Body Mass Index Is a Better Indicator of Body Composition than Weight-for-Length at Age 1 Month

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Objective To assess whether body mass index (BMI) provides a better assessment of measured adiposity at age 1 month compared with weight-for-length (WFL).

Study design Participants were healthy term-born infants in the Infant Growth and Microbiome (n = 146) and the Baby Peas (n = 147) studies. Length, weight, and body composition by air displacement plethysmography were measured at 1 month. World Health Organization-based WFL and BMI *z*-scores were calculated. Within-cohort *z*-scores of percent fat-Z, fat mass-Z, fat mass/length^2-Z, fat mass/length^3-Z, fat-free mass-Z, and fat-free mass/length^2-Z were calculated. Correlation and multiple linear regression (adjusted for birth weight) analyses tested the associations between body composition outcomes and BMI-Z vs WFL-Z. Quantile regression was used to test the stability of these associations across the distribution of body compositions.

Results The sample was 52% female and 56% African American. Accounting for birth weight, both BMI-Z and WFL-Z were strongly associated with fat mass-Z (coefficients 0.56 and 0.35, respectively), FM/L^2-Z (0.73 and 0.51), and FM/L^3-Z (0.79 and 0.58), with stronger associations for BMI-Z compared with WFL-Z ($P < .05$). Even after accounting statistically for birth weight, BMI-Z was persistently more strongly associated than WFL-Z with body composition outcomes across the distribution of body composition outcomes.

Conclusions We demonstrate in 2 distinct cohorts that BMI is a better indicator of adiposity in early infancy compared with WFL. Our findings support the preferred use of BMI for growth and nutritional status assessment in infancy. *(J Pediatr 2018;■■:■■-■■).*

See editorial, p •••

Rapid weight gain during early infancy is related to later obesity risk.[1-4] However, whether gains in fat mass (vs lean mass) in early infancy represent the salient component of this risk factor is unclear. In human infants, adiposity increases during the first year of life, reaching a peak around age 6-9 months.[5] The deposition of adipose tissue is thought to be protective, insulating the body from temperature extremes and providing energy reserves. However, with 8% of US infants and toddlers thought to carry excess weight, and an obesity prevalence of 17% among US children and adolescents,[6] there is increasing interest in body composition changes in early life, because this period may represent an opportunity for early targeted interventions in populations at high risk for future obesity.[7] There is no widely accepted definition of obesity in infants,[6] and body composition assessment in infants is challenging. However, studies have shown that air displacement plethysmography provides accurate and validated assessments of body fat in early infancy.[8-11]

Because routine measurement of body composition in the clinical setting is not feasible, it is useful to identify the anthropometric measurements that provide the most accurate proxy for body composition. The World Health Organization (WHO) released body mass index (BMI)-for-age growth charts for children aged <2 years in 2006,[12] but these charts have not been adopted for routine general pediatric

BMI	Body mass index
BMI-Z	Body mass index *z*-score
BW-Z	Birth weight *z*-score
IGRAM	Infant Growth and Microbiome Study
WFL	Weight-for-length
WFL-Z	Weight-for-length *z*-score
WHO	World Health Organization

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use. Although BMI is the anthropometric standard recommended by the American Academy of Pediatrics for assessment of weight status in children aged >2 years, weight-for-length (WFL) is recommended for children aged <2 years.[13] We previously showed that BMI *z*-score (BMI-Z) in infancy had a significantly higher positive predictive value for early childhood obesity compared with WFL *z*-score (WFL-Z).[14] The associations of these 2 measures with body composition during infancy is unknown. The aim of this study was to investigate whether BMI-Z or WFL-Z at age 1 month provides a better assessment of body composition by air displacement plethysmography using 2 independent cohorts.

Methods

The study sample included healthy, term (≥37 weeks of gestational age) infants with simultaneous measurements of length, weight, and body composition by air displacement plethysmography performed at age 1 month ± 14 days. Subjects were enrolled in the Infant Growth and Microbiome Study (IGRAM) between 2014 and 2015 at The Children's Hospital of Philadelphia or in the Baby Peas Study between 2003 and 2009 at the Oklahoma University Health Sciences Center. Both studies were performed in accordance with the policies and procedures of the Institutional Review Boards of the respective institutions.

IGRAM is a prospective, longitudinal cohort study of infant growth in the first 2 years of life in infants born to African American mothers. Inclusion criteria included otherwise healthy African American mothers (aged ≥18 years) planning to deliver at the Hospital of the University of Pennsylvania who attended prenatal visits starting before 18 weeks gestation, had a prepregnancy BMI <25 kg/m^2 or >30 kg/m^2, and had pregnancies that delivered at term without any maternal or fetal adverse outcomes. Infants were excluded if they were born preterm (<37 weeks), were of twin/other multiples status, or was discovered to have a chromosomal anomaly, intrauterine growth restriction, a significant illness affecting growth and development, or a sibling enrolled in the study.

