Validity of Body Mass Index as a Measure of Adiposity in Infancy

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Objectives To assess the validity of body mass index (BMI) and age- and sex-standardized BMI z-score (BMIZ) as surrogates for adiposity (body fat percentage [BF%], fat mass, and fat mass index [kg/m^2]) at 3 time points in infancy (1, 4, and 7 months) and to assess the extent to which the change in BMIZ represents change in adiposity.

Study design We performed a secondary analysis of 447 full-term infants in a previous trial of maternal vitamin D supplementation during lactation. Study staff measured infant anthropometrics and assessed body composition with dual-energy x-ray absorptiometry at 1, 4, and 7 months of age. We calculated Spearman correlations (r_s) among BMI, BMIZ, and adiposity at each time point, and between change in BMIZ and change in adiposity between time points.

Results Infants (N = 447) were 52% male, 38% white, 31% black, and 29% Hispanic. The BMIZ was moderately correlated with BF% (r_s = 0.43, 0.55, 0.48 at 1, 4, and 7 months of age, respectively). BMIZ correlated more strongly with fat mass and fat mass index, particularly at 4 and 7 months of age (fat mass r_s = 0.72-0.76; fat mass index r_s = 0.75-0.79). Changes in BMIZ were moderately correlated with adiposity changes from 1 to 4 months of age (r_s = 0.44 with BF% change; r_s = 0.53 with fat mass change), but only weakly correlated from 4 to 7 months of age (r_s = 0.21 with BF% change; r_s = 0.27 with fat mass change).

Conclusions BMIZ is moderately correlated with adiposity in infancy. Changes in BMIZ are a poor indicator of adiposity changes in later infancy. BMI and BMIZ are limited as surrogates for adiposity and especially adiposity changes in infancy. *(J Pediatr 2018;■■:■■-■■).*

Trial Registration ClinicalTrials.gov NCT00412074.

Anthropometric measures of body proportionality are widely used in research and clinical practice as surrogates for body composition. In particular, body mass index (BMI, kg/m^2) is often used as a proxy for adiposity, based on high correlations (correlation coefficients of 0.79-0.92) between BMI and directly measured adiposity in adults,[1] adolescents,[2,3] and school-aged children.[2-5] In infants, BMI and other indices of body proportionality such as weight-for-length (WFL, kg) have similarly been interpreted as surrogates for adiposity, with higher BMI or WFL measurements interpreted as reflecting higher adiposity.[6-11]

BMI in infancy is predictive of subsequent obesity, with higher peak BMI, rapid increases in BMI, and BMI z-score (BMIZ) values above the 85th percentile all associated with obesity in early childhood or adulthood.[10,12-15] One hypothesis for the mechanism underlying this association is that accumulation of excess adiposity during a critical period in early infancy predisposes infants to excess adiposity in childhood and adulthood.[16,17] However, the extent to which BMI, BMIZ, and their changes over time accurately reflect adiposity gains in infancy is poorly understood.

Although a few prior studies have examined associations between BMI or BMIZ and adiposity in infancy, most were limited by small sample sizes (<70 infants)[16-18] or methods of body composition assessment (such as isotope dilution or total body electrical conductivity)[16-18,19,20] that are potentially less accurate than newer methods such as dual-energy x-ray absorptiometry (DXA)[21,22] and a single time point of assessment.[16,18,23] A recent study using air displacement plethysmography overcomes most of those limitations, but only assessed infants at 2 time points and only followed infants to 5 months of age.[24] Therefore, we analyzed the associations

BF%	Body fat percentage
BMI	Body mass index
BMIZ	BMI z-score
DXA	Dual-energy x-ray absorptiometry
FMI	Fat mass index
LMI	Lean mass index
WFL	Weight-for-length
WFLZ	Weight-for-length z-score

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Funding for the initial trial was provided by the National Institutes of Health (NIH) 5R01HD043921, NIH RR01070, Medical University of South Carolina Department of Pediatrics, and the South Carolina Clinical & Translational Research Institute, NIH/National Center for Advancing Translational Sciences grant UL1 TR000062. H.F. receives research support from the Boston Children's Hospital Clinical Research Center. The authors declare no conflicts of interest.

Portions of this study were presented as an oral abstract at the Pediatric Academic Societies annual meeting, May 6-9, 2017, San Francisco, California.

https://doi.org10.1016/j.jpeds.2018.01.028

of BMI and BMIZ, and their changes over time, with adiposity in a large, racially diverse cohort of healthy infants during the first 7 months of life.

