Body composition from birth to 6 mo of age in Ethiopian infants: reference data obtained by air-displacement plethysmography[1–3]

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ABSTRACT

Background: Data on body composition in infancy may improve the understanding of the relation between variability in fetal and infant growth and disease risk through the life course. Although new assessment techniques have recently become available, body composition is rarely described in infants from low-income settings.

Objective: The aim of this study was to provide reference data for fat mass (FM) and fat-free mass (FFM) from birth to the age of 6 mo from an urban African population.

Design: We conducted a prospective cohort study among infants from Jimma, Ethiopia. FM and FFM were measured at birth and at 1.5, 2.5, 3.5, 4.5, and 6 mo of age with air-displacement plethysmography (ADP) validated against a stable isotope method in a subsample. Reference charts and reference tables with *z* scores and percentiles for FM, FFM, FM index (FMI; in kg/m^2), and FFM index (FFMI: in kg/m^2) were constructed with the lambda-mu-sigma method.

Results: Body composition growth charts were based on a total of 2026 measurements of body composition obtained from 378 infants. FM and FMI gain progressed in a logarithmic-shaped curve and variation increased with increasing age, whereas FFM increased in an almost linear manner with a minor deceleration at around 3 mo of age. The FFMI curve showed a very modest exponential increase with age.

Conclusions: By presenting *z* scores and centile reference charts for an apparently healthy urban Ethiopian infant population, this study represents a first step toward providing reference data on FM and FFM for an urban African context, which is important for future clinical care and research. This study was registered at www.controlled-trials.com as ISRCTN46718296. *Am J Clin Nutr* 2013;98:885–94.

INTRODUCTION

Data on body composition in infancy and childhood may improve the understanding of the relation between early growth and disease risk through the life-course (1). This may be particularly relevant in low-income settings where impaired growth and suboptimal nutritional status early in life are common and have significant long-term consequences (2). Studies from Ethiopia and India have demonstrated marked variability in fat mass (FM)[4] and fat-free mass (FFM) in newborns with similar weight and length (3, 4), but such differences are not captured with the widely applied anthropometric assessment of growth and nutritional status early in life. With new techniques available, detailed assessment of body composition in infancy and childhood is now obtainable (5), but reference data are needed for clinicians and researchers to evaluate growth in body composition at an individual and population level (6).

Reference data on childhood growth in FM and FFM were recently published based on studies of UK children (7), but only for children aged 5 y and upward. With the recent development of infant air-displacement plethysmography (ADP), fast, safe, precise, and accurate assessment of body composition in neonates and infants up to the age of 6 mo is now possible in large samples (8, 9). A number of ADP studies have recently described early-life growth in FM and FFM (10–14). However, few of these studies provided data for future reference. Moreover, these studies were all conducted in high-income countries.

Few data are available on infant and child body composition from low- and middle-income countries, although this is where impaired growth is common and may have the most significant consequences. One study assessed FM and FFM by stable isotope methods in 3- to 18-mo-old Gambian children and found an increasing deficit in FFM, but not in FM, when compared with UK children as they grew from 3 to 18 mo of age (15). We recently published data on the body composition of Ethiopian

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[4] Abbreviations used: ADP, air-displacement plethysmography; D_{FFDT}, density of fat-free dry tissue; D_{FFM}, density of fat-free mass; D_{FM}, density of fat mass; FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index; JUSH, Jimma University Specialized Hospital; LMS, lambda-mu-sigma; TBW, total body water; % fat, fat percentage.

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newborns and found a wide variation in FM and FFM across the range of birth weight (3). These studies indicate that body composition assessment in a low-income setting adds important information beyond what is captured by weight and length and that body composition may differ from that reported from high-income populations. Thus, although these studies did not provide reference data, they do underscore the need for population-specific infant body composition reference data.

In the present study, we followed healthy urban Ethiopian infants with repeated ADP measurements of body composition and present *z* score and centile reference charts on FM and FFM from birth to 6 mo of age for an urban sub-Saharan African population.

