Muscularity and Fatness of Infants and Young Children Born Small- or Large-for-Gestational-Age

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ABSTRACT. ***Objective.*** **There is growing interest in the extent to which body composition, both short- and long-term, differs in infants and children born at the extremes of birth weight. This is because a growing number of studies have linked low birth weight and fetal growth restriction to the chronic diseases in adulthood that often are obesity-related, and there is also evidence to suggest that heavy infants may be at increased risk for obesity in later life, again with the attendant obesity-related chronic diseases. Our objective was to compare anthropometric indices of body composition of infants and young children born small-for-gestational-age (SGA, <10th percentile) or large-for-gestational age (LGA, ≥90th percentile) with those of normal birth weight status (appropriate-for-gestational-age, AGA) in a US sample.**

Design. **National sample of US-born non-Hispanic white, non-Hispanic black, and Mexican-American infants and young children, 2 to 47 months of age, examined in the third National Health and Nutrition Examination Survey (NHANES III, 1988–1994), for whom birth certificates were obtained. The primary outcomes were normalized anthropometric indices (*z* scores or standard deviation units [SDU]) of nutritional status and body composition (mid-upper arm circumference, triceps and subscapular skinfolds, mid-upper arm muscle and mid-upper arm fat areas (UFA), and the arm fat index). The outcomes thus were scaled to permit comparison across chronologic ages.**

Results. **The prevalence of SGA was 8.6%, appropriate-for-gestational-age 80.9%, and LGA 10.5%. From ages 2 to 47 months, for infants and young children born SGA, there was a persistent overall deficit in muscularity (mid-upper arm circumference and mid-upper arm muscle area) of approximately −0.50 SDU, but less of a deficit in fatness, particularly at the youngest ages. For infants and young children born LGA, there was a surfeit in muscularity of ~0.45 SDU, with less of a surfeit in fatness, particularly at the youngest ages. Across all ages, the mean UFA showed a statistically significant deficit for SGA children (−0.27 ± 0.10 SDU) and surfeit for LGA children (0.24 ± 0.08 SDU). At individual ages for UFA and at individual and all ages combined for skinfold thicknesses, there were no significant differences in level of subcutaneous fatness in the three birth-weight-for-gestational-age groups. There was a tendency in the first year for the arm fat index (% arm fat) to be significantly higher for SGA infants, but the effect did not persist after the first year.**

Conclusion. **SGA infants remain smaller and LGA infants larger in size through early childhood, but the discrepancies in weight are primarily attributable to differences in lean body mass (muscularity). Fatness is less affected. Thus, based on the fatness indicators used, at any given weight for infants and children 2 to 47 months of age, percent body fat appears to be relatively higher for children who were SGA at birth and lower in those who were LGA at birth. These differences in body composition for SGA infants support the evidence documenting a link between disturbances in intrauterine growth and chronic disease associated with subsequent adiposity in adulthood. *Pediatrics* 1998;102(5). URL: http://www.pediatrics.org/cgi/content/full/102/5/e60; *small-for-gestational-age, large-for-gestational-age, muscularity, fatness, growth, infants.***

ABBREVIATIONS. NHANES III, Third National Health and Nutrition Examination Survey; SGA, small-for-gestational-age; LGA, large-for-gestational-age; MUAC, mid-upper arm circumference; SDU, standard deviation unit; SE, standard error; AGA, appropriate-for-gestational-age; LMP, last menstrual period; LBW, low birth weight; BMI, body mass index; TUA, total mid-upper arm area; UMA, mid-upper arm muscle area; UFA, mid-upper arm fat area.

