore, BMI percentile may reflect different degrees of "overfatness" in boys versus girls and in younger versus older children. The most striking demonstration of this relationship is shown by the estimated mean change in %BF in boys across a given age range and BMI percentile change (Table 3). %BF was predicted to decline with each 10-unit increases in BMI percentile in boys who were going through adolescence (ie, from 13 to 18 years of age; Table 3). This likely stems from the changing composition of BMI (FFMI and FMI) in this age group. There exist very strong age-related increases in the relative proportion of lean mass to fat mass in adolescent boys, which we observed as large ΔFFMI compared with ΔFMI in boys from 13 to 18 years, even in the overweight range. Thus, changes in BMI percentile may be a somewhat inaccurate barometer of underlying changes in adiposity in male adolescents.

Using a somewhat different approach from the one used in our study, Freedman et al[44] highlighted the nonlinear relationship between BMI percentile and body fatness. In a large multiethnic sample, children who were above the 50th BMI percentile (and especially above the 85th percentile) showed correlations between BMI and FMI but weak correlations between BMI and FFMI. In contrast, in children who were below the 50th percentile of BMI, the correlation between BMI and FMI was weak and the correlation between BMI and FFMI was strong.[44] These researchers concluded, as do we, that differences in BMI percentile in children who are relatively light are largely attributable to differences in FFM (FFMI), not fat mass (FMI). We extended their findings by the use of longitudinal data, which allowed estimates of the impact of particular changes in BMI percentile on body composition to be made.

Few studies have examined the relationship between BMI and the fat-free (lean) component of body weight in healthy children (eg, 30,39,44); most recent studies have emphasized the relationship of BMI to fat mass or %BF,[13,21,23–25,27,29,45] yet, as we have shown here and have reported previously,[30,46] BMI increases are attributable predominantly to increases in the fat-free component of BMI (FFMI) in growing children, particularly in adolescent boys. Indeed, the majority of the age-related increase in BMI from mid-childhood onward (which follows the age at "adiposity rebound"[47]) has been attributed to increasing FFM, rather than fat mass, relative to height in both genders.[48] We found that increases in BMI percentile primarily reflect linear increases in FFMI and that the increase in FFMI for a 10-unit increase in BMI percentile (ΔFFMI) was similar (at ~2 kg/m^2) in both younger and older girls and across all BMI percentile increments. ΔFFMI was somewhat higher in older boys (4–5 kg/m^2) than in younger boys (2–3 kg/m^2), yet, overall, these results indicate that height-adjusted FFM changes predictably with BMI percentile. To that extent, BMI percentile may be a more stable indicator of FFM than it is of body fat in children.

A number of articles have critiqued the use of %BF (in which fat mass is adjusted only for weight and not for height) and FFM (which is not adjusted for body size) to express body composition in children.[28,37,48] The advantages of the FMI and FFMI used in our study are that they are height-adjusted measures of body composition that are discrete, easy to calculate, and expressed in the common units of BMI.[38] Despite these advantages, height$^{2.0}$ may not be the best adjustment of body composition for stature in children[49]; the power to which height must be raised (p) to minimize the correlation with height may be higher or lower than 2.0, depending on age and skeletal maturity.[50] In our study, the residual correlations between height and both FMI and FFMI ranged between 0.0 and 0.4 (for FMI, r was highest at ages 8–12 years; for FFMI, r was highest at ages 12–16 years). This indicates that p tended to be >2.0, as was found by both Franklin[51] and Freedman et al.[52] To examine the impact of residual correlation on the models, we added height as a continuous covariate in our regression analyses. Our results did not qualitatively change after this addition, so we concluded, as did Wells and Cole,[38] that misspecification of p does not have a major effect on the relationship between BMI and body composition unless one makes comparisons across groups with substantially different growth patterns. Presentation of both height-adjusted (eg, FMI) and weight-adjusted (%BF) body fat measures may allow for a better understanding of the impact of growth on body-composition changes in children.

Our study sample was composed entirely of white children. It has been shown that race is a significant modifier of the relationship between BMI and childhood body composition.[13] Therefore, our results cannot be extended to Hispanic, non-Hispanic black, or Asian children. The relationship between BMI percentile and body composition may also be affected by sexual maturation,[13,21] and we did not address this in the present analysis. Pubertal development is not routinely assessed when monitoring BMI in clinical practice, and because Tanner stage–specific BMI charts are not available, our choice of chronological age provides useful estimates of the changing relationship between BMI percentile and body composition in growing children.