SUBJECTS AND METHODS

Study setting and participants

Participants were recruited among women giving birth at Jimma University Specialized Hospital (JUSH), Ethiopia. Women and their infants were considered eligible for the study if they were living in Jimma town and had given birth to a term child (gestation ≥37 wk) without congenital malformation and with a birth weight ≥1500 g. Newborns with serious medical conditions were not included in the study, as they were admitted to the neonatology unit whereas recruitment for this study was done at the maternity ward. Newborns with medical conditions and/or edema observed during baseline examination were also not included. If consent was given, women and newborns were examined shortly after birth while still admitted to the hospital and no later than 48 h after birth. An upper limit of 48 h after birth was used to obtain the highest precision in the New Ballard score test used for assessment of gestational age. However, 93.4% of the birth examinations were performed within 24 h after birth.

For the present study, mothers were asked to return with their infants for clinical examination at 1.5, 2.5, 3.5, 4.5, and 6 mo of age, and only infants with a clinical examination at least at birth and 6 mo of age were included in this longitudinal cohort.

Infant measurements

Infant length, weight, FM, and FFM were measured at all time points. Length was measured in duplicate to the nearest 0.1 cm with a SECA 416 Infantometer. Following the method described by Gibson (16), one research nurse held the infant's head and body in place, while another kept the infant's knees straight and pushed the footboard firmly against the heels. Assessment of weight, FM, and FFM was undertaken with the PeaPod (COSMED USA), an ADP device specifically developed for infants (17). During the 2-min ADP measurement, infants were lying on a plastic bed in a closed compartment without clothes wearing only a wig cap. The research nurses and the mother could watch the infant through a plexi-glass window and the compartment door could be opened at any time should the baby or mother feel uncomfortable.

Gestational age was estimated by physical examination within 48 h after birth according to the New Ballard Score (18, 19). When validated against gestational assessment by prenatal ultrasonography, the New Ballard Score was found to be valid and accurate with a mean difference of 0.15 ± 1.46 wk (19). Three experienced research nurses were trained in Ballard score testing by a pediatrician and interpersonal variation was tested and discussed following training and at a later repetition course.

Maternal anthropometric measurements

Maternal weight was measured within 48 h after delivery to the nearest 0.1 kg with the scale of a Tanita 418 Bioimpedance analyzer and height to the nearest 0.1 cm with a SECA 214 stadiometer.

Questionnaire data

Information on maternal age, parity, delivery and delivery outcome, antenatal care, maternal food intake, and parental background characteristics was obtained through questionnaires presented to the mothers shortly after delivery during their infants' birth examination. Breastfeeding status at 6 mo was assessed at the 6-mo examination based on 9 locally developed questions taking local cultural traditions into account. Breastfeeding was then coded into 4 categories: exclusively breastfed (only human milk), almost exclusively breastfed (infrequent small amounts of water or tea), partly breastfed, or not breastfed, in accordance with Labbok and Krasovec (20). Maternal food intake was assessed shortly after delivery with an 18 item food-frequency questionnaire adapted to reflect local diet and asking about food intake in the past week.

All measurements and questionnaires were presented orally to the mothers by trained and experienced research nurses speaking local languages.

Validity of infant ADP

The ADP method permits calculation of fat percentage (% fat) in a 2-component model of body composition (FM and FFM). The % fat calculation was based on measured body density (D_b) combined with an assumed constant density of FM (D_{FM}) at 0.9007 g/mL and values for the density of FFM (D_{FFM}) ranging from 1.063 g/mL at birth to 1.067 g/mL at 6 mo as outlined by Fomon et al (21). The % fat was then obtained by solving a modified version of Siri's (22) equation for % fat, as proposed by Lohman (23):