Infants born growth-restricted or small generally show some measure of compensatory growth within the first year of life, and the growth of large infants slows in infancy.[1–3] Both clinical[4,5] and large cohort studies[6] have shown that after this initial period of growth compensation, a growth deficit or excess in body weight and length persists or tracks through childhood. In analyses from the third National Health and Nutrition Examination Survey (NHANES III, 1988–1994), we demonstrated, for a national sample of infants and young children 2 to 47 months of age, that there are significant associations between birth-weight-for-gestational-age status and growth status in infancy and early childhood.[7] Small-for-gestational-age (SGA, <10th percentile birth-weight-for-gestational age) infants remained shorter, lighter, and had smaller head circumferences, whereas large-for-gestational-age (LGA, ≥90th percentile) infants remained longer, heavier, and had larger head circumferences through age 47 months.[7]

Several studies have shown that the low weight of

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infants born SGA and preterm is primarily attributable to reduced lean body mass (muscle), and bone mineral content also is reduced. Adiposity is less affected.[8,9] On the other hand, the LGA infants of diabetic mothers clearly have increased fat mass as well as increased muscularity.[10] It is not known whether there are differences in body composition or whether they persist when the SGA infants are not also preterm or the LGA infants are not macrosomic and born to overtly diabetic mothers.

There is growing interest in the extent to which body composition, both short- and long-term, differs in infants and children born at the extremes of birth weight. Although they have not gone without some criticism,[11] a growing number of studies have linked low birth weight and fetal growth restriction to the chronic diseases in adulthood that often are obesity-related (eg, cardiovascular disease, hypertension, noninsulin-dependent diabetes mellitus).[12–14] LGA infants also may be at increased risk for obesity in later life, with the attendant obesity-related chronic diseases.[3,10]

As part of the protocol of NHANES III, anthropometric measurements of growth, nutritional status, and body composition were made for a US sample of infants and children as young as 2 months of age.[15] The objective of these analyses is to compare the body composition of infants and children, at 2 to 47 months of age, born SGA and LGA with that of children with normal birth weight status.

METHODS

The measurements on infants and children were taken from the nationally representative sample of the NHANES III, conducted from 1988 to 1994.[15] The NHANES III was a cross-sectional, statistical probability sample of the civilian, noninstitutionalized population of the United States. For these analyses, we focused on the infants and children from 2 to 47 months of chronologic age. As part of the complex stratified, multistage probability cluster sample design, infants and children from 2 to 71 months were oversampled in NHANES III. Black and Mexican-American US residents also were oversampled to allow adequate sample sizes to support separate estimates for non-Hispanic blacks and Mexican-Americans.[15]

Growth status and anthropometric measurements of body composition were obtained in a health examination conducted by trained technicians.[16] From age 2 to 47 months, along with recumbent length, weight and head circumference, the measurements obtained were mid-upper arm circumference (MUAC), triceps, and subscapular skinfold thicknesses. At these ages, the growth measurements (length, weight, head circumference) were obtained by NHANES III to provide additional reference data for the development of new child growth charts. The measures of MUAC and the skinfold thicknesses were made to augment the growth data with concurrent measures of fatness.[16] These particular anthropometric measurements were taken because they are obtainable in survey situations and considered reliable for infants and young children.[17]

To determine birth status, birth certificates were requested from each state for the US-born infants and children for whom the parents or guardians had given specific informed consent (Table 1).[7] The birth certificate number was linked to the demographic and medical information compiled by birth year in the vital statistics data system maintained by the National Center for Health Statistics, Centers for Disease Control and Prevention.

The target sample consisted of 5566 infants and children who were examined and measured anthropometrically. Of this number, birth certificates were not obtained for 137 foreign-born infants. Birth certificates were matched for 94.5% (5129 of 5429) of the US-born infants and children. Four cases were excluded because of missing birth weights, 1 where gender was discrepant, and 118 who were determined from the birth certificates to be twins or triplets. There were no exclusions based on other perinatal or child developmental factors.

TABLE 1. Sample of US Non-Hispanic White, Non-Hispanic Black, and Mexican-American Infants and Children 2 to 47 Months of Age from NHANES III, 1988–1994

	N
Sampled	6038
Interviewed	5897
Examined	5566
US-born	5429
Birth certificates obtained and verified	5129
Exclusions for analysis	
Missing birth weight	4
Discrepant sex	1
Twin/Triplet	118
Missing or invalid gestation	280
All other race/ethnicity	295
Final analytic sample	4431

Length of gestation from the mother's last menstrual period (LMP) was obtained from the birth certificates and examined for validity. Length of gestation from the LMP was considered invalid if >44 weeks (N = 89, 1.8%) or, at a gestation of 35 weeks or less, if birth weight was inconsistent with gestation (N = 78, 1.5%).[18] Gestation from the LMP was missing on 113 records (2.3%). Cases with missing or invalid data for length of gestation were excluded (Table 1).