Baby Peas is a collection of prospective longitudinal growth studies investigating various endpoints in infancy and early life. These studies had the following inclusion criteria: maternal age between 18 and 45 years at the time of delivery, term pregnancy lasting >37 weeks, singleton birth, and an infant hospital stay of <3 days after delivery. Exclusion criteria for both included tobacco use or alcohol consumption (>1 drink per week) during pregnancy, pregestational or gestational diabetes, and presumed or known congenital birth defects.

Sex and gestational age were obtained, and exact age (in days) at the 1-month visit was calculated. Weight (in kilograms) and length (in centimeters) measured using a length board were obtained on all subjects using standard procedures[15] by trained anthropometrists, and BMI (weight in kilograms divided by height in meters squared) was calculated. Body composition (percent fat, fat mass in kilograms, and fat-free mass in kilograms) was determined by air displacement plethysmography (Pea Pod Infant Body Composition System; COSMED, Concord, California), following the manufacturer's recommended procedures. To express these body tissue compartments relative to skeletal size, indices of fat mass and fat free mass were calculated.[16] Fat mass was adjusted for length using length-squared and length-cubed indices: fat mass/length^2 and fat mass/length^3, respectively. The latter was considered the optimal index of fat mass independent of length in a cohort of Irish infants at birth and at age 2 months.[16] Fat-free mass index was calculated using fat-free mass/length^2, which has previously been posited to be the optimal index of correction of fat-free mass for length in this age group.[16]

WHO weight-for-length (WFL) *z*-scores (WFL-Z) and BMI *z*-scores (BMI-Z) were calculated using "zanthro" commands in Stata version 14.0 (StataCorp, College Station, Texas), based on published references.[17] WFL-Z and BMI-Z were each calculated using sex-specific values. BMI-Z was also adjusted for gestational age, because the WHO BMI references include this capacity, even among infants born at ≥37 weeks gestational age.

Body composition changes rapidly in early infancy and is significantly associated with age and sex.[18] Accordingly, linear regression models were used to adjust all body composition measures for age and sex. The standardized regression residuals were used to calculate body composition variable *z*-scores (percent fat-Z, fat mass-Z, fat mass/length^2-Z, fat mass/length^3-Z, fat-free mass-Z, and fat-free mass/length^2-Z) for infants in the combined IGRAM and Baby Peas cohorts.

Population ancestry (self-reported), birth weight, and birth length were obtained in all subjects where available. Population ancestry was categorized as European, African American, or other, because the majority of subjects in the Baby Peas cohort were European and all subjects in the IGRAM study, by design, were African-American. Given the significant difference in population ancestry between cohorts, a sensitivity analysis was performed adjusting each body composition variable for cohort (IGRAM vs Baby Peas) and ancestry in addition to age and sex. The *z*-scores for birth weight (BW-Z) and birth length (birth length-Z) were calculated using the INTERGROWTH-21st newborn size application tool, which included adjustment for sex, and gestational age.[19]

Statistical Analyses

Bivariate analyses (2-sided *t* and χ^2 tests, as appropriate) were used to assess for differences in clinical characteristics between the 2 cohorts. Pearson correlation analysis was performed to investigate the association between each body composition variable *z*-score and BMI-Z or WFL-Z. To determine whether a stronger correlation existed with either BMI-Z or WFL-Z and each body composition variable, Fisher *r*-to-*z* transformation was used to test for significant differences between the 2 correlation coefficients using the Stata command "corcor" and the R package "cocor."[20] Sensitivity analyses were performed using body composition *z*-scores that were also adjusted for age, sex, and cohort along with age, sex, and population ancestry. To examine expected associations between size at birth and later body composition and growth,[21] Pearson correlation analysis was used to test the associations between BW-Z and BMI-Z or WFL-Z at age 1 month, and Fisher *r*-to-*z*

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transformation was used to test for significant differences between the 2 correlation coefficients.

Multivariable linear regression analyses were then performed to test the associations of BMI-Z and WFL-Z at age 1 month with each body composition variable *z*-score, independent of BW-Z. The adjustment for BW-Z was done to understand the extent to which body composition at age 1 month is simply a reflection of birth size. Quantile regression analysis[22,23] was used to test the associations of BMI-Z and WFL-Z at the median and at percentiles above and below the median of each body composition variable *z*-score, independent of BW-Z. This analysis was done to understand how BMI-Z and WFL-Z vary across the distribution of each body composition variable *z*-score. Postestimation linear combinations of estimators were performed to examine the effect of the 10th percentile vs the 90th percentile of BMI-Z or WFL-Z at age 1 month on each body composition variable *z*-score.

Analyses were performed using Stata version 14.0 (StataCorp, College Station, Texas) and R version 3.0.0 statistical software. For all analyses, 2-tailed statistical significance was noted as $P < .05$.

