

Body Composition From Birth to 4.5 Months in Infants Born to Non-Obese Women

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ABSTRACT: Infant body composition is affected by maternal obesity, which results in increased % body fat in the infant. With the rapidly increasing incidence of obesity, it is important that normative data are available for infant body composition that is not affected by this trend in maternal obesity. This study assessed body composition in infants born at term to women with a BMI between 18.5 and 25. Infant % body fat, fat mass (FM), and fat free mass (FFM) were assessed at birth, 6 wk, 3 mo, and 4.5 mo of age by air displacement plethysmography, using the PEA POD body composition system. The effects of age, gender, GA, and feeding mode on these parameters were assessed. The % body fat doubled between birth and 6 wk of age and then increased at a slower rate. FFM was higher in male infants at all ages, whereas % body fat was higher in female infants at 4.5 mo. There was a trend to increased % fat and decreased FFM in breastfed (BF) infants. The study provides unique data regarding changes in infant body composition and growth in infants born to women in the healthy weight range. (*Pediatr Res* 68: 84–88, 2010)

Body composition in early life may play a key role in the programming of a variety of health outcomes, including hypertension, stroke, type 2 diabetes, obesity, and cardiovascular disease (1). The Barker hypothesis states that undernutrition and small size at birth are associated with increased risk of cardiovascular disease and type 2 diabetes later in life (2). Observational evidence also suggests that faster growth during infancy is associated with an increased risk of obesity (2–5). This is an area of very active research, and in this environment, it is important to establish normal values for infant body composition and growth. In addition, the assessment of feeding interventions for preterm infants may be improved by measuring changes in fat free mass (FFM) vs. fat mass (FM). Deviations from normal developmental patterns of body composition may program these infants for later health problems (2–5). Again, it is critical that normative data be established for infant body composition.

Historically, growth has been monitored by serial measurements of weight, length, and head circumference, with little information available on the compositional nature of infant growth. Early data were based on chemical analysis of a small number of stillborn infants (6,7). More recently,

body composition has been measured using dual-energy x-ray absorptiometry (DXA) (8,9), total body electrical conductivity (TOBEC) (10), magnetic resonance imaging (11), or multicompartment models based on total body water, total body potassium, and bone mineral content measurements (12). However, many of these studies did not measure body composition at birth, and no studies have taken maternal body composition into account. Because it has been shown that maternal overweight/obesity is associated with increased body fat in the newborn infant (13,14), and the prevalence of maternal obesity is increasing, there is a need to establish normal values of body fat and growth in infants born to women of normal BMI.

With the introduction of newer methods such as the air displacement plethysmography (ADP), it is now possible to accurately and noninvasively measure changes in body composition (15–17). ADP is now considered a criterion method of body composition analysis in children (18), and in several studies, it has provided more accurate measurements of body fat than DXA (19,20). Recently, a new ADP system called the PEA POD has been developed to measure body composition in infants from birth to ~6 mo of age. The PEA POD has been validated against other reference models (21–25) and is comfortable and safe for infants.

The aim of this study was to investigate body composition from birth to 4.5 mo of age in infants born at term to women with a BMI in the normal range.

METHODS

Subjects were recruited from healthy term infants (≥ 37 -wk gestation) born at the Royal Brisbane and Women's Hospital, Brisbane, Australia, between January 2008 and April 2009. The study was approved by the Human Research Ethics Committees of both the Royal Brisbane and Women's Hospital and the University of Queensland. Informed parental written consent was obtained, and participation was voluntary.

Subjects eligible for the study were healthy term infants (37- to 42-wk gestation) born to women with a BMI 18.5–25 based on weight at the first antenatal visit. This visit usually takes place in the first trimester before significant weight gain. Infants were excluded if there was a history of maternal illness or gestational diabetes, infants were below the 10th percentile for weight, infants were from a multiple birth set, or infants had congenital anomalies.