CONCLUSIONS

Our results suggest caution in the use of BMI percentile changes as an indicator of changes in body fatness in children. In this sample of white children, differences in BMI percentile tended to reflect large differences in body fatness only when BMI percentile was relatively high. In fact, BMI percentile changes in boys who were 13 to 18 years of age were associated with decreases in %BF even in the overweight range. In contrast, increases in BMI percentile were accompanied by uniform increases in the FFM component across the range of BMI percentiles, with older boys increasing faster in FFMI than younger boys. We conclude that increases in BMI percentile may represent varying changes (and sometimes decreases) in relative fatness, depending on the gender, age, and BMI percentile of the child.

From a clinical standpoint, our results indicate that concern regarding excess body fat would still lie with the child who is at a high BMI percentile more than with the child who is at a low BMI percentile at a given point in time. Nonetheless, national pediatric guidelines currently indicate that serial changes in BMI over time should be monitored for all children, not just for those who are at a higher BMI, to detect significant divergence from the child's BMI trajectory. Given the current recommendation of BMI as a global indicator of obesity risk in children, it is important for clinicians to be aware that a child who deviates substantially from their previous BMI percentile may not have experienced changes in adiposity but rather may have experienced changes in lean body mass, particularly if the child is a male adolescent or falls at the lower BMI percentiles. These findings have implications for the interpretation of BMI percentile changes in clinical practice, not only for understanding the process of adipose tissue accrual in children but also for the tracking of general nutritional status.

ACKNOWLEDGMENTS

This work was supported by National Institutes of Health grants HD-12252, HD-36342, and HD-38356.

We thank the children who participated in the study and the anonymous reviewers for helpful and insightful comments.

REFERENCES

1. American Academy of Pediatrics, Committee on Nutrition. Prevention of pediatric overweight and obesity. *Pediatrics.* 2003; 112:424–430
2. Barlow S, Dietz W. Obesity evaluation and treatment: expert committee recommendations. *Pediatrics.* 1998;102(3). Available at: www.pediatrics.org/cgi/content/full/102/3/e29
3. Bellizzi MC, Dietz WH. Workshop on childhood obesity: summary of the discussion. *Am J Clin Nutr.* 1999;70:173S–175S
4. Dietz WH, Bellizzi MC. Introduction: the use of body mass index to assess obesity in children. *Am J Clin Nutr.* 1999;70: 123S–125S
5. Flegal KM, Wei R, Ogden C. Weight-for-stature compared with body mass index-for-age growth charts for the United States from the Centers for Disease Control and Prevention. *Am J Clin Nutr.* 2002;75:761–766
6. Himes J, Dietz W. Guidelines for overweight in adolescent preventive services: recommendations from an expert committee. *Am J Clin Nutr.* 1994;59:307–316
7. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, et al. CDC growth charts: United States. *Adv Data.* 2000;(314):1–27