Results

The combined sample consisted of 293 subjects, including 146 from the IGRAM cohort and 147 from the Baby Peas cohort (**Table I**). The sample was 52% female, with 56% of African American and 33% of European ancestry, and mean age 30.1 ± 5.8 days. There was a difference in ancestry between the 2 cohorts: 100% of the IGRAM subjects were African American, compared with 12% of the Baby Peas subjects. The IGRAM infants had significantly lower birth weight, BW-Z, birth length, and birth length-Z, consistent with previous reports among African American infants (**Table I**).[24,25]

IGRAM infants had significantly higher mean 1-month BMI than Baby Peas infants (14.9 kg/m^2 vs 14.5 kg/m^2; $P = .006$). This reflected their significantly shorter mean length (53.3 cm vs 54 cm; $P = .005$) despite the same mean weight in the 2 groups of infants (**Table I**). IGRAM subjects had significantly higher mean percent fat (19.3% vs 18.1%; $P = .018$), fat mass/length^2 (2.91 kg/m^2 vs 2.64 kg/m^2; $P = .005$), and fat mass/length^3 (5.46 kg/m^2 vs 4.88 kg/m^2; $P = .001$) values, but there were no significant between-group differences in fat mass, fat-free mass, or fat-free mass/length^2. Of note, the mean age at 1 month was significantly higher in the IGRAM infants compared with Baby Peas infants (31.4 days vs 28.7 days; $P < .001$).

BMI-Z was more strongly correlated than WFL-Z with fat mass-Z ($r = 0.61$ vs 0.41; $P < .001$), fat mass/length^2-Z ($r = 0.70$ vs 0.59; $P < .001$), fat mass/length^3-Z ($r = 0.72$ vs 0.66; $P = .006$), and fat-free mass-Z ($r = 0.38$ vs 0.11; $P < .001$) (**Figure 1**). There was no significant difference in correlation of fat-free mass/length^2-Z ($r = 0.71$ vs 0.72; $P = .745$) with either BMI-Z or WFL-Z. Cohort-stratified analyses demonstrated similar results to those seen for the combined cohort. There were no significant differences in findings with additional adjustment

Table I. Characteristics of the sample

Characteristics	Combined cohort (n = 293)	IGRAM cohort (n = 146)	Baby Peas cohort (n = 147)	Cohort difference (*P* value)
Characteristics at birth				
Sex, n (%)				.60
Male	141 (48)	68 (47)	73 (50)	
Female	152 (52)	78 (53)	74 (50)	
Ancestry, n (%)	(n = 291)			<.001
European	95 (33)	0 (0)	95 (65)	
African American	164 (56)	146 (100)	18 (12)	
Other	32 (11)	0 (0)	32 (22)	
Gestational age, wk, mean (SD)	39.3 (1.1) (n = 287)	39.4 (1.1)	39.3 (1.1)	.53
Birth weight, kg, mean (SD)	3.3 (0.4) (n = 287)	3.2 (0.4)	3.4 (0.4) (n = 141)	<.001
BW-Z, mean (SD)*	0.21 (0.98) (n = 286)	−0.11 (0.92)	0.54 (0.93) (n = 140)	<.001
Birth length, cm, mean (SD)	49.8 (2.5) (n = 286)	49.0 (0.02)	50.6 (0.02) (n = 140)	<.001
Birth length-Z, mean (SD)*	0.41 (1.30) (n = 286)	−0.04 (1.12)	0.88 (1.31) (n = 140)	<.001
Characteristics at age 1 month				
Age, d, mean (SD)	30.1 (5.8)	31.4 (3.3)	28.7 (7.2)	<.001
Weight, kg, mean (SD)	4.3 (0.6)	4.3 (0.5)	4.3 (0.6)	.98
Length, cm, mean (SD)	53.7 (2.3)	53.3 (2.1)	54.0 (2.4)	.005
BMI, kg/m^2, mean (SD)	14.7 (1.3)	14.9 (1.2)	14.5 (1.4)	.006
BMI-Z, mean (SD)	0.24 (0.9)	0.33 (0.9)	0.17 (1.0)	.15
WFL-Z, mean (SD)	0.1 (1.1)	0.3 (1.0)	−0.2 (1.2)	<.001
Body composition at age 1 month				
Percent fat, %, mean (SD)	18.7 (4.4)	19.3 (3.9)	18.1 (4.8)	.018
Fat mass, kg, mean (SD)	0.80 (0.3)	0.83 (0.2)	0.78 (0.3)	.085
Fat mass/length^2, kg/m^2, mean (SD)	2.77 (0.8)	2.91 (0.7)	2.64 (0.9)	.005
Fat mass/length^3, kg/m^3, mean (SD)	5.17 (1.50)	5.46 (1.31)	4.88 (1.63)	.001
Fat-free mass, kg, mean (SD)	3.44 (0.4)	3.42 (0.4)	3.46 (0.4)	.386
Fat-free mass/length^2, kg/m^2, mean (SD)	11.94 (0.9)	12.03 (0.8)	11.84 (0.9)	.068

P values indicate the differences between the IGRAM and Baby Peas cohorts (2-sided *t* test for continuous variables and χ^2 test for categorical variables). Birth weight and birth length *z*-scores account for sex and gestational age. BMI *z*-score accounts for age, sex, and gestational age. WFL *z*-score accounts for age and sex. The number of participants with available measurement is as shown if different for the total number in the cohort.