The sample was then limited to the non-Hispanic white, non-Hispanic black, and Mexican-American infants and young children. Those of all other race/ethnicities (N = 295) were excluded, leaving a final analytic sample of 4431 (Table 1).

Infants and children were categorized by birth-weight-for-gestational-age status using reference percentiles derived for singleton infants from 1989 US natality statistics.[18] Using these reference data, infants can be categorized separately by race (white vs black) and within race by infant sex and maternal parity. Infants designated by NHANES III as non-Hispanic white and Mexican-American were categorized using the reference percentiles for whites, consistent with the reference data[18]; non-Hispanic black infants were categorized using the reference percentiles for blacks. Small-for-gestational-age (SGA),[19] was defined as below the 10th percentile of birth-weight-for-gestational-age, appropriate-for-gestational-age (AGA) from the 10th–89th percentile, and large-for-gestational-age (LGA) or macrosomia at or above the 90th percentile. Birth weight categories independent of gestation were defined using standard criteria: low birth weight (LBW) as <2500 g, macrosomia at or >4000 g. Using length of gestation from the LMP, very preterm delivery was defined as <33 weeks' gestation, preterm from 33 to 36 weeks, and term as 37+ weeks.

Age Cohorts and Anthropometry

Six chronologic age cohorts were used in the analysis: 2 to 5 months (N = 530); 6 to 8 months (N = 497); 9 to 11 months (N = 463); 12 to 23 months (N = 1067); 24 to 35 months (N = 1004); and 36 to 47 months (N = 870) based on age at examination. The infants and children were also grouped into the same cohorts based on gestation-corrected age, that is, age in months adjusted for length of gestation.[7]

The anthropometric measurements considered were MUAC (cm), triceps and subscapular skinfold thicknesses (mm), and the sum of these two skinfolds (mm). The indices of body composition that were derived were total mid-upper arm area (cm^2), mid-upper arm muscle area (cm^2), mid-upper arm fat area (cm^2), and the arm fat index (%). The indices of body composition were derived from mid-upper arm anthropometry using conventional formulae: total mid-upper arm area (TUA) = arm circumference^2/(4 × π); arm muscle area (UMA) = [arm circumference − (triceps × π)]^2/(4 × π); mid-upper arm fat area (UFA) = TUA − UMA; and the arm fat index (percent arm fat area) = (UFA/TUA) × 100.[17,20] Findings on measurements of weight (kg), recumbent length (cm), and head circumference (cm) have been reported separately.[7]

Because the distribution of measurements for fatness and derived indices of body composition can be skewed in infancy and childhood, the anthropometric data were transformed to allow for comparison across chronologic age cohorts. The variables were first transformed to approximate normal distributions using power transformations.[21,22] The transformations used were log(x) for mid-upper arm muscle area (UMA) and the arm fat index; $-1/\sqrt{x}$ (reciprocal square root) for weight, MUAC, triceps skinfold, and the mid-upper arm fat area (UFA); and $-1/x$ (reciprocal) for subscapular skinfold and the sum of the two skinfolds.[22]

To control for group differences, the anthropometric variables were converted into *z*-scores (standard deviation units, SDU)[17] within chronologic age cohort, sex, and race/ethnicity groups. Because the distributions of the anthropometric variables were approximately normal, percentiles corresponding to the *z*-scores can be estimated using the area under the normal curve. An SDU (*z*-score) of zero represents the median; the 10th and 90th percentiles are −1.28 SDU and +1.28 SDU, respectively.

Other Variables

Other variables used in analysis were taken both from the birth certificates and NHANES III. Maternal parity and infant birth order (firstborn being equivalent to maternal primiparity) were based on number of previous births reported on the birth certificate. Categories of race/ethnicity were based on the parental self-reports from NHANES III, using US Bureau of the Census definitions.[15] Information on maternal smoking during pregnancy (yes/no) was taken from the questionnaire administered to the infant's parent or other respondent in the home.