8. Must A, Dallal G, Dietz W. Reference data for obesity: 85th and 95th percentiles of body mass index (wt/ht^2) and triceps skinfold thickness. *Am J Clin Nutr.* 1991;53:839–846
9. Must A, Dallal G, Dietz W. Reference data for obesity: 85th and 95th percentiles of body mass index (wt/ht^2)—a correction. *Am J Clin Nutr.* 1991;54:773
10. Ogden CL, Kuczmarski RJ, Flegal KM, et al. Centers for Disease Control and Prevention 2000 growth charts for the United States: improvements to the 1977 National Center for Health Statistics version. *Pediatrics.* 2002;109:45–60
11. Flegal KM, Ogden CL, Wei R, Kuczmarski RL, Johnson CL. Prevalence of overweight in US children: comparison of US growth charts from the Centers for Disease Control and Prevention with other reference values for body mass index. *Am J Clin Nutr.* 2001;73:1086–1093
12. Ogden CL, Flegal KM, Carroll MD, Johnson CL. Prevalence and trends in overweight among US children and adolescents, 1999–2000. *JAMA.* 2002;288:1728–1732
13. Daniels SR, Khoury PR, Morrison JA. The utility of body mass index as a measure of body fatness in children and adolescents: differences by race and gender. *Pediatrics.* 1997;99:804–807
14. Freedman DS, Dietz WH, Srinivasan SR, Berenson GS. The relation of overweight to cardiovascular risk factors among children and adolescents: the Bogalusa Heart Study. *Pediatrics.* 1999;103:1175–1182
15. Freedman DS, Khan LK, Dietz WH, Srinivasan SR, Berenson GS. Relationship of childhood obesity to coronary heart disease risk factors in adulthood: the Bogalusa Heart Study. *Pediatrics.* 2001;108:712–718
16. Srinivasan SR, Myers L, Berenson GS. Rate of change in adiposity and its relationship to concomitant changes in cardiovascular risk variables among biracial (black-white) children and young adults: the Bogalusa Heart Study. *Metab Clin Exp.* 2001;50:299–305
17. Sun S, Wu W, Chumlea W, Roche AF. Predicting overweight and obesity in adulthood from body mass index values in childhood and adolescence. *Am J Clin Nutr.* 2002;76:653–658
18. Must A, Jacques P, Dallal G, Bajema C, Dietz W. Long-term morbidity and mortality of overweight adolescents: a follow-up of the Harvard Growth Study of 1922 to 1935. *N Engl J Med.* 1992;327:1350–1355
19. Must A, Strauss RS. Risks and consequences of childhood and adolescent obesity. *Int J Obes.* 1999;23:S2–S11
20. Siervogel RM, Wisemandle W, Guo SS, Chumlea WC, Towne B. Lifetime overweight status in relation to serial changes in body composition and risk factors for cardiovascular disease: the Fels Longitudinal Study. *Obes Res.* 2000;8:422–430
21. Field A, Laird N, Steinberg E, Fallon E, Semega-Janneh M, Yanovski J. Which metric of relative weight best captures body fatness in children? *Obes Res.* 2003;11:1345–1352
22. Goran MI, Driscoll P, Johnson R, Nagy TR, Hunter G. Cross-calibration of body-composition techniques against dual-energy X-ray absorptiometry in young children. *Am J Clin Nutr.* 1996;63:299–305
23. Goulding A, Gold E, Cannan R, Taylor R, Williams S, Lewis-Barned N. DEXA supports the use of BMI as a measure of fatness in young girls. *Int J Obes.* 1998;20:1014–1021
24. Lindsay RS, Hanson RL, Roumain J, Ravussin E, Knowler WC,