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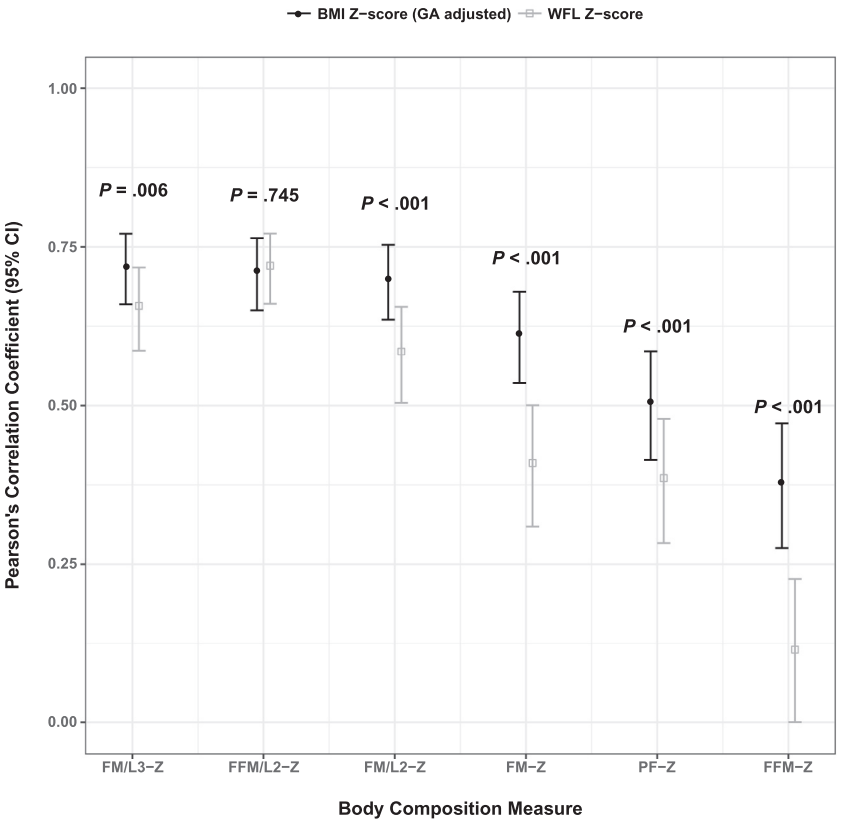

Figure 1. Correlation between body composition and BMI-Z vs WFL-Z at age 1 month. By Pearson correlation, at age 1 month, BMI-Z was more strongly correlated than WFL-Z with fat mass-Z ($r = 0.62$ vs 0.41; $P < .001$), fat mass/length^2-Z ($r = 0.70$ vs 0.59; $P = .022$), and fat-free mass-Z ($r = 0.38$ vs 0.11; $P < .001$) after adjusting for age and sex.

for cohort or ancestry (data not shown); thus, cohort and ancestry were not included in subsequent models.

BW-Z was more strongly correlated with BMI-Z than with WFL-Z ($r = 0.36$ vs 0.05; $P < .001$), implying that BMI-Z contains more information about weight at birth compared with WFL-Z. Similar results were noted in cohort-stratified analyses (data not shown).

The independent association of BMI-Z vs WFL-Z with each body composition *z*-score was investigated, accounting for BW-Z (**Table II**). For all fat mass and fat-free mass body composition measures, each 1-unit change in BMI-Z (vs WFL-Z) was independently associated with a greater increase in body composition *z*-score; for example, for fat mass/length^3-Z, the coefficient for BMI-Z was 0.79 (95% CI, 0.70-0.89) and that for WFL-Z was 0.58 (95% CI, 0.50-0.66) (**Table II**). Of note, the association of BW-Z with each body composition *z*-score was higher in all models including WFL-Z (vs BMI-Z), consistent with previously described results, again demonstrating that BMI-Z intrinsically incorporates more information about birth weight compared with WFL-Z. Similar results were noted in cohort-stratified analyses (**Table II**).

