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KEY WORDS
neonatal, body fat, fetal growth, body composition, plethysmography

ABBREVIATIONS
%BF—percentage body fat
BASELINE—Babies After SCOPE: Evaluating the Longitudinal Impact Using Neurological and Nutritional Endpoints

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WHAT'S KNOWN ON THIS SUBJECT: Air-displacement plethysmography provides reliable and accurate measurements of percentage body fat.

WHAT THIS STUDY ADDS: Increasing gestational age and female gender are associated with an increased percentage of body fat. We present accurate centiles for percentage body fat according to gestational age and gender.

abstract

BACKGROUND: There is increasing evidence that in utero growth has both immediate and far-reaching influence on health. Birth weight and length are used as surrogate measures of in utero growth. However, these measures poorly reflect neonatal adiposity. Air-displacement plethysmography has been validated for the measurement of body fat in the neonatal population.

OBJECTIVE: The goal of this study was to show the normal reference values of percentage body fat (%BF) in infants during the first 4 days of life.

METHODS: As part of a large population-based birth cohort study, fat mass, fat-free mass, and %BF were measured within the first 4 days of life using air-displacement plethysmography. Infants were grouped into gestational age and gender categories.

RESULTS: Of the 786 enrolled infants, fat mass, fat-free mass, and %BF were measured in 743 (94.5%) infants within the first 4 days of life. %BF increased significantly with gestational age. Mean (SD) %BF at 36 to 37⅙ weeks' gestation was 8.9% (3.5%); at 38 to 39⅙ weeks' gestation, 10.3% (4%); and at 40 to 41⅙ weeks' gestation, 11.2% (4.3%) ($P < .001$). Female infants had significantly increased mean (SD) %BF at 38 to 39⅙(11.1% [3.9%] vs 9.8% [3.9%]; $P = .012$) and at 40 to 41⅙ (12.5% [4.4%] vs 10% [3.9%]; $P < .001$) weeks' gestation compared with male infants. Gender- and gestational age–specific centiles were calculated, and a normative table was generated for reference.

CONCLUSION: %BF at birth is influenced by gestational age and gender. We generated accurate %BF centiles from a large population-based cohort. *Pediatrics* 2011;128:e645–e651

Childhood obesity remains a significant problem in developed countries, with the prevalence of obesity in 2- to 10-year-olds in the United Kingdom increasing from 3.1% in 1995 to 6.9% in 2007.[1] Currently, 16.4% of US children are obese, and 31.6% are overweight.[2] There is increasing concern regarding the risk this poses for the adult health of these children. Overweight children as young as 3 years old have increased inflammatory markers when compared with nonobese children.[3] The metabolic consequences of obesity, such as dyslipidemia, hypertension, and dysglycemia, are also seen in childhood, with 19% to 38% of obese children meeting recognized criteria for metabolic syndrome.[4,5]

Obese children are likely to become obese adults, with a protracted obese state leading to increased risk of obesity-related complications.[6,7] It is possible that the propensity to develop obesity may be determined at birth or even before conception.[8,9] In addition, there is now strong evidence for the role of fetal programming in later metabolic disease and cardiovascular risk.[10,11] Fetal growth restriction leads to adult metabolic dysfunction and cardiovascular risk.[12]

For these clear reasons there is growing interest in the body composition of the infant at birth. Assessment of neonatal adiposity is difficult because anthropometric measurements such as birth weight centiles[13] and skinfold thickness[14] do not correlate well with body composition and body fat percentage (%BF). Other methods used to estimate infant body composition, such as stable isotope dilution, dual-energy radiograph absorptiometry and MRI, are limited by the difficulties in applying them to large studies.[15] The recently developed PEA POD Infant Body Composition Tracking System (Life Measurement Inc, Concord, CA) uses air-displacement plethysmography to measure %BF in infants. It has been shown to provide reliable and accurate measurements of infant %BF.[16,17]

To the best of our knowledge, no large, population-based studies of infant fat mass have been performed. Previous studies, because of their smaller numbers, have varied in their ability to demonstrate differences in body composition between males and females.[18–24] The goal of the present study was to describe %BF in infants born after 36 weeks' gestation within the first 4 days of life, and to detail the effect of infant gender and gestation on %BF.