Statistical Methods

Sample weights were used to account for the oversampling and unit nonresponse. SUDAAN software that uses a Taylor series expansion to adjust variance estimates to account for the sample design was used to estimate standard errors (SE) of the prevalence data and background characteristics.[23] Analyses of the body composition indices across age cohorts were performed using SUDAAN regression procedures. Separate indicator variables were created for SGA and LGA for each age cohort and entered into a single regression with AGA infants and children of all ages serving as the reference group and the anthropometry *z*-scores as the dependent variables. Summary effects for birth-weight-for-gestational-age status were estimated accounting for age cohort effects in the models predicting the anthropometry *z*-scores. Results from the regression procedures are regression coefficients (± SE) in SDU, tested for statistical significance ($\alpha = .05$) from zero.

RESULTS

The overall prevalence of SGA in this sample was 8.6%, 80.9% were born AGA, and 10.5% LGA (Table 2). The distribution of the birth-weight-for-gestational-age categories by chronologic age cohort were fairly consistent, and the sample sizes at the extremes for each cohort sufficiently large, even in the first year, for analysis by cohort.

The distributions of the birth weight-for-gestational-age categories by various characteristics, such as race/ethnicity, sex, and birth order, are presented in Table 3. There was a relatively consistent distribution of the birth weight-for-gestational-age categories within race/ethnicity groups, although Mexican-American infants were somewhat less likely to be categorized as LGA (Table 3). In this sample, there were more female infants than males categorized as either SGA or LGA. Firstborn infants were somewhat less likely to be LGA. The infants of mothers who smoked during pregnancy were appreciably more likely to be SGA and less likely to be LGA compared with the infants of mothers were did not smoke (Table 3). Infants born very preterm (<33 weeks) and preterm (33 to 36 weeks) were more likely to be SGA than infants born at term. Nearly 60% of the LBW infants (<2500 g) were also SGA. Of the macrosomic infants (≥4000 g), 86% were LGA at birth.

The regression coefficients from the models using the chronologic age cohorts are presented in SDU (± SE) on Table 4 for the effects over all ages and Table 5 for the coefficient estimates for individual age cohorts. Using the cohorts based on gestation-corrected ages, there was no difference in the pattern or significance of the findings for any outcome, so that only the results for the chronologic age cohorts are presented. There are significant effects of birth weight status on body weight through chronologic age 47 months (Tables 4 and 5).[7] Regression coefficients reported in SDU show similarly that, although there were some cohort effects, the predominant tendency was for MUAC to remain significantly smaller for SGA infants and children and larger for LGA infants and children.

In terms of body composition, as estimated using mid-upper arm anthropometry and subscapular skinfold thicknesses, mid-upper arm muscle area paralleled weight and MUAC, evidencing some catch-up in the first 6 to 8 months (Table 5) among SGA infants and children but overall was −0.45 SDU (Table 4). The muscularity of the LGA infants continued to track substantially above the mean throughout infancy and childhood (Fig 1).

There is much less reduction in subcutaneous fatness, estimated by mid-upper arm fat area for SGA children, averaging -0.27 ± 0.10 SDU ($P < .01$) across all ages (Table 4), and although the summary coefficient for all ages is significant, the coefficients for individual chronologic age cohorts are not (Table 5 and Fig 2). At all ages, compared with AGA infants and children, SGA infants and children showed no

TABLE 2. Sample Size and Prevalence of Birth Weight Status for Infants and Young Children, 2 to 47 Months, NHANES III, 1988–1994

	SGA*			AGA			LGA		
	N	%	(SE)	*N*	%	(SE)	*N*	%	(SE)
2–5 mo	45	8.7	(1.5)	423	78.7	(2.6)	62	12.5	(2.1)
6–8 mo	44	8.1	(1.1)	404	81.4	(2.0)	49	10.5	(1.8)
9–11 mo	39	8.1	(1.2)	378	81.4	(2.2)	46	10.5	(2.2)
12–23 mo	103	8.9	(1.1)	860	80.5	(1.1)	104	10.6	(0.8)
24–35 mo	87	7.3	(0.9)	824	82.3	(1.5)	93	10.4	(1.2)
36–47 mo	105	10.0	(1.6)	681	80.1	(1.9)	84	9.9	(2.1)
All ages	423	8.6	(0.7)	3570	80.9	(0.6)	438	10.5	(0.7)