After accounting for BW-Z, the associations between BMI-Z and indices of body composition (percent fat-Z, fat mass-Z, fat mass/length^2-Z, fat mass/length^3-Z, and fat-free mass/length^2-Z) were consistently stronger than the associations between WFL-Z and these same indices across the entire distribution of each body composition measure. However, there was no association between either BMI-Z or WFL-Z with fat-free mass-Z except for a modest positive association with BMI-Z at the highest end of the distribution (**Figure 2**; **Table III**, available at www.jpeds.com).

Postestimation linear combination of estimators was used to evaluate the stability of BMI-Z vs WFL-Z at the tails (10th and 90th percentiles) of each body composition variable (**Figure 2**; **Table III**). Overall, both BMI-Z and WFL-Z were modestly more strongly associated with body composition parameters at the upper end of the distribution (**Figure 2**; **Table III**).

Discussion

Because detailed assessments of body composition are not feasible in clinical settings, determining which anthropometric measure is the best indicator of infant adiposity is critical. There is no gold standard method for assessing adiposity in infancy. We used air displacement plethysmography, a widely accepted noninvasive technique for infant body composition measurement.[26] We expressed adiposity in several ways, because which adiposity measure or index best captures nutritional status in very early infancy remains unclear. We have

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Table II. Associations between BMI-Z and WFL-Z at age 1 month and body composition at age 1 month, accounting for BW-Z

	Percent fat-Z	Fat mass-Z	Fat mass/length^2-Z	Fat mass/length^3-Z	Fat-free mass-Z	Fat-free mass/length^2-Z
Combined cohort (n = 285)						
BMI-Z	**0.53 (0.42-0.65)***	**0.56 (0.46-0.66)***	**0.73 (0.63-0.83)***	**0.79 (0.70-0.89)***	**0.19 (0.09-0.29)***	**0.74 (0.65-0.83)***
BW-Z	0.01 (–0.10 to 0.12)	**0.25 (0.15-0.35)***	0.05 (–0.04 to 0.14)	–0.06 (–0.15 to 0.03)	**0.58 (0.48-0.68)***	0.04 (–0.05 to 0.13)
R^2	0.25	0.42	0.49	0.52	0.41	0.50
WFL-Z	**0.33 (0.23-0.43)***	**0.35 (0.26-0.43)***	**0.51 (0.43-0.59)***	**0.58 (0.50-0.66)***	0.08 (0.00-0.16)§	**0.64 (0.57-0.71)***
BW-Z	**0.18 (0.08-0.29)†**	**0.43 (0.33-0.53)***	**0.28 (0.18-0.37)***	**0.19 (0.10-0.28)***	**0.63 (0.53-0.72)***	**0.25 (0.17-0.33)***
R^2	0.17	0.33	0.40	0.45	0.38	0.58
IGRAM cohort (n = 146)						
BMI-Z	**0.53 (0.37-0.69)***	**0.57 (0.44-0.70)***	**0.73 (0.60-0.86)***	**0.78 (0.66-0.91)***	**0.24 (0.09-0.39)†**	**0.75 (0.61-0.89)***
BW-Z	0.10 (–0.05 to 0.25)	**0.31 (0.19-0.43)***	0.12 (0.00-0.24)§	0.01 (–0.10 to 0.13)	**0.58 (0.44-0.72)***	0.04 (–0.09 to 0.17)
R^2	0.28	0.49	0.53	0.55	0.41	0.47
WFL-Z	**0.35 (0.21-0.48)***	**0.37 (0.25-0.49)***	**0.53 (0.42-0.64)***	**0.59 (0.48-0.70)***	**0.16 (0.03-0.28)‡**	**0.70 (0.60-0.80)***
BW-Z	**0.25 (0.10-0.39)‡**	**0.47 (0.34-0.59)***	**0.32 (0.20-0.44)***	**0.23 (0.11-0.35)***	**0.65 (0.51-0.78)***	**0.24 (0.13-0.35)***
R^2	0.20	0.39	0.44	0.47	0.40	0.59
Baby Peas cohort (n = 139)						
BMI-Z	**0.56 (0.38-0.75)***	**0.56 (0.39-0.73)***	**0.74 (0.58-0.89)***	**0.81 (0.66-0.96)***	0.11 (–0.04 to 0.27)	**0.69 (0.55-0.83)***
BW-Z	–0.10 (–0.30 to 0.10)	**0.20 (0.02-0.38)‡**	–0.01 (–0.18 to 0.16)	–0.13 (–0.29 to 0.04)	**0.64 (0.48-0.81)***	0.12 (–0.03 to 0.27)
R^2	0.23	0.37	0.45	0.49	0.40	0.52
WFL-Z	**0.33 (0.18-0.48)***	**0.32 (0.19-0.46)***	**0.50 (0.37-0.63)***	**0.58 (0.46-0.70)***	–0.02 (–0.14 to 0.10)	**0.57 (0.47-0.67)***
BW-Z	0.12 (–0.07 to 0.30)	**0.41 (0.23-0.58)***	**0.24 (0.08-0.40)†**	0.14 (–0.01 to 0.29)§	**0.69 (0.54-0.84)***	**0.30 (0.17-0.43)***
R^2	0.14	0.28	0.37	0.43	0.38	0.56