METHODS

The SCOPE pregnancy study[25] is a multicenter cohort study that recruits primiparous, low-risk women at 15 (±1) weeks' gestation. The aim of the SCOPE study is to develop biomarkers for the prediction of preeclampsia, fetal growth restriction, and preterm birth in a low-risk population. Therefore, the specific exclusion criteria were: multiple pregnancies, known major fetal anomalies, prepregnancy essential hypertension, diabetes, renal disease, systemic lupus erythematosus, antiphospholipid syndrome, major uterine anomaly, cervical cone biopsy, ≥3 miscarriages, and treatment with low-dose aspirin, calcium intake >1 g/24 h, low-molecular-weight heparin, fish oil, or antioxidants.

The Cork BASELINE (Babies After SCOPE: Evaluating the Longitudinal Impact Using Neurological and Nutritional Endpoints) Birth Cohort Study is a longitudinal birth cohort study established as a follow-up to the SCOPE pregnancy study in Ireland. Women recruited to the SCOPE Ireland study are approached at 20 weeks' gestation and recruited to the Cork BASELINE Birth Cohort Study. This study is ongoing, and aims to recruit a total of 2000 infants.

The PEA POD Infant Body Composition Tracking System is an air-displacement plethysmograph that allows for the measurement of body composition in infants with a body weight between 1 and 8 kg. The naked infant is placed in a closed chamber. Air displacement is measured using pressure and volume changes. Calculated body volume and body mass are used to determine body density. Age- and gender-specific fat-free mass density values are used to calculate the %BF.[26,27] Interobserver variability was reduced by having 1 trained midwife perform almost all measurements, per standard operating procedure. Repeated PEA POD measurements were not performed.

This report focuses on the study period of March 2008 to October 2010. All firstborn infants, between 36 and 41⅙ weeks' gestation recruited to the SCOPE/Cork BASELINE Birth Cohort Study, were included. Gestational age, gender, birth weight, and length were recorded at birth for each infant. Gestational age was determined from a first trimester scan or the last menstrual period. Gestational age based on last menstrual period was confirmed against dates calculated from a first trimester dating scan. If there was disparity of >7 days between last menstrual period and scan dates, then the scan-based gestational age was used. Fat mass, %BF, fat-free mass, percentage fat-free mass, and surface area were measured by using the PEA POD system within the first 4 days of life.

Maternal BMI was measured on initial visit at 16 weeks' gestation. Maternal cigarette use was self-reported. Infant anthropometric measurements were recorded on the same day as PEA POD measurement, using standardized operating procedures. Length was measured using a neonatometer to the nearest millimeter. Midarm circumference was measured once on the left arm at the midpoint between the olec-

ranon and acromion processes. Abdominal circumference was measured once at the level just above the umbilicus, in centimeters to 1 decimal place.

Ethical approval was granted by the clinical research ethics committee of the Cork Teaching Hospitals.

Statistical Analysis

Data were entered prospectively into a secure Internet database, and SPSS 16 (SPSS Inc Chicago, IL) was used for analysis. Infants were grouped according to gestational age (weeks + days) into 3 groups: 36 to 37⅙, 38 to 39⅙, and 40 to 41⅙ weeks' gestation. Weighted average percentile values were calculated at 2.5, 5, 10, 25, 50, 75, 90, 95, and 97.5.

One-way analysis of variance was used to compare categorical clinical/demographic variables between groups, and independent samples *t* tests were used to compare continuous variables. Because %BF values were normally distributed (Fig 1), independent samples *t* tests were used to compare data between groups. One-way analysis of variance testing was used to compare %BF between the 3 gestational age groups. This testing was also used to determine if there was a significant difference in %BF between days of PEA POD measurement. Stepwise linear regression was used to determine the independent effect of gestation on %BF. Statistical significance was accepted at $P < .05$.

RESULTS

Over the study time period from March 2008 to October 2010, a total of 2530 women were approached to enter the SCOPE/BASELINE study, and 1622 were recruited. Of these, 1203 women delivered live-born infants and 7 had miscarriages. Another 417 delivered before PEA POD availability, leaving 786 live-born infants eligible for PEA POD measurement during the study period.

Thirty-one infants were excluded because they did not have %BF analyzed within 4 days of birth. Twelve more were outside the gestational age range of 36 to 41 weeks. The total number of infants born between 36 and 41⅙ weeks' gestation with body composition measurements taken within the first 4 days of life was 743.