$$\%\,fat = \left(\frac{C1}{D_b} - C2\right) \times 100 \qquad (1)$$

where C1 = ($D_{FFM} \times D_{FM}$)/($D_{FFM} - D_{FM}$), and C2 = D_{FM}/($D_{FFM} - D_{FM}$). However, D_{FFM} is a function of the relative contributions of water, mineral, and protein to FFM and water content in fat-free tissue may differ across populations. Therefore, although ADP assessment was found to be accurate and precise in a study from the United States (9), we found it necessary to evaluate, in the present population, the values for D_{FFM} presented by Fomon et al (21) and used by the PeaPod to calculate FM and FFM. Therefore, we estimated D_{FFM} in a subsample of 29 infants between 1.5 and 6 mo of age with a 3-component model of body composition. The 12 male and 17 female participants included in this subsample were recruited by convenience from the main study and had a mean ± SD weight-for-age *z* score of −0.17 ± 1.05 and height-for-age

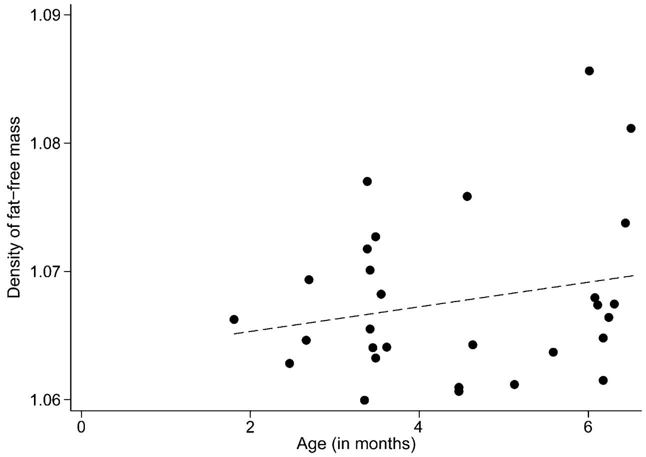

FIGURE 1. Scatter plot and linear regression of D_{FFM} against age in months based on a subsample of 29 infants measured between 1.5 and 6 mo of age. Regression equation: $D_{FFM} = 0.9728 \times 10^{-3} \times$ age (mo) + 1.063346, $P = 0.25$, $r^2 = 0.05$. D_{FFM}, density of fat-free mass.

z score of −0.32 ± 1.09 based on the 2006 WHO growth standards (24).

In the 3-component model (22), D_{FFM} was calculated from values for body volume (BV), body weight (BW), total body water (TBW), and published data on the density of fat-free dry tissue (D_{FFDT}). We obtained body volume and body weight from ADP and measured TBW by deuterium dilution (^2H_2O). To measure TBW, a predose sample of 0.50 mL saliva was withdrawn from the infant's mouth and followed by oral administration of 0.1 g of 99.9% deuterium oxide (^2H_2O) per kg body weight diluted in 6 mL H_2O. The oral dose was then followed by withdrawal of a postdose saliva sample 3 h after the dosing (25). The isotopic enrichment of the dose and the saliva samples was determined with isotope ratio mass spectrometry (26) at Medical Research Council Human Nutrition Research, Cambridge, United Kingdom, and TBW was calculated as described by Davies and Wells (27).

Values of D_{FFDT} are given by the ratio of protein-to-mineral. We calculated age-specific values for D_{FFDT} based on age-specific values for the fraction of protein in fat-free dry tissue (w_p) as presented by Fomon et al (21) and published densities of proteins (d_p) and minerals (d_m) as presented by Brozek et al (28).

$$D_{FFDT} = \frac{d_p \times d_m}{\left(d_m - d_p\right) \times w_p + d_p} \qquad (2).$$

With the values for total body density, TBW, and D_{FFDT}, we calculated D_{FFM} by first obtaining FM by solving a modified