* Cutoffs are based on reference percentiles specific to ethnicity, maternal parity, and infant sex derived from 1989 US vital statistics by Zhang and Bowes.[18]

TABLE 3. Birth Weight Status Categories by Various Characteristics for Infants and Children, 2 to 47 Months of Age, NHANES III, 1988–1994

	N	SGA		AGA		LGA	
		%	(SE)	%	(SE)	%	(SE)
Race/ethnicity							
Non-Hispanic white	2016	8.3	(0.9)	80.9	(0.9)	10.8	(0.9)
Non-Hispanic black	1205	9.3	(1.1)	80.0	(1.0)	10.7	(0.8)
Mexican-American	1210	9.7	(1.2)	82.3	(1.4)	8.0	(1.0)
Sex							
Male	2221	7.5	(0.9)	82.8	(0.9)	9.7	(0.9)
Female	2210	9.9	(0.9)	78.8	(1.1)	11.3	(1.2)
Birth order							
First born	1761	9.1	(0.8)	81.8	(1.0)	9.1	(0.8)
Second born	1419	7.6	(1.1)	80.5	(1.0)	11.9	(1.1)
Third born +	1251	9.2	(1.4)	80.0	(1.2)	10.8	(1.4)
Maternal smoking							
Yes	941	14.9	(1.7)	80.7	(1.7)	4.5	(0.9)
No	3483	6.7	(0.6)	80.9	(0.7)	12.4	(0.9)
Gestation							
Very preterm	49	15.1	(7.3)	84.9	(7.3)	—	—
Preterm	318	12.0	(3.3)	78.8	(3.3)	9.2	(2.1)
Term	4064	8.3	(0.7)	81.0	(0.7)	10.7	(0.7)
Birth weight							
Low birth weight	258	59.1	(4.1)	40.9	(4.1)	—	
Normal weight	3777	6.5	(0.5)	90.8	(0.7)	2.8	(0.3)
Macrosomic	396	—	—	13.8	(2.3)	86.2	(2.3)

The prevalence data are percent (SE) and are estimated using the statistical weights to account for the NHANES III sample design. The data are from Hediger et al.[7]

TABLE 4. Summary Regression Coefficients (All Ages) of Normalized* Growth Indicators for Birth Weight Categories, Infants and Children 2 to 47 Months, NHANES III, 1988–1994

	SGA		LGA	
	Coefficient	(SE)	Coefficient	(SE)
Body size indicators				
Body weight	−0.73	(0.08)‡	0.54	(0.06)‡
Mid-upper arm circumference	−0.46	(0.10)‡	0.43	(0.07)‡
Muscularity				
Mid-upper arm muscle area	−0.45	(0.09)‡	0.43	(0.09)‡
Subcutaneous fatness				
Mid-upper arm fat area	−0.27	(0.10)†	0.24	(0.08)†
Arm fat index (% arm fat)	0.01	(0.08)	−0.01	(0.10)
Triceps skinfold	−0.14	(0.09)	0.13	(0.09)
Subscapular skinfold	−0.04	(0.08)	0.09	(0.10)
Sum of two skinfolds	−0.11	(0.10)	0.13	(0.10)

* The regressions coefficients are derived from models using normalized anthropometric scores (*z*-scores or standard deviation units, SDU) as the dependent variables and birth weight status and age cohort as the independent variables. The regression coefficients ± SE are presented in SDU, with the reference group for each anthropometric variable being the values for infants and young children born AGA (SDU = 0).
† Coefficient significantly different from zero at $P < .01$; ‡ $P < .001$.

significant differences in subcutaneous fatness measured by subscapular skinfolds and the arm fat index (Table 4). In fact, there is a tendency in the first year for the arm fat index to be significantly higher for SGA infants compared with AGA infants (Table 5). For all ages, neither the coefficient for the triceps skinfold nor that for the sum of the two skinfolds was significant (Table 4).