Most (553 of 743 [74.4%]) PEA POD measurements were taken on the second or third day of life (mean [SD]: 1.9 [0.9]) days. Within the limit of days 0 to

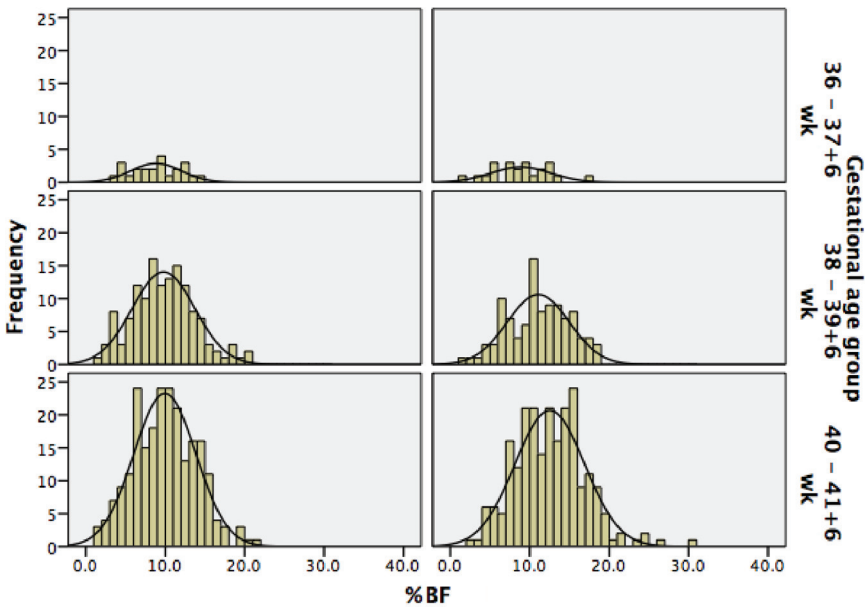

FIGURE 1
%BF for male (left) and female (right) infants at 36 to 37⅙, 38 to 39⅙, and 40 to 41⅙ weeks' gestation. Normal curves displayed.

TABLE 1 Demographic Data of Study Population Grouped According to Gestational Age

	36–37⅙ wk ($n = 45$)	38–39⅙ wk ($n = 243$)	40–41⅙ wk ($n = 455$)	Total (N = 743)	P[a]
Male, %	23 (51.1)	139 (57.2)	228 (50.1)	390 (52.5)	.199
Gestational age, wk	37.2 (0.6)	39.1 (0.5)	40.8 (0.5)	40.1 (1.2)	<.001
Birth weight, g	2955 (313)	3326 (422)	3643 (437)	3498 (470)	<.001
Day of PEA POD measurement	2.1 (1)	1.9 (0.9)	1.8 (0.9)	1.9 (0.9)	.064
White ethnicity, %	44 (97.8)	240 (98.8)	447 (98.2)	731 (98.4)	.826
Maternal age, y	29.8 (4.9)	29.7 (4.6)	29.7 (4.3)	29.7 (4.5)	.999
Maternal university degree or higher, %	15 (33.3)	102 (42)	222 (48.8)	339 (45.6)	.053
Smoked in pregnancy, %	14 (31.1)	65 (26.7)	125 (27.5)	204 (27.5)	.835
Maternal BMI at 16 wk' gestation	23.6 (4.2)	24.6 (4.1)	24.9 (4.1)	24.7 (4.2)	.124
Socioeconomic status, %[b]					
1	2 (4.4)	10 (4.1)	34 (7.5)	46 (6.2)	.897
2	7 (15.6)	41 (16.9)	60 (13.2)	108 (14.5)	
3	18 (40)	91 (37.4)	176 (38.7)	285 (38.4)	
4	3 (6.7)	17 (7)	37 (8.1)	57 (7.7)	
5	4 (8.9)	42 (17.3)	69 (15.2)	115 (15.5)	
6	11 (24.4)	42 (17.3)	79 (17.4)	132 (17.8)	

Values are given as mean (SD).
[a] One-way analysis of variance.
[b] Using the New Zealand Socioeconomic Index.[44,45]

4, day of measurement did not influence %BF ($P = .08$).