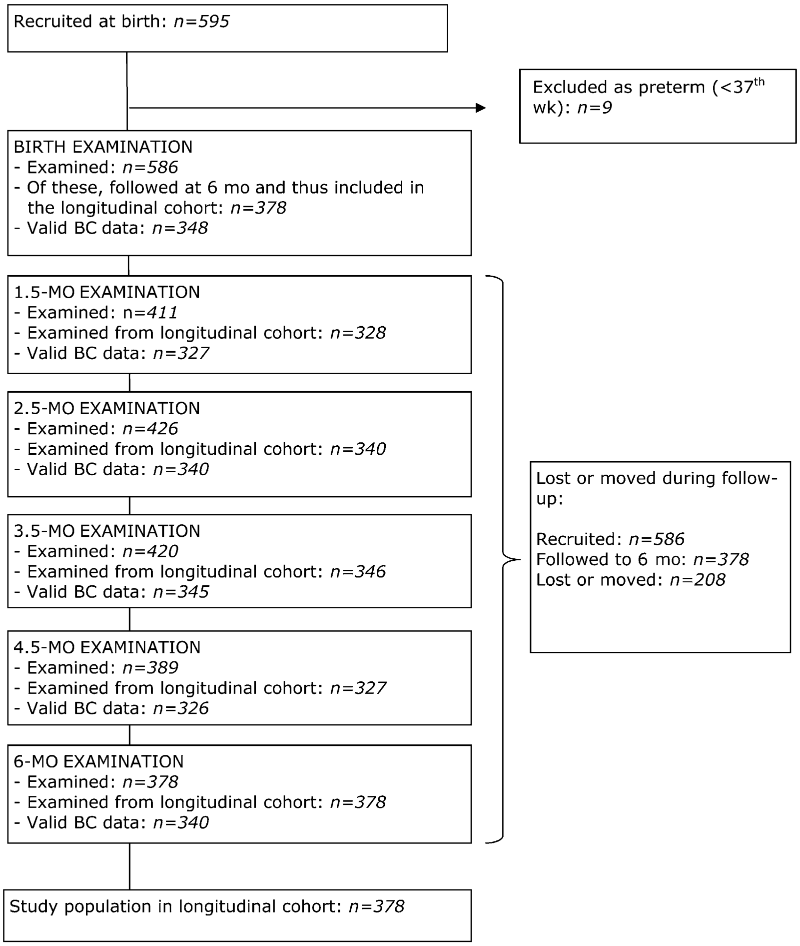

FIGURE 2. Flow diagram of the study participants. BC, body composition.

version of Siri's 3-component equation taking the age-specific D_{FFDT} into account (29):

$$FM = BW \times \left\{ \left(\frac{D_{FM}}{D_{FFDT} - D_{FM}} \right) \times \left[\left(\frac{D_{FFDT} \times BV}{BW} \right) - \left(\frac{TBW}{BW} \right) \left(\frac{D_{FFDT} - 0.9937}{0.9937} \right) - 1 \right] \right\} \quad (3).$$

Then, because *fat-free volume* = (*total volume*−*fat volume*), and $FFM = (BM - FM)$, D_{FFM} may be calculated as:

$$D_{FFM} = \frac{BW - FM}{\mathrm{BV} - (FM \div D_{FM})} \quad (4).$$

As there were no measurements at birth, the D_{FFM} from birth to 6 mo of age was derived by regressing D_{FFM} against age [regression equation: $D_{FFM} = 0.9728 \times 10^{-3} \times$ age (mo) + 1.063346, $P = 0.25$, $r^2 = 0.05$]. This resulted in a mean (SE) D_{FFM} of 1.068 (0.001) g/mL, with an increase of 0.001 g/mL per month from 1.063 (0.004) g/mL at birth to 1.069 (0.002) g/mL at 6 mo of age (**Figure 1**). A large variation in the FFM densities and the fact that the values were based partly on extrapolation calls for cautious use of this data. Saliva sampling and dosing of diluted ^2H_2O to infants is difficult and despite systematic registration and weighing of spillage and coughed-up dilution during dosing, some unregistered spillage or contamination of saliva samples cannot be completely ruled out. Nonetheless, very little data are available on D_{FFM} among newborns and infants, and the present D_{FFM} values we present here were very similar to the values by Fomon et al (21) that are default in the PeaPod software. Consequently, with the D_{FFM} presented here supporting those by Fomon et al (21), we considered the "Fomon" values appropriate for the present study.