Methods

This study was conducted as a secondary analysis of data collected during a previously completed study of maternal vitamin D supplementation.[25] Mother–infant dyads were recruited from the newborn nursery at the Medical University of South Carolina in Charleston, South Carolina, or Rochester General Hospital in Rochester, New York, as well as from local community hospitals in Charleston and Rochester between January 2007 and December 2011. Eligibility criteria included healthy singleton infant born at ≥35 weeks of gestation, age of infant at enrollment <6 weeks of age, and mother planning to exclusively breastfeed or exclusively formula feed for 6 months. Mothers were excluded if they had pre-existing type 1 or 2 diabetes mellitus, hypertension, parathyroid disease, uncontrolled thyroid disease, hypocalcemia, hypercalcemia, or were taking diuretics or cardiac medications. Infants were excluded if they had an inborn error of metabolism, congenital anomalies, or admission to the neonatal intensive care unit lasting >72 hours. Eligibility criteria for this secondary analysis included any infant with ≥1 visit with both anthropometric data and body composition measurement. Of the 460 infants enrolled in the original study, 447 (97%) were included in the analysis; 13 were excluded because they had no DXA measurements performed.

Birthweight was obtained from the infants' medical records. Subsequent weights and lengths were measured monthly by trained study staff. At each study visit, infants were weighed on a standard infant scale (Scale-Tronix, Inc, Wheaton, Illinois) to the nearest gram and length was measured to the nearest 0.1 cm on either a vinyl or plexiglass infant length board (Perspective Enterprises, Portage, Michigan) by the 2-person technique. BMI was calculated using the standard formula: weight/length^2 (kg/m^2). Birthweight z-scores were determined from the 2010 Olsen growth charts accounting for gestational age and sex.[26] The z-scores were computed for weight, length, BMI, and WFL at 1, 4, and 7 months of age using the World Health Organization growth standards via the macro 'WHO Child Growth Standards SPSS Syntax File (igrowup.sps)' (World Health Organization, Geneva, Switzerland, 2005).

At 1, 4, and 7 months of age, infants underwent whole body DXA using a Hologic Discovery A (Hologic, Inc, Waltham, Massachusetts) with the Hologic infant whole body software (version 12.7.3:3). Both study sites used a Hologic Discovery A and a spine phantom standard was sent to each site twice during the study period for cross-calibration of the scanners; 20 scans were performed at each site on the phantom, with a correlation of 0.998 and no statistically significant differences in body composition of the phantom as measured by the 2 different scanners. A standard procedure was followed to limit infant movement and only scans without motion artifact were used. DXA is safe (radiation exposure equivalent to about 1 day's exposure to background radiation), as accurate as more sophisticated methods for measuring infant body composition such as magnetic resonance imaging,[27] and is superior to anthropometric measures such as skinfold thicknesses.[22]

We obtained 2 measures of adiposity—body fat percentage (BF%) and fat mass (in kg)—from each scan. We then calculated a third measure of adiposity, fat mass index (FMI), from the standard formula: fat mass/length^2 (kg/m^2), using the length measured by study staff. BF% is the most commonly used measure of adiposity in research,[28] but has been criticized as a poor measure of adiposity because it is affected by changes in lean mass even if fat mass does not change.[28,29] Measuring fat mass alone does not account for proportionality of the fat mass for body size, whereas the FMI adjusts for the patient's height or length.[28,29] It is unknown which measure of adiposity is most predictive of subsequent health outcomes; therefore, we examined all 3 measures. Lean mass (in kg) also was obtained directly from each scan and used to calculate the lean mass index (LMI) using the formula: lean mass/length^2 (kg/m^2).

The trial from which these data were obtained was approved by the Institutional Review Boards of the Medical University of South Carolina (#16536) and the University of Rochester (#14460) and was registered via clinicaltrials.gov (NCT00412074). Parents of infants who participated in the study provided informed consent. This secondary analysis of de-identified data was classified as exempt by the Institutional Review Board of Brigham and Women's Hospital.

Statistical Analyses

Using the DXA-derived adiposity measures as the gold standard for adiposity, we calculated correlation coefficients to examine the extent to which anthropometric measurements were correlated with adiposity at each time point. We chose Spearman (r_s) rather than Pearson correlation coefficients because they do not assume normality of data or a linear relationship between the measurements. To evaluate whether changes in BMI and BMIZ were associated with changes in adiposity, we calculated Spearman correlation coefficients between pairs of changes in anthropometric measurements and concurrent changes in body composition. Pearson correlations were almost identical to Spearman correlations (data not shown).

We used stratification to assess for differences in correlations among racial/ethnic groups, between sexes, and by feeding type (breastmilk or formula feeding). We used the method of Zou to assess for significant differences between correlated correlation coefficients with a variable in common (such as whether BMI is more strongly correlated with fat mass than lean mass).[30] To compare the correlation between 2 given variables across subsamples (such as whether correlations differ between males and females), we applied the Fisher z-transformation ($\tanh^{-1}r$) and performed an asymptotic z-test (for 2 groups) or χ^2 test (for 3 groups), using the sample-specific standard errors ($(n-3)^{-½}$). Significance was set at $P = .05$.

Our primary focus was to examine associations of BMI, rather than other possible indices of body proportionality such as WFL or ponderal index (kg/m^3), with DXA-assessed adiposity

FLA 5.5.0 DTD ■ YMPD9734_proof ■ March 15, 2018