The demographic data of our population is shown in Table 1. There was no significant difference in ethnicity, mean maternal age, mean maternal BMI, and socioeconomic status between gestational age categories.

Gestational Age Categories

Mean body fat percentage increased with gestational age %BF (Table 2). At 36 to 37⅐ weeks' gestation, mean (SD) %BF was 8.9% (3.5%), which increased to 10.3% (4%) at 38 to 39⅐ weeks' and to 11.2% (4.3%) at 40 to 41⅐ weeks' ($P < .001$) gestation. On stepwise linear regression analysis, gestational age remained a significant association ($R = 0.193$; $P < .001$) when corrected for maternal BMI at 16 weeks' gestation, socioeconomic group, maternal age, and cigarette consumption. The other significant and consistent association with %BF on multivariate analysis was maternal BMI at 16 weeks' gestation (Table 3). %BF increased linearly with increasing gestation and increasing maternal BMI.

Effect of Gender

The %BF in males and females was normally distributed within each gestational age category (Fig 1). Male infants had lower mean %BF than female infants in each category. The difference became more pronounced with advancing gestational age, and reached statistical significance in the 38 to 39⅐ ($P = .012$) and 40 to 41⅐ ($P < .001$) weeks' gestation categories.

Although female infants had a greater %BF than male infants at each gestational age, male infants had a greater birth weight. This was not significant at 36 to 37⅐ weeks ($P = .24$) or 38 to 39⅐ weeks ($P = .13$) but reached statistical significance at 40 to 41⅐ weeks, with males weighing 3683 g

TABLE 2 Measurements of Male and Female Infants at Different Gestational Ages

	Male	Female	Total	*P*
36–37⅐ wk gestation, *n*	23	22	45	
Birth weight, g	3009 (340)	2898 (277)	2955 (313)	.24
Fat mass, g	253 (99)	245 (112)	249 (105)	.801
%BF	8.8 (3.2)	8.9 (3.8)	8.9 (3.5)	.968
Fat-free mass, g	2588 (285)	2485 (227)	2548 (261)	.188
Fat-free mass, %	91.2 (3.2)	91.1 (3.8)	91.1 (3.5)	.968
Surface area, cm^3	2049 (148)	2010 (112)	2030 (132)	.317
Head circumference, cm	33.5 (1.3)	33.3 (1.1)	33.4 (1.2)	.453
Ponderel index, kg/m^3	27 (3.1)	26 (2.5)	26.5 (2.9)	.241
Length, cm	48.2 (2.5)	48.2 (1.7)	48.2 (2.1)	.973
Abdominal circumference, cm	32.2 (1.9)	31.3 (1.4)	31.7 (1.7)	.085
Midarm circumference, cm	9.8 (0.7)	9.7 (0.8)	9.7 (0.8)	.681
38–39⅐ wk gestation, *n*	139	104	243	
Birth weight, g	3362 (436)	3279 (399)	3326 (422)	.13
Fat mass, g	322 (159)	351 (148)	334 (155)	.159
%BF	9.8 (3.9)	11.1 (3.9)	10.3 (4)	.012
Fat-free mass, g	2879 (331)	2757 (311)	2827 (328)	.004
Fat-free mass, %	90.2 (3.9)	88.9 (3.9)	89.7 (4)	.012
Surface area, cm^3	2203 (172)	2159 (162)	2184 (169)	.043
Head circumference, cm	34.8 (1.4)	34.1 (1.3)	34.5 (1.4)	<.001
Ponderel index, kg/m^3	27.2 (2.5)	27.7 (2.3)	27.4 (2.5)	.132
Length, cm	49.8 (1.9)	49.1 (1.8)	49.5 (1.9)	.004
Abdominal circumference, cm	33 (2)	32.9 (2)	33 (2)	.806
Midarm circumference, cm	10.4 (1)	10.2 (0.9)	10.3 (1)	.12
40–41⅐ wk gestation, *n*	228	227	455	
Birth weight, g	3687 (431)	3598 (440)	3643 (437)	.029
Fat mass, g	358 (171)	437 (188)	397 (184)	<.001
%BF	10 (3.9)	12.5 (4.4)	11.2 (4.3)	<.001
Fat-free mass, g	3122 (348)	2962 (345)	3042 (355)	<.001
Fat-free mass, %	90 (3.9)	87.5 (4.4)	88.8 (4.3)	<.001
Surface area, cm^3	2335 (160)	2290 (164)	2312 (164)	.003
Head circumference, cm	35.4 (1.3)	34.9 (1.2)	35.1 (1.3)	<.001
Ponderel index, kg/m^3	27.4 (2.5)	27.9 (2.3)	27.6 (2.4)	.026
Length, cm	51.2 (1.8)	50.5 (1.7)	50.9 (1.8)	<.001
Abdominal circumference, cm	33.9 (1.9)	33.7 (2)	33.8 (2)	.526
Midarm circumference, cm	10.8 (1)	10.8 (1)	10.8 (1)	.397
Total cohort, *n*	390	351	743	
Birth weight, g	3531 (472)	3460 (466)	3498 (470)	.04
Fat mass, g	339 (165)	400 (182)	368 (176)	<.001
%BF	9.8 (3.9)	11.9 (4.3)	10.8 (4.2)	<.001
Fat-free mass, g	3003 (372)	2872 (355)	2941 (370)	<.001
Fat-free mass, %	90.2 (3.9)	88.1 (4.3)	89.2 (4.2)	<.001
Surface area, cm^3	2271 (184)	2234 (181)	2254 (183)	.006
Head circumference, cm	35.1 (1.4)	34.6 (1.3)	34.8 (1.4)	<.001
Ponderel index, kg/m^3	27.3 (2.5)	27.7 (2.4)	27.5 (2.5)	.023
Length, cm	50.5 (2)	50 (1.9)	50.3 (2)	<.001
Abdominal circumference, cm	33.4 (2)	33.3 (2.1)	33.4 (2)	.503
Midarm circumference, cm	10.6 (1)	10.6 (1)	10.6 (1)	.911