Follow-up

After the birth examination, participants were invited to return to the clinic when their infant was 1.5, 2.5, 3.5, 4.5, and 6 mo of age. Those who failed to show up for an appointment within 1 wk of the appointment date were called and reminded to attend. If participants could not be reached by telephone, they were visited at their home within 14 d of the appointment date and asked whether they were willing to attend.

Data handling and statistics

To describe the study population in relation to a general standard, weight-for-age *z* score, and height-for-age *z* score were calculated based on the 2006 WHO growth standards (24).

FM and FFM were calculated from the crude ADP outputs as weight × % fat and weight − FM, respectively. To index FM and FFM according to body size, we followed the approach of VanItallie et al (30) and adjusted FM and FFM for length. Thus, similar to the way BMI adjusts weight for size, we calculated an FM index (FMI) as FM (kg)/length $(m)^2$ and FFM index (FFMI) as FFM (kg)/length $(m)^2$.

Birth to 6 mo body composition centile charts were fitted with the lambda-mu-sigma (LMS) method with maximum penalized likelihood as developed by Cole and Green (31). This method has been widely used to construct growth reference charts, including the WHO 2006 (24) and UK growth charts (32), and estimates the centiles in terms of 3 age-sex-specific cubic spline curves: *1*) the smoothed median curve (M) representing the outcomes' relation to age, *2*) the CV (S) representing the scatter around the mean, and *3*) the skewness (L), which is addressed with age-specific Box-Cox transformation to achieve normal distribution. Goodness of fit was assessed as described by Wells et al (7).

Data analysis was performed with Stata IC 11.2 (StataCorp), LMS ChartMaker (Medical Research Council), and R 2.15.1 (http://www.R-project.org/). All body composition results from the PeaPod were obtained with PeaPod software version 3.0.1.

Ethics

Ethical permission was granted from Jimma University Ethical Review Committee and consultative approval was obtained from the Danish National Committee on Health Research Ethics. Thorough information about the study and examinations was given orally and written in local language. Written informed consent was obtained from all participating women. Women were informed that they were free to withdraw from the study at any time. Newborns with serious medical conditions were admitted to the neonatology unit at JUSH and were not recruited to the study. Infants with medical conditions observed during clinical examination and Ballard score testing during baseline examination

TABLE 1

Description of maternal anthropometric characteristics, antenatal care, and delivery among 372 mothers in addition to infant sex, gestational age at birth, and feeding practice at 6 mo of age among their 378 infants[1]

	Values	N
Maternal characteristics		
Age (y)	24.0 ± 4.6[2]	369
Weight (kg)	56.0 ± 8.5	293
Height (cm)	157.6 ± 5.8	290
BMI (kg/m^2)	22.5 ± 3.0	289
Parity [*n (%)*]		368
Para 1	203 (55.2)	
Para 2	82 (22.3)	
Para ≥3	83 (22.6)	
Delivery (cesarean delivery) [*n (%)*]	20 (5.4)	372
Pregnancy outcome (twin births) [*n (%)*]	6 (1.6)	372
Iron, iron-folic, or multivitamin supplementation in pregnancy [*n (%)*]	42 (11.2)	372
Antenatal care (≥4 visits) [*n (%)*]	292 (86.1)	339
Infant characteristics		
Gestational age at birth (wk)	39 (37–42)[3]	378
Sex (boys) [*n (%)*]	182 (48.2)	378
Breastfeeding status at 6 mo of age [*n (%)*]		348
Exclusively breastfed	37 (10.6)	
Almost exclusively breastfed	74 (21.3)	
Partially breastfed	218 (62.6)	
Not breastfed	19 (5.5)	

[1] All data, except those on feeding practice, were obtained shortly after delivery during the infants' birth examination.

[2] Mean ± SD (all such values).