There is a persistent excess in muscularity (+0.43 ± 0.07 SDU, $P < .001$), but less of an excess in mid-upper arm fat area (+0.24 ± 0.08 SDU, $P < .01$) for LGA children compared with AGA children (Table 4). For LGA infants and young children there was no significant increase in levels of subscapular skinfolds or the arm fat index either overall or for most individual chronologic age cohorts (Tables 4 and 5). Again, for all ages, neither the coefficient for the triceps skinfold nor that for the sum of the two skinfolds was significantly different from zero (Table 4).

DISCUSSION

There are persistent associations of birth-weight-for-gestational-age status with anthropometric indices of body composition in infancy and early childhood, particularly the index of muscularity (mid-upper arm muscle area). We have documented for a national sample of US-born non-Hispanic white, non-Hispanic black, and Mexican-American infants and young children that SGA infants tend to remain lighter and LGA infants heavier through early childhood.[7] We show here that the discrepancies in weight are primarily attributable to differences in

TABLE 5. Regression Coefficients for Weight and Body Composition Indicators by Birth Weight Categories and Chronologic Age Cohort for Infants and Children, 2 to 47 Months, NHANES III, 1988–1994

Age Cohorts	Weight§	Mid-upper Arm Circumference	Mid-upper Arm Muscle Area	Mid-upper Arm Fat Area	Arm Fat Index	Subscapular Skinfold
			Small-for-Gestional-Age			
2–5 mo	−0.87 (0.23)‡	−0.64 (0.17)*	−0.75 (0.19)*	−0.25 (0.18)	0.34 (0.13)*	0.01 (0.16)
6–8 mo	−0.72 (0.19)‡	−0.31 (0.19)	−0.41 (0.18)	−0.04 (0.13)	0.20 (0.13)	0.11 (0.12)
9–11 mo	−0.73 (0.14)‡	−0.38 (0.15)*	−0.52 (0.16)†	0.02 (0.13)	0.35 (0.15)*	0.04 (0.16)
12–23 mo	−0.57 (0.14)‡	−0.30 (0.13)*	−0.22 (0.13)	−0.27 (0.14)	−0.15 (0.10)	0.08 (0.10)
24–35 mo	−0.79 (0.15)‡	−0.45 (0.20)*	−0.39 (0.12)*	−0.32 (0.18)	−0.08 (0.14)	−0.05 (0.15)
36–47 mo	−0.79 (0.16)‡	−0.61 (0.18)†	−0.61 (0.14)†	−0.34 (0.19)	0.01 (0.16)	−0.23 (0.19)
			Large-for-Gestational-Age			
2–5 mo	0.46 (0.14)‡	0.38 (0.12)†	0.47 (0.13)‡	0.09 (0.20)	−0.22 (0.22)	0.07 (0.18)
6–8 mo	0.80 (0.19)‡	0.51 (0.22)*	0.49 (0.24)*	0.28 (0.17)	0.01 (0.15)	0.03 (0.34)
9–11 mo	0.52 (0.09)‡	0.36 (0.10)†	0.32 (0.15)*	0.12 (0.20)	−0.08 (0.25)	−0.01 (0.17)
12–23 mo	0.51 (0.10)‡	0.43 (0.12)†	0.28 (0.16)	0.44 (0.09)‡	0.28 (0.13)*	0.15 (0.15)
24–35 mo	0.56 (0.15)‡	0.40 (0.15)†	0.43 (0.16)†	0.11 (0.13)	−0.15 (0.14)	0.09 (0.17)
36–47 mo	0.52 (0.08)‡	0.48 (0.18)*	0.59 (0.25)*	0.22 (0.14)	−0.14 (0.17)	0.10 (0.17)

The regressions coefficients in SDU are derived from models using normalized anthropometric scores as the dependent variable and birth weight status by age cohort as the independent variables and scores for infants and young children born AGA as the reference group (SDU = 0).
* Coefficient significantly different from zero at $P < .05$; † $P < .01$; ‡ $P < .001$.
§ Data are taken from reference 7.