Values are given as mean (SD).

TABLE 3 Stepwise Linear Regression

Independent Variables	Correlation Coefficient	*P*	Standardized β Coefficient	*t*
Gestational age	0.200	<.001	0.192	5.32
Maternal BMI[a]	0.114	.006	0.099	2.71
Cigarette consumption[b]	−0.011	.387	−0.011	−0.302
Socioeconomic group	0.029	.450	0.013	0.329
Maternal age	−0.24	.263	−0.026	−0.672

Dependent variable = %BF days 1 to 4. $F = 7.815$, $P < .001$.

[a] Maternal BMI at 16 weeks' gestation.

[b] Number of cigarettes smoked per day during pregnancy according to maternal self-report.

TABLE 4 Centiles for %BF According to Gestational Age and Gender

Centile	36–37⁶⁄₇ wk Gestation			38–39⁶⁄₇ wk Gestation			40–41⁶⁄₇ wk Gestation		
	Male	Female	All	Male	Female	All	Male	Female	All
97.5th	14.9	17.5	17.1	19.0	18.2	18.4	18.2	22.1	19.8
95th	14.5	16.9	14.4	17.1	17.7	17.5	16.2	19.2	18.3
90th	13.0	13.1	12.9	14.5	16.3	15.5	15.0	17.9	16.7
75th	11.9	12.0	11.9	12.2	14.1	13.0	12.7	15.4	14.2
50th	9.2	8.9	9.2	9.6	11.0	10.3	9.9	12.5	10.9
25th	6.0	5.7	5.9	7.2	7.9	7.5	6.9	9.4	8.1
10th	4.6	4.0	4.4	4.7	6.2	5.1	4.9	7.2	5.8
5th	3.4	1.8	3.3	3.2	4.7	3.4	3.4	5.6	4.4
2.5th	3.1	1.4	1.7	2.4	2.9	2.6	2.8	4.7	3.2

(SD: 435 g) and females weighing 3593 g (SD: 447 g) ($P = .029$).

Centile Chart

A centile chart was compiled for males, females, and all infants at each gestational age category and is shown in Table 4.

DISCUSSION

This large observational birth cohort study revealed the distribution of %BF in the first 4 days of life among firstborn infants >36 weeks' gestation in a largely white Irish population. We revealed an upward trend in %BF at increasing gestational age and demonstrated a significantly higher %BF at birth in female infants than in male infants. We also created a centile chart for %BF in male and female infants that will assist physicians and researchers in the interpretation of measured neonatal %BF.