Body composition measurements were performed at birth (0–4 d), 6 wk, 3 mo, and 4.5 mo of age using the PEA POD (Life Measurement Inc, Concord, CA). Before testing, the infant's clothes were removed and a head

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Abbreviations: ADP, air displacement plethysmography; DXA, dual-energy x-ray absorptiometry; FFM, fat free mass; FM, fat mass

cap applied to reduce the amount of air behaving isothermally. The infant's mass was measured using the integrated scale. Mass and volume calibrations took into account the presence of two hospital identification bracelets and an umbilical cord clip on each neonate at birth. The % body fat was computed by software integral to the PEA POD system (version 3.0.1) based on a two compartment model—fat and fat free compartments. Within the volume calculation, corrections are applied for air within the lungs and in close proximity to the subject's skin, which behaves isothermally. Infant % body fat is calculated from body density assuming the density of fat to be 0.9007 kg/L. Age- and gender-specific densities of FFM are computed based on the data of Fomon *et al.* (7). For infants up to 6 d old, this FFM density calculation also takes into account reported fluctuations in hydration level (26). FM and FFM are computed from weight and % body fat. Infant length was measured heel to crown using an infant length board (Ellard Instrumentation Ltd, Seattle, WA). Infant data recorded included birth weight, length, gender, ethnicity, and GA.

At each visit, mothers were asked about current breastfeeding frequency and intake of formula and solids. Based on this information, at each age infants were categorized as either breastfed (BF; fed exclusively or predominantly with breast milk) or artificially fed (AF).

SPSS version 17 was used for statistical analysis. The *t* test was used to assess differences between subjects with incomplete data and remaining subjects. Repeated measures ANOVA was used to determine the effects of age and gender on FM, FFM, % body fat, and increase in fat as a proportion of weight gain. Pearson's correlation was used to assess the relationship between GA and infant % body fat. The *t* test was used to assess differences between BF and other infants.

RESULTS

Maternal and infant demographic characteristics of the subjects are presented in Table 1. Seventy-seven infants were recruited for the study and measured at birth. Fifty-four infants (70%) returned for assessment at 6 wk, 55 (71%) at 3 mo, and 53 (69%) at 4.5 mo. One baby was not able to be assessed at 4.5 mo because he was too large for the PEA POD chamber. Data at all time points were available for 47 infants. Data from 30 infants were not able to be analyzed because they failed to attend all follow-up assessments. Two infants were excluded from the analysis because their % body fat at 4.5 mo was almost three standard deviations away from the mean for their gender. One of these infants had an extremely low body fat and had consistently fallen across the weight percentiles over the study period. The other infant had an extremely high % body fat. The father of this infant was of Tongan ethnicity, where both BMI and % body fat are higher than in the

Australian population (27). All data analysis was performed on the remaining 45 infants unless stated otherwise. Demographic characteristics, % fat at birth, FFM and FM at birth, and birth weight in subjects who did not have complete data (*n* = 30) or were excluded (*n* = 2) were not significantly different to the remaining subjects (Table 1). Among the 77 infants, 90% had Caucasian ethnicity. Among the 45 included in the analysis, 98% had Caucasian ethnicity.

Effect of age and gender on body composition. Body composition for each gender, at each time point, is shown in Table 2. The % body fat was normally distributed at each age. Infant % body fat increased with age (*p* < 0.001). The greatest increase in % body fat occurred between birth and 6 wk of age when % body fat doubled. Mean % body fat in female infants was higher than in male infants at all time points, but the difference was only statistically significant at 4.5 mo. FFM was significantly higher in male infants than in female infants at all ages tested. There was no significant difference in FM or weight between male and female infants.

The increase in FM as a percentage of weight gain did not alter with age (Table 3). Three infants had a small decrease in % body fat between 3 and 4.5 mo, resulting in a decrease in FM. These infants also showed a lower than normal weight gain during the same period and were excluded from this analysis. There was no difference between gender groups in this proportional increase in fat at 6 wk and 3 mo, but between 3 and 4.5 mo, the rate of fat increase was significantly higher in female infants (Table 3).