Tataranni PA. Body mass index as a measure of adiposity in children and adolescents: relationship to adiposity by dual energy X-ray absorptiometry and to cardiovascular risk factors. *J Clin Endocrinol Metab.* 2001;86:4061–4067
25. Pietrobelli A, Faith MS, Allison DB, Gallagher D, Chiumello G, Heymsfield SB. Body mass index as a measure of adiposity among children and adolescents: a validation study. *J Pediatr.* 1998;132:204–210
26. Roche A, Siervogel R, Chumlea W, Webb P. Grading body fatness from limited anthropometric data. *Am J Clin Nutr.* 1981; 34:2831–2838
27. Hannan W, Wrate R, Cowen S, Freeman C. Body mass index as an estimate of body fat. *Int J Eat Disord.* 1995;18:91–97
28. Horlick M. Body mass index in childhood-measuring a moving target. *J Clin Endocrinol Metab.* 2001;86:4059–4060
29. Taylor R, Jones I, Williams S, Goulding A. Body fat percentages measured by dual-energy x-ray absorptiometry corresponding to recently recommended body mass index cutoffs for overweight and obesity in children and adolescents aged 3–18 y. *Am J Clin Nutr.* 2002;76:1416–1421
30. Maynard LM, Wisemandle W, Roche AF, Chumlea WC, Guo SS, Siervogel RM. Childhood body composition in relation to body mass index. *Pediatrics.* 2001;107:344–350
31. Roche AF. *Growth, Maturation and Body Composition: The Fels Longitudinal Study 1929–1991*. Cambridge, United Kingdom: Cambridge University Press; 1992
32. Lohman TG, Roche AF, Martorell R, eds. *Anthropometric Standardization Reference Manual*. Champaign, IL: Human Kinetics Publishers; 1988
33. Chumlea W, Knittle J, Roche A, Siervogel R, Webb P. Size and number of adipocytes and measures of body fat in boys and girls 10 to 18 years of age. *Am J Clin Nutr.* 1981;34:1791–1797
34. Guo S, Chumlea W, Roche A, Siervogel R. Age- and maturity-related changes in body composition during adolescence into adulthood: the Fels Longitudinal Study. *Int J Obes Relat Metab Disord.* 1997;21:1167–1175
35. Demerath E, Choh A, Sun S, et al. Changes in the tissue composition of BMI in children, 1980–2000: the Fels Longitudinal Study. *Obes Res*. 2006;13(suppl):A27–A28
36. Van Itallie T, Yang M-U, Heymsfield S, Funk R, Boileau F. Height-normalized indices of the body's fat-free mass and fat mass: potentially useful indicators of nutritional status. *Am J Clin Nutr.* 1990;52:953–959
37. Wells JCK. A critique of the expression of paediatric body composition data. *Arch Dis Child.* 2001;85:67–72
38. Wells JCK, Cole TJ. Adjustment of fat-free mass and fat mass for height in children aged 8 y. *Int J Obes Relat Metab Disord.* 2002;26:947–952
39. Wells JCK, Coward WA, Cole TJ, Davies PSW. The contribution of fat and fat-free tissue to body mass index in contemporary children and the reference child. *Int J Obes Relat Metab Disord.* 2002;26:1323–1328
40. Akaike H. A new look at the statistical model identification. *IEEE Trans.* 1974;19:716–723
41. Schwarz G. Estimating the dimension of a model. *Ann Stat.* 1978;6:461–464
42. Guo S, Chi E, Wisemandle W, Chumlea W, Roche A, Siervogel R. Serial changes in blood pressure from childhood into young adulthood for females in relation to body mass index and maturational age. *Am J Hum Biol.* 1998;10:589–598
43. Asayama K, Ozeki T, Sugihara S, et al. Criteria for medical intervention in obese children: a new definition of "obesity disease" in Japanese children. *Pediatr Int.* 2003;45:642–646
44. Freedman DS, Wang J, Maynard LM, et al. Relation of BMI to fat and fat-free mass among children and adolescents. *Int J Obes Relat Metab Disord.* 2005;29:1–8
45. Mei ZG, Grummer-Strawn LM, Pietrobelli A, Goulding A, Goran MI, Dietz WH. Validity of body mass index compared with other body composition screening indexes for the assessment of body fatness in children and adolescents. *Am J Clin Nutr.* 2002;75:978–985
46. Siervogel R, Maynard LM, Wisemandle W, et al. Annual changes in total body fat and fat free mass in children from 8 to 18 years in relation to changes in body mass index: the Fels Longitudinal Study. *Ann N Y Acad Sci.* 2000;904:420–423
47. Rolland-Cachera MF, Deheeger M, Bellisle F, Sempe M, Guilloud-Bataille M, Patois E. Adiposity rebound in children: a simple indicator for predicting obesity. *Am J Clin Nutr.* 1984; 39:129–135
48. Wells JCK. Body composition in childhood: effects of normal growth and disease. *Proc Nutr Soc.* 2003;62:521–528
49. Freedman DS, Thornton JC, Mei Z, et al. Height and adiposity among children. *Obes Res.* 2004;12:846–853
50. Cole TJ. Weight/height^p compared to weight/height^2 for assessing adiposity in childhood: influence of age and bone age on p during puberty. *Ann Hum Biol.* 1986;13:433–451
51. Franklin M. Comparison of weight and height relations in boys from 4 countries. *Am J Clin Nutr.* 1999;70:157S–162S
52. Freedman D, Khan L, Serdula M, Dietz W, Srinivasan S, Berenson G. Inter-relationships among childhood BMI, childhood height, and adult obesity: the Bogalusa Heart Study. *Int J Obes Relat Metab Disord.* 2004;28:10–16

PEDIATRICS®

OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Do Changes in Body Mass Index Percentile Reflect Changes in Body Composition in Children? Data From the Fels Longitudinal Study

Ellen W. Demerath, Christine M. Schubert, L. Michele Maynard, Shumei S. Sun, W. Cameron Chumlea, Arthur Pickoff, Stefan A. Czerwinski, Bradford Towne and Roger M. Siervogel

Pediatrics 2006;117;e487
DOI: 10.1542/peds.2005-0572