Previous studies of %BF at birth in term infants have shown varying mean values. These values have varied from 8.6% (3.7%) in 87 Italian infants,[28] to 10.6% (4.6%) in a cohort of 87 US infants[29] and 12.9% (4%) in 108 term Swedish infants in the first 10 days of life.[23] No previously studied cohorts have been large enough to delineate normative data for gestational age categories in term infants. Our mean values varied considerably depending on the gestational age and gender of our studied infants, and this may explain the variance seen between previous reports.

In this cohort, we found that females have a greater %BF than males at birth at each of the studied gestational age categories, a difference that increased with advancing gestational age. Although it is known that female children[30] and adults[31] have higher fat mass and lower lean body mass than males, there is disagreement in the published literature regarding the degree of difference, and whether this is present from birth. In 1967, Foman et al[19] first observed this difference using a multicomponent model to determine body fat, based on measurements of total body water, total body potassium, and bone mineral content. This finding has been replicated using dual-energy radiograph absorptiometry[13,21] and air-displacement plethysmography.[22] However, Butte et al[20] used the multicompartment model in 76 infants and did not find a difference between genders at 2 weeks of age. Eriksson et al[23] and Gilchrist,[24] in 2 separate studies using air-displacement plethysmography, found that %BF did not differ significantly between genders at 1 and 2 weeks of age. Once again, these cohort sizes were much smaller (108 and 80 infants, respectively) than in our study.

As expected, we found that male infants were heavier than their female counterparts at each gestational age. Despite this finding, their %BF was lower, meaning that this increase in weight was due to increased fat-free mass. The effect of fetal growth restriction on the subsequent risk of cardiovascular disease differs substantially between the genders, with males being consistently more vulnerable. There is evidence that boys grow faster than girls in utero and are more reliant on placental function and maternal nutrition during pregnancy, rather than maternal growth.[32] Male infants seem more vulnerable to undernutrition, as evidenced by the greater effect of the Dutch famine on the male risk of later cardiovascular disease[33] and the greater effect of malnutrition on male infants in animal experiments.[34,35] We have shown that as gestation progresses, female infants increase their %BF to a greater extent than their male counterparts. The exact meaning of this finding is unclear but confirms an important difference between males and females in their handling of the nutrition supplied to them in utero.

Air-displacement plethysmography allows for the easy measurement of %BF, and further study has the potential to increase our understanding of the determinants of %BF at birth, as well as the consequences of elevated or reduced values for the infant's future health. Epidemiologic studies have demonstrated reduced glucose tolerance[36] and increased obesity,[37] cardiovascular disease,[38] dyslipidemia,[39] and obstructive airway disease[40] in adults who were exposed to inadequate nutrition in utero. This fetal programming for adult disease begins in utero,[41] and estimation of %BF at birth may have a role in identifying infants at risk. The majority of studies to date examining the link between intrauterine growth and later metabolic risk have focused on birth weight alone. It is unclear whether birth weight or body composition is most important in determining later metabolic risk. We hope to be able to answer some of these questions over time using our well-characterized birth cohort.

Because our study recruited primiparous volunteers with singleton pregnancies, and was conducted in a single Irish center, there is a potential bias that may affect the generalizability of the results. However, our study population closely reflects that of the Irish population as a whole. In the Irish census of 2006, the demographic characteristics of females aged 15 to 44 years compared with our study population were as follows: white, 94% versus 98.4%; completed third level education, 33.7% versus 45.6%.[42] A recent study of 1000 pregnant Irish women recorded a mean (SD) first trimester BMI equal to 25.7,[43] which compares closely with the 24.7 (4.2) found in our study population. Thus, the infants included in our study are close to a representative sample of Irish firstborn infants.

Many factors may influence infant growth and body composition, such as maternal BMI, paternal BMI, maternal nutrition, and socioeconomic group. In this initial report, our goal was not to examine the determinants of infant body fat, nor the consequences. We have reported the normative values found in a large population-based study, which has allowed us to report gender- and gestational age–specific ranges.

CONCLUSIONS

To fully study the effects of fetal growth on long-term health, an important initial step is the determination of normal neonatal body composition. Neonatal adiposity cannot be evaluated without accurate normative data. The data provided in this article will prove useful in the further study of the developmental origins of pediatric and adult disease.

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