Effect of GA on body composition. There was a positive correlation between % body fat at birth and GA (*R* = 0.322, *p* = 0.004). Infant % body at 6 wk, 3 mo, and 4.5 mo was not significantly correlated with GA at birth.

Effect of feeding on body composition of infants. This analysis was performed on all infants for whom feeding data and body composition data were available at 4.5 mo (*n* = 50). There was no difference in demographic characteristics between BF and AF infants (Table 4). There was also no difference in body composition at 4.5 mo although the *p* value was 0.06 for FFM and 0.07 for % body fat indicating a possible trend toward lower FFM and higher % body fat in BF infants (Table 4).

There was no difference between BF and other infants in FM increase as a proportion of weight gain at 6 wk or 3 mo, but at 4.5 mo, those infants who were still BF had a greater increase in FM as a proportion of weight gain (Table 4).

Table 1. Demographic characteristics of the study subjects

	All subjects (<i>N</i> = 77)	Incomplete or excluded (<i>n</i> = 32)	Remaining subjects (<i>n</i> = 45)
Maternal BMI	21.8 ± 2.1	21.8 ± 2.3	21.8 ± 1.9
GA (wk)	40.0 ± 1.1	40.0 ± 1.0	40.0 ± 1.2
Birth weight (kg)	3.599 ± 0.408	3.606 ± 0.437	3.593 ± 0.392
Length at birth (cm)	51.1 ± 2.3	51.0 ± 2.3	51.2 ± 2.3
Gender	53% M	50% M	56% M
Parity	1.6 ± 1.0	1.6 ± 0.8	1.6 ± 1.0
FFM at birth (kg)	3.045 ± 0.320	3.038 ± 0.316	3.050 ± 0.326
FM at birth (kg)	0.350 ± 0.162	0.368 ± 0.176	0.336 ± 0.153
% Body fat at birth	10.05 ± 4.05	10.53 ± 4.31	9.72 ± 3.86
Age at measurement			
Birth (d)	2.0 ± 1.1	1.8 ± 1.2	2.1 ± 0.9
6 wk	6.3 ± 0.5	6.2 ± 0.4	6.4 ± 0.6
3 mo (wk)	12.7 ± 0.6	13.0 ± 0.8	12.6 ± 0.6
4.5 mo (wk)	19.4 ± 0.8	19.4 ± 0.3	19.4 ± 0.8

All values are presented as mean ± standard deviation except for gender. M, male.

DISCUSSION

This study provides normative, gender-specific, longitudinal body composition values for infants starting from the first few days of life until 4.5 mo of age. This dataset is important in several respects. First, the data include only those infants born to women with a BMI in the normal range. Only two other studies examine body composition in infants born specifically to normal weighted women, and the only study that provides useful data does not provide gender specific results or values beyond birth (13,14). These studies also assess infants born to overweight or obese women and indicate that

Table 2. Body composition in male and female infants at birth, 6 wk, 3 mo, and 4.5 mo of age

	Age	Weight (kg)	FFM (kg)	FM (kg)	% fat
Male (n = 25)	Birth	3.540 ± 0.395	3.197 ± 0.296	0.341 ± 0.149	9.42 ± 3.42
	6 wk	5.146 ± 0.586	4.146 ± 0.342	1.001 ± 0.329	19.10 ± 4.61
	3 mo	6.350 ± 0.741	4.813 ± 0.437	1.525 ± 0.389	23.76 ± 4.07
	4.5 mo	7.297 ± 0.940	5.478 ± 0.557	1.819 ± 0.518	22.56 ± 4.67
Female (n = 20)	Birth	3.195 ± 0.348	2.865 ± 0.265*	0.331 ± 0.162	10.09 ± 4.41
	6 wk	4.862 ± 0.419	3.797 ± 0.354*	1.065 ± 0.248	21.84 ± 4.20
	3 mo	6.041 ± 0.470	4.458 ± 0.306*	1.583 ± 0.303	26.07 ± 3.60
	4.5 mo	6.995 ± 0.603	4.931 ± 0.355*	2.064 ± 0.405	29.33 ± 3.98*

All values are presented as mean ± standard deviation.