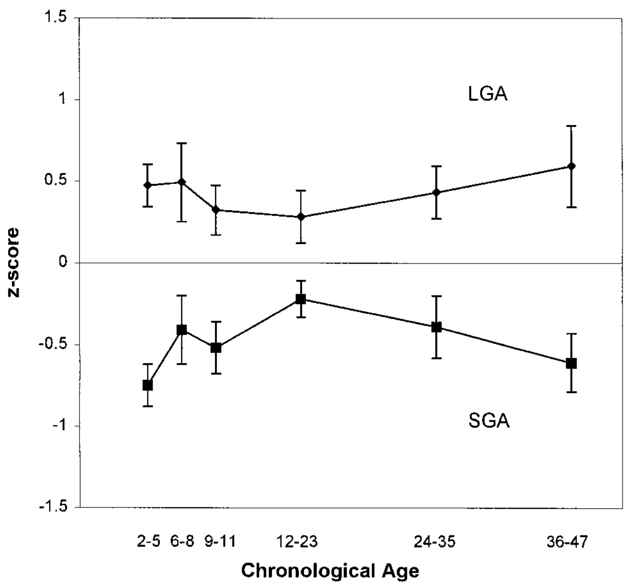

Fig 1. Regression coefficients ± SE in SDU (*z*-scores) for mid-upper arm muscle area for infants and children born SGA (■—■) and LGA (♦—♦) compared with infants and children born AGA (*z*-score = 0). All points are statistically different from zero at $P < .05$ with the exception of the 6 to 8 month and 12 to 23 month cohorts for SGA and the 12 to 23 month cohort for LGA.

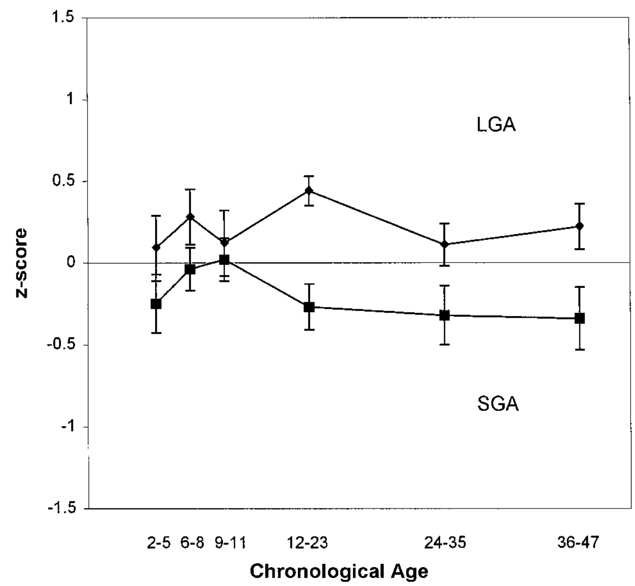

Fig 2. Regression coefficients ± SE in SDU (*z*-scores) for mid-upper arm fat area for infants and children born SGA (■—■) and LGA (♦—♦) compared with infants and children born AGA (*z*-score = 0). No point, with the exception of that for infants born LGA at age 12 to 23 months, is statistically different from zero at $P < .05$.

lean body mass (muscularity) and only to a limited extent to fatness.

There was a significant deficit in mid-upper arm fat area over all ages for SGA children (−0.27 ± 0.10 SDU, $P < .01$) and excess for LGA children (0.24 ± 0.08 SDU, $P < .01$). At individual ages for mid-upper arm fat area and at individual and all ages for skinfold thicknesses, there were no significant differences in level of subcutaneous fatness among the three birth-weight-for-gestational-age groups. In contrast, levels of arm muscularity were still significantly lower for children at 47 months born SGA and higher for those born LGA, and the divergence from AGA infants and children (in SDU) was nearly twice that for muscularity as for arm fatness.

These differences appear to be continuations of differences in body composition noted at or near birth for SGA infants. Using mid-upper arm anthropometry and indices, Yau and Chang[8] followed 38 preterm, SGA infants from birth to a postmenstrual age of 37 to 40 weeks and compared the SGA infants with 193 AGA infants at similar postmenstrual ages. At birth, the SGA infants were smaller in all dimensions, including MUAC, mid-upper arm muscle and fat areas. However, at 37 to 40 postmenstrual weeks, the SGA infants still weighed less and had smaller MUAC but had skinfold thicknesses that were comparable.[8] Thus, preterm SGA infants in the postpartum appear disproportionately to retain excess calories as fat, while protein reserves in the form of muscle remain low. There is no reason to believe that this same pattern does not also apply to growth-restricted infants born at term and account for the tendency of the arm fat index to be higher in the first year of life when percent body fat is sharply increasing.[24,25] After the first year of life, when the arm fat index gradually declines,[20] there are no longer and differences in percent arm fat between SGA and AGA infants.