Multivariable linear regression analysis performed to investigate the association between BMI-Z (accounting for age, sex, and gestational age) or WFL-Z (account for age and sex) at age 1 month on each body composition measure *z*-score (accounting for for age and sex) at age 1 month, accounting statistically for BW-Z. Results are shown as coefficient (95% CI).
Statistical significance ($P < .05$) is indicated by bold type.
*$P < .001$.
†$P < .01$.
‡$P < .05$.
§$P < .10$.

demonstrated, in 2 distinct cohorts with different ancestral backgrounds, that BMI is a better indicator of adiposity in early infancy compared with WFL, as reflected by fat mass and fat mass index. Although there is no commonly accepted definition of excess adiposity in children aged <2 years,[6] fat mass accrual in early infancy is related to later childhood obesity.[27] Our study suggests that infants with high BMI have higher fat mass, even as early as age 1 month. This is important given that most, if not all, clinical settings can feasibly measure BMI. In addition, the use of BMI in infancy would provide continuity in assessment of excess adiposity throughout the life cycle.

We previously reported discordance between BMI and WFL in young infants, with BMI at 2 months the better predictor of high BMI at age 2 years.[14] WFL is currently the recommended anthropometric measure for assessing weight status in children aged <2 years both in the US and worldwide, although BMI is the measure recommended from age 2 years through adulthood.[13,28] We and others have provided evidence that early infant BMI has a significantly higher positive predictive value for early childhood obesity compared with WFL.[14,29,30] Our present findings provide further evidence that BMI provides a more accurate reflection than WFL of adiposity at age 1 month.

The American Academy of Pediatrics recommendation that WFL be used for nutritional assessment in children aged <2 years likely dates back to the publication of the National Center for Health Statistics growth charts in 1977.[31] The compilers of those charts acknowledged that in a normal population of healthy infants of the same length, older infants are likely to weigh more; however, they argued that for children aged <2 years, the relationship between length and weight is close enough to being age-independent, and thus WFL is a useful indicator of nutritional status, especially when age is not reliably known.[31] WFL has been used for this purpose for more than 40 years. The empirically observed association between low WFL and subsequent mortality has been cited to justify its ongoing use.[32]

Importantly, the association between infant BMI and future health outcomes merits further consideration. Recent studies suggest overall good agreement between WFL and BMI and note that BMI may actually be more sensitive in identifying wasting in infants.[33] As noted above, early infant BMI is a better predictor of early childhood obesity than WFL.[14,29,30] Our study further supports that BMI may have the additional advantage of being more closely associated with body composition, even after accounting for birth size.

Two key differences between the BMI and WFL growth charts might account for some of our findings. First, BMI charts allow for a combined measure of weight and length to be plotted according to age. In contrast, WFL charts plot weight and length but do not account for age; thus, a short infant could be considered to have high WFL because she or he is being compared with younger infants who have not yet gained as much weight. Second, because BMI charts take age into account, BMI