* Significantly different from male values ($p < 0.05$).

Table 3. Increase in fat mass as a percentage of weight gain for male and female infants

	Age	Increase in FM/weight gain (%)
Male (n = 23)	Birth to 6 wk	39.8 ± 10.5
	6 wk to 3 mo	43.5 ± 10.4
	3 mo to 4.5 mo	34.2 ± 19.5
Female (n = 19)	Birth to 6 wk	43.4 ± 11.5
	6 wk to 3 mo	43.7 ± 16.8
	3 mo to 4.5 mo	51.2 ± 15.6*

All values are presented as mean ± standard deviation.

* Significantly different from male values ($p < 0.05$).

Table 4. Demographic characteristics and body composition at 4.5 mo in breastfed (BF) and other (AF) infants

	BF infant (n = 30)	AF infant (n = 20)
Demographic characteristics		
Maternal BMI	21.8 ± 2.0	21.6 ± 1.7
GA (wk)	40.1 ± 1.1	39.9 ± 1.3
Birth weight (kg)	3.546 ± 0.373	3.642 ± 0.464
Gender	50% M	55% M
FFM at birth (kg)	3.008 ± 0.317	3.094 ± 0.372
FM at birth (kg)	0.328 ± 0.155	0.346 ± 0.150
% Body fat at birth	9.64 ± 3.94	9.77 ± 3.65
Body composition at 4.5 mo		
Weight (kg)	7.066 ± 0.824	7.235 ± 0.789
FFM (kg)	5.093 ± 0.576	5.390 ± 0.504
FM (kg)	1.973 ± 0.440	1.845 ± 0.509
% Body fat	27.76 ± 4.47	25.20 ± 5.24
FM gain since 3 mo/weight gain (%)	46.7 ± 21.5	34.8 ± 12.2*

All values are presented as mean ± standard deviation except for gender.

* Significantly different from BF ($p < 0.05$).

infant body composition is related to maternal BMI with higher FM and % body fat seen in infants of overweight or obese women (13,14). In contrast, one study has reported that there is no relationship between infant body fat and maternal BMI (28), but this study includes only a small number of obese women (5% of 108 subjects) and does not exclude a number conditions that could significantly confound results (*i.e.* infants born small for GA and infants born to women with diabetes). As the prevalence of obesity continues to increase at an alarming rate, it is important that normative data for infant body composition is not skewed by this trend. With the growing interest in the relationship between the *in utero* environment and later health outcomes, there will be an

increasing requirement for information regarding normal body composition at birth. This study provides information regarding normal body composition at birth in 77 infants significantly increasing the size of the data pool available for combined analyses.

This study also provides longitudinal data regarding body composition at specific ages beginning at birth. The study indicates that body composition changes very rapidly in the first 6 wk of life with % body fat doubling in this period. Other studies have performed cross-sectional assessments only (10,11), studied only one or two ages before 6 mo (12,28), not commenced at birth (10,12,28), or pooled data collected from infants at a wide range of ages in the first month (14). Because of our finding of large rapid changes in body composition from birth to 6 wk, data obtained 2–4 wk after birth cannot be regarded as indicative of birth values or compared with birth measurements. Data pooled from a range of ages in the first month of life is also difficult to interpret because of the rapid changes that occur during this period. Normative data must be provided for specific ages in these first weeks of life. The importance of this is underlined by the result of Hull *et al.* (14) who found that, across the first 35 d of life, infant age was the only significant predictor of % body fat. For future studies, it would be informative to measure % body fat at 2 and 4 wk to determine whether the increase in % fat is linear during this period. Data from Butte *et al.* (12) exhibited a high degree of variability in % body fat at 0.5 mo, suggesting a very rapid change is occurring at this time.