A limitation of this study is that the anthropometric measurements used to index muscularity and fatness were the ones fairly easy to obtain in survey situations, and not the most technologically sophisticated and precise. In future research, smaller, longitudinal clinical studies using more precise techniques for assessing body composition[26] should be able to assess more clearly these patterns of changes in muscularity and fatness for SGA infants. Further, the concurrent contributions of diet and physical activity to body composition at these ages should be evaluated.

Nevertheless, these findings at or near birth are consistent with metabolic evidence that decreased rates of fetal growth as evidenced by an SGA outcome are an adaptation to an inadequate nutrient supply. Growth-restricted infants are characterized by fetal hypoglycemia, which acts to maintain the maternal/fetal glucose concentration gradient and transport of glucose across the placenta to the fetus.[27] The hypoglycemia also limits insulin secretion, initially potentiating fetal glucose production, but subsequently resulting in increased protein breakdown and decreased protein accretion, limiting the growth of lean body mass.

There may be both short- and long-term implications of our finding that infants and young children born SGA may have continued reduced muscularity, but accrue fat at greater rates or similar to AGA and LGA infants and children. In the short-term, reduced muscularity in infancy and early childhood could be associated with delays in motor development, influencing both the timing and, as importantly, the quality of upright locomotion and exploratory behavior. At least one recent study[28] has shown that preterm infants are delayed in walking, and among the preterm infants, those who were SGA were more likely to show deviant walking quality.

Long-term, SGA infants could be at increased risk in later life for a number of conditions. These include impaired glucose tolerance, insulin resistance,[3,12–14,29] and relative adiposity (high percent body fat), factors that are associated with coronary vascular disease, hypertensive disease, and diabetes in adults. Hofman et al[29] have demonstrated that short (<5th percentile for height) prepubertal children born SGA have abnormal insulin sensitivity, tending toward insulin resistance, compared with short children born AGA. With the increasing adiposity of puberty, such children could develop significant insulin resistance. If these findings can be generalized to all prepubertal children born SGA, then a substantial percentage of children born SGA, especially those who later tend toward overweight, may be at significant risk for insulin resistance and its associated chronic diseases in adulthood.[29]

The chronic diseases of adulthood tend also to be associated with disproportionate localization of subcutaneous fat on the trunk, compared with limbs. Although in adolescence there may no longer be differences in levels of fatness associated with birth weight status, there may still be differences in fat patterning with a localization of fat on the trunk that is associated with low birth weight, especially for girls.[30,31]

The majority of LGA infants are thought to be overgrown resulting from abnormalities of maternal glucose metabolism or gestational diabetes mellitus. With gestational diabetes, the fetus is exposed to high levels of both glucose and amino acids, and the resulting fetal hyperglycemia is associated with increased insulin secretion (hyperinsulinemia) and accelerated growth of lean body mass and fat.[3,10] However, we have shown that LGA infants maintain a consistent and significant excess in muscularity through age 47 months as expected, but show less of an excess in fatness. The importance of these findings is that body size early in life has been associated with the timing of puberty, such that LGA infants and children with increased muscularity may enter puberty earlier.[32] Thus, the trends toward higher birth weight with improved maternal nutrition and prenatal care may at least partially account for the trend toward earlier maturation among US children.[33,34]

CONCLUSION

Finally, these findings have implications for the importance of the assessment of nutritional status in infancy and young childhood. They suggest that together with current anthropometric data, birth weight status and gestational age may be useful in assembling a prognostic risk profile. For example, SGA infants who appear to be gaining weight adequately may be found instead to have increasing fatness but poor growth in lean body mass. To the extent that diet and physical activity can modify body composition, it may be possible to identify at an early age infants and children who might benefit from nutritional and physical activity management. Although additional research is warranted in this area, early intervention and prevention predicated on a risk profile beginning at birth could reduce risk of obesity and chronic disease in later life.

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