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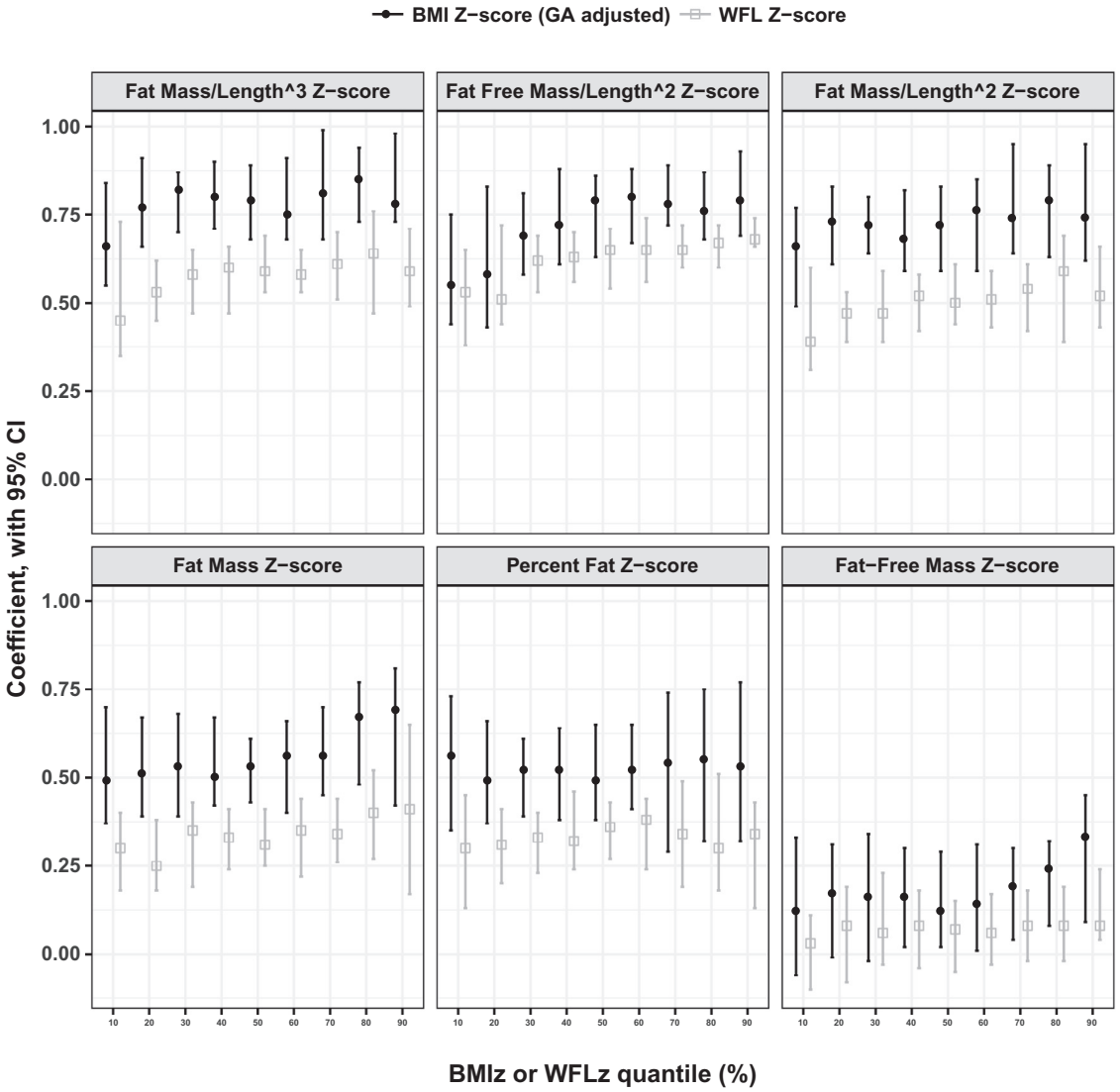

Figure 2. Variation in BMI-Z and WFL-Z across body composition distributions at age 1 month by quantile regression analysis. Quantile regression analyses assessed for consistency in the association of BMI-Z (black circles) and WFL-Z (gray squares) across the distribution of each body composition measure. Postestimation linear combination of estimators evaluated the stability of BMI-Z vs WFL-Z at the tails of each measure.

can be further adjusted for gestational age, whereas WFL charts cannot make such an adjustment.

It has been reported that in children and in adolescents, BMI is a better measure of fat mass for overweight and obese children than in thin and normal-weight children.[34-36] Accordingly, we examined the stability of both BMI and WFL across the distribution of body composition outcomes during early infancy. We observed that BMI was more highly associated with indices of fat mass across the distributions of body composition in early infancy compared with WFL. Overall, both indices demonstrated a modestly stronger association with body composition at the higher end of the distribution.

Limitations of this study include its cross-sectional design, and the implications of these measures on later health outcomes are not known. Future studies should investigate these same associations throughout infancy and into childhood. In addition, infant feeding data were not consistently available and thus are not considered in this study. Previous studies have evaluated the test characteristics of air displacement plethysmography for measuring body composition in infants and concluded that it has adequate accuracy and reproducibility for assessing fat mass but may have less reproducibility for assessing lean mass.[26] This study was not designed to specifically consider lean body mass, and the extent to which BMI-Z and WFL-Z are good indicators of this component of nutritional status in at-risk infants cannot be concluded from this study. Furthermore, because there are no clinical definitions of underweight or obesity in very young infants, it was not possible to determine the sensitivity and specificity of WFL vs BMI. As an alternative, we compared the strength of associations

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between WFL and BMI with body composition outcomes and used quantile regression techniques to evaluate these associations across the range of body composition outcomes. However, quantile regression is a nonparametric method, and our study might have been underpowered to detect additional quantile-specific associations.