This study also provides unique gender-specific information regarding body composition at birth. Although differences in weight between male and female infants were not significant in this study, population data indicate that male infants are generally heavier than female infants. The study did show that FFM is significantly lower in female infants suggesting that gender differences in FFM are a major component of the gender differences in weight. We found that although the mean % body fat was always higher in female than in male infants, this difference was only significant at 4.5 mo. Similarly, both Rigo *et al.* (9) and Butte *et al.* (12) found that FFM tended to be higher in male infants and while mean % fat was always higher in females, this did not become significant until after 3 mo. Eriksson *et al.* (28) also observed a tendency for higher FFM in male infants at 1 and 12 wk, and higher % fat in females at 1 wk, although infant % fat was identical in males and females at 12 wk.

The longitudinal nature of the data in this study has allowed the calculation of increases in FM as a proportion of weight gain. To our knowledge, this is the only data of this nature available. This parameter is quite variable but clearly significantly higher in female than in male infants from 3 to 4 mo. This may account for the significant increase in % fat seen in female infants at 4.5 mo.

The values for % body fat, FM, and FFM presented in this study for the combined genders at birth agree well with those of Sewell *et al.* (13) for infants born to women with a normal BMI. The other study on infants of normal BMI women uses pooled data from birth to 35 d of age, which cannot be compared with data in this study (14). Our values obtained at birth cannot be compared with those of Butte *et al.* (12) for 0.5 mo or Eriksson *et al.* (28) at 1 wk because of the rapid changes in % fat during the first weeks of life. Values of % fat at 3 mo in this study are substantially lower than those of Butte *et al.* (12), who did not exclude infants born to women with increased BMI. This may have contributed to the higher body fat and lower FFM in the study by Butte *et al.*, although these variations could also be the result of the different methodologies used (Butte *et al.* used a multicompartment model). Infant % body fat in males in our study was also slightly lower than that reported by Eriksson *et al.* (28), again possibly because the cohort studied by Eriksson *et al.* included some overweight and obese women, although % body fat was very similar in female infants. The higher proportion of BF infants in the study by Eriksson *et al.* (28) could also contribute to these differences. Our data for all body composition parameters agree closely with those reported by Wells (29) at 3 mo of age.

Recent reviews of literature surrounding breast feeding and the programming of body composition have reported that breast feeding is associated with a decreased risk of later obesity (30,31). There are limited data available regarding the effects of breast feeding compared with artificial feeding on body composition in infancy. De Curtis *et al.* (32) found no difference in body composition or weight gain composition between BF and formula fed infants at the age of 2 mo. Two other studies have shown that body fat at 3–4 mo is higher and FFM lower in BF infants than in formula-fed infants (33,34), but these differences are no longer apparent at 1 y of age (33–35). Similarly, this study found no differences before 3 mo but a trend for lower FFM and higher % fat at 4 mo in BF infants. This is supported by the finding of a significantly higher increase in FM as a proportion of weight gain at 4 mo in BF infants.

In this study, body composition was assessed using the PEA POD, a relatively new instrument that uses ADP to assess body composition in infants. It has been validated against both physical and biologic phantoms (21,22) and also against a four-compartment model using reference methods in neonates (24,25). The between test reliability is excellent (25). Although relatively new, ADP is already considered a criterion method for body composition in children (18) and has been shown to provide better estimates than DXA in some studies (19,20). The PEA POD takes into account the fact that hydration status is different in the neonate to that in the adult, and

in particular, allows for the greater hydration of the FFM in the first week of life.

This study did not assess the influence of maternal weight gain on infant body composition. However, all three studies that have investigated this issue have found that maternal weight gain does not affect body fat in infants born to normal-weighted women (13,14,28).

In conclusion, this study has provided normative body composition data for infants born to women with a BMI in the healthy weight range. The data are also age and gender specific, and the longitudinal data collection has allowed proportional increases in FM to be calculated. It has been suggested that the relationship between birthweight and adult health may be simply a reflection of body composition, which may be the more important determinant of adult health than weight *per se* (14). Body composition at birth probably provides a better reflection of *in utero* conditions than weight alone and thus may be a better predictor of subsequent risk of chronic disease. In this context, normative body composition and growth data representative of a healthy *in utero* environment are critically important.

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