[3] Median; range in parentheses.

TABLE 2
Description of parental socioeconomic characteristics[1]

	Mothers		Fathers	
	n (%)	N	*n* (%)	N
Ethnicity		372		
Oromo	192 (51.5)			
Amhara	62 (16.6)			
Dawro	34 (9.1)			
Other	85 (22.8)			
Religion		372		
Muslim	148 (39.8)			
Orthodox Christian	159 (42.7)			
Protestant Christian	61 (16.4)			
Other	4 (1.1)			
Marital status		372		
Married	358 (96.2)			
Never married, divorced, widowed	14 (3.8)			
Education		372		360
No or some primary school	204 (54.8)		153 (42.5)	
Completed primary school	58 (15.6)		68 (18.9)	
Completed secondary school	66 (17.7)		62 (17.2)	
Higher education	44 (11.8)		77 (21.4)	
Occupation		372		363
Housewife	231 (62.3)		0 (0.0)	
Merchant	27 (7.2)		63 (17.2)	
Public or private employee	71 (18.9)		225 (62.2)	
Student	31 (8.5)		5 (1.1)	
Dayworker	8 (2.1)		35 (9.8)	
Other	4 (1.3)		35 (9.8)	

[1] Data were obtained by questioning the 372 mothers shortly after delivery during their infants' birth examination.

were also not recruited to the study but referred for further management at JUSH. If the research nurses observed medical conditions or significant growth failure during any of the follow-up examinations, a pediatrician was called for further clinical examination and if the pediatrician confirmed, the infant was referred for further management at JUSH.

RESULTS

A total of 595 women were recruited and examined together with their infants within 48 h after birth, but 9 were found to be born preterm and were excluded. Of the remaining ($n = 586$), 378 lived in Jimma town and could be traced and followed to the age of 6 mo and were included in the longitudinal cohort for the present study. In 30 of the 378 clinical examinations performed at birth, the PeaPod assessments resulted in negative values of FM as reported by the PeaPod software. Therefore, we obtained valid birth body-composition data on only 348 of the 378 infants in the study. Further, 38 mothers and infants arrived more than 14 d late for the 6 mo examination, and the data from these examinations were not used in analyses that included assessment of body composition at 6 mo of age. Details are given in the flow diagram (**Figure 2**).

A description of maternal anthropometrics, antenatal care, and delivery among the 372 mothers (there were 6 twin births) in addition to infant gender, gestational age at birth, and feeding practice at 6 mo of age among the infants is presented in **Table 1**, and further details on parental background characteristics and maternal feeding practices are given in **Tables 2** and **3**.

Weight, length, and % fat increased with increasing age from birth to 6 mo for both boys and girls. Across the age-span, boys were consistently lighter and shorter than the WHO 2006 reference data, whereas girls were only lighter at birth and caught up to the WHO standard in the 6-mo age period (**Table 4**).

LMS-based percentiles for 0–6 mo FM, FFM, FMI, and FFMI are presented for boys (**Figure 3**) and girls (**Figure 4**). FFM increased almost linearly with age with a minor deceleration at around 3 mo of age in both sexes. In contrast, the height-adjusted FFMI curve showed modest exponential increase with age, indicating that FFM growth in the first 3 mo of life is mainly proportional to growth in length. FM growth followed a logarithmic-shaped curve, indicating a decrease in growth velocity from birth to almost zero FM accretion at 6 mo for boys and a modest FM accretion rate at 6 mo for girls. When adjusted for height in the form of FMI, this logarithmic pattern was even further pronounced.

From birth to 6 mo of age, variability in FM increased along with a >9-fold increase in mean FM for boys and girls. In comparison, the FFM increase was <2-fold. The *z* scores and percentiles by sex and month for FM, FMI, FFM, and FFMI are presented in **Tables 5–8** for future reference.