The results of the present study, together with our previous work showing the association of BMI-Z in infancy with obesity in early childhood, add to the accumulating evidence supporting the preferred use of BMI-for-age for assessing growth and nutritional status in infancy. ■

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Table III. Quantile regression analysis of how BMI-Z and WFL-Z vary across the distribution of body composition

Variables	Quantile									*P* value
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	.10 vs .90
Percent fat-Z										
BMI-Z	0.56‡ (0.35-0.73)	0.49‡ (0.37-0.66)	0.52‡ (0.39-0.61)	0.52‡ (0.38-0.64)	0.49‡ (0.38-0.65)	0.52‡ (0.41-0.65)	0.54‡ (0.29-0.74)	0.55‡ (0.32-0.75)	0.53‡ (0.32-0.77)	.23
WFL-Z	0.3‡ (0.13-0.45)	0.31‡ (0.2-0.41)	0.33‡ (0.23-0.4)	0.32‡ (0.24-0.46)	0.36‡ (0.27-0.43)	0.38‡ (0.24-0.44)	0.34‡ (0.19-0.49)	0.3† (0.18-0.51)	0.34‡ (0.13-0.43)	.65
Fat mass-Z										
BMI-Z	0.49‡ (0.37-0.7)	0.51‡ (0.39-0.67)	0.53‡ (0.39-0.68)	0.5‡ (0.42-0.67)	0.53‡ (0.43-0.61)	0.56‡ (0.4-0.66)	0.56‡ (0.45-0.7)	0.67‡ (0.48-0.77)	0.69‡ (0.42-0.81)	.06
WFL-Z	0.3‡ (0.18-0.4)	0.25‡ (0.18-0.38)	0.35‡ (0.19-0.43)	0.33‡ (0.24-0.41)	0.31‡ (0.25-0.41)	0.35‡ (0.22-0.44)	0.34‡ (0.26-0.44)	0.4‡ (0.27-0.52)	0.41‡ (0.17-0.65)	.16
Fat mass/ length^2-Z										
BMI-Z	0.66‡ (0.49-0.77)	0.73‡ (0.61-0.83)	0.72‡ (0.64-0.8)	0.68‡ (0.59-0.82)	0.72‡ (0.59-0.83)	0.76‡ (0.59-0.85)	0.74‡ (0.64-0.95)	0.79‡ (0.63-0.89)	0.74‡ (0.62-0.95)	.06
WFL-Z	0.39‡ (0.31-0.6)	0.47‡ (0.39-0.53)	0.47‡ (0.39-0.59)	0.52‡ (0.42-0.58)	0.5‡ (0.44-0.61)	0.51‡ (0.43-0.59)	0.54‡ (0.42-0.61)	0.59‡ (0.39-0.69)	0.52‡ (0.43-0.66)	.16
Fat mass/ length^3-Z										
BMI-Z	0.66‡ (0.55-0.84)	0.77‡ (0.66-0.91)	0.82‡ (0.7-0.87)	0.8‡ (0.71-0.9)	0.79‡ (0.68-0.89)	0.75‡ (0.68-0.91)	0.81‡ (0.68-0.99)	0.85‡ (0.73-0.94)	0.78‡ (0.73-0.98)	.04
WFL-Z	0.45‡ (0.35-0.73)	0.53‡ (0.45-0.62)	0.58‡ (0.47-0.65)	0.6‡ (0.47-0.66)	0.59‡ (0.53-0.69)	0.58‡ (0.53-0.65)	0.61‡ (0.51-0.7)	0.64‡ (0.47-0.76)	0.59‡ (0.49-0.71)	.30
Fat-free mass-Z										
BMI-Z	0.12 (-0.06 to 0.33)	0.17* (-0.01 to 0.31)	0.16 (-0.02 to 0.34)	0.16* (0.02-0.3)	0.12 (0.02-0.29)	0.14* (0.01-0.31)	0.19† (0.04-0.3)	0.24† (0.08-0.32)	0.33† (0.09-0.45)	.03
WFL-Z	0.03 (-0.1 to 0.11)	0.08 (-0.08 to 0.19)	0.06 (-0.03 to 0.23)	0.08 (-0.04 to 0.18)	0.07 (-0.05 to 0.15)	0.06 (-0.03 to 0.17)	0.08 (-0.02 to 0.18)	0.08 (-0.02 to 0.19)	0.08 (0.04-0.24)	.008
Fat-free mass/ length^2-Z										
BMI-Z	0.55‡ (0.44-0.75)	0.58‡ (0.43-0.83)	0.69‡ (0.58-0.81)	0.72‡ (0.61-0.88)	0.79‡ (0.63-0.86)	0.8‡ (0.67-0.88)	0.78‡ (0.72-0.89)	0.76‡ (0.68-0.87)	0.79‡ (0.69-0.93)	.03
WFL-Z	0.53‡ (0.38-0.65)	0.51‡ (0.44-0.72)	0.62‡ (0.53-0.69)	0.63‡ (0.56-0.7)	0.65‡ (0.54-0.71)	0.65‡ (0.56-0.74)	0.65‡ (0.6-0.72)	0.67‡ (0.6-0.72)	0.68‡ (0.66-0.74)	.02

From quantile regressions, coefficients and 95% CI (in parentheses) are shown. ANOVA was used to compare results from 10th vs 90th quantile regression models (last column).
*P <.05.
†P <.01.
‡P <.001.

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