DISCUSSION

In this article, we used the widely applied LMS method to calculate reference data on FM, FFM, FMI, and FFMI based on a large study of apparently healthy urban Ethiopian infants repeatedly measured with ADP from birth to 6 mo of age. Other studies have previously presented data on infant body composition

TABLE 3
Frequency of food intake by major food categories in the week before delivery[1]

	Total	Every day	3–6 d/wk	1–2 d/wk	Not at all
Grains, cereals, rice, pasta	365	353 (96.7)	9 (2.5)	1 (0.3)	2 (0.6)
Meat (red meat, chicken, organ meat)	366	10 (2.7)	100 (27.3)	154 (42.1)	102 (27.8)
Dairy products (milk, yogurt, cheese)	364	37 (10.2)	32 (8.8)	76 (20.9)	219 (60.2)
Eggs	358	12 (3.4)	44 (12.3)	106 (29.6)	196 (54.8)
Vegetables (green leafy, carrots, avocados)	365	63 (17.2)	144 (39.5)	128 (35.1)	30 (8.2)
Legumes (lentils, beans, chickpeas, peas)	365	144 (39.5)	139 (38.1)	68 (18.6)	14 (3.8)
Fish (including as part of stews)	365	0 (0)	0 (0)	15 (4.1)	350 (95.9)
Fruit (including juice)	365	49 (13.4)	98 (26.9)	158 (43.3)	60 (16.4)

[1] Values are *n* (%). Data were obtained by questioning the mothers shortly after delivery during their infants' birth examination.

TABLE 4
Length, weight, and percentage of fat in 378 young infants by sex and age[1]

	n	Length	HAZ[2]	Weight	WAZ[2]	% Fat
		cm		*kg*		
Boys						
Birth	170	49.4 ± 1.7[3]	−0.29 ± 0.90	3.11 ± 0.38	−0.49 ± 0.81	7.3 ± 4.4
1.5 mo	155	56.4 ± 2.2	−0.22 ± 1.11	4.78 ± 0.60	−0.58 ± 1.04	21.6 ± 4.9
2.5 mo	165	59.3 ± 2.4	−0.28 ± 1.18	5.57 ± 0.75	−0.62 ± 1.16	25.0 ± 5.4
3.5 mo	166	62.0 ± 2.5	−0.25 ± 1.22	6.30 ± 0.81	−0.53 ± 1.54	26.7 ± 6.5
4.5 mo	157	64.1 ± 2.5	−0.25 ± 1.20	6.87 ± 0.87	−0.47 ± 1.17	27.5 ± 5.7
6 mo	182	66.5 ± 2.4	−0.55 ± 1.14	7.52 ± 0.92	−0.57 ± 1.14	26.0 ± 5.8
P		<0.01	0.08	<0.01	0.87	<0.01
Girls						
Birth	178	48.9 ± 1.9	−0.21 ± 1.03	3.00 ± 0.39	−0.53 ± 0.91	7.8 ± 3.7
1.5 mo	171	55.4 ± 2.2	−0.13 ± 1.12	4.54 ± 0.61	−0.38 ± 1.04	21.1 ± 5.4
2.5 mo	175	58.5 ± 2.3	0.05 ± 1.10	5.38 ± 0.69	−0.21 ± 1.02	25.8 ± 5.5
3.5 mo	179	61.0 ± 2.2	0.10 ± 1.02	6.05 ± 0.75	−0.12 ± 1.01	28.7 ± 6.6
4.5 mo	169	62.9 ± 2.2	0.03 ± 1.00	6.57 ± 0.83	−0.11 ± 1.07	28.5 ± 5.6
6 mo	196	65.5 ± 2.3	−0.19 ± 1.04	7.29 ± 0.90	−0.11 ± 1.07	27.7 ± 6.2
P		<0.01	0.62	<0.01	<0.01	<0.01

[1] Values were determined by Wilcoxon rank-sum test for trend across age. HAZ, height-for-age *z* score; WAZ, weight-for-age *z* score; % fat, fat percentage.

[2] WAZ and HAZ are based on the 2006 WHO growth standard (24).

[3] Mean ± SD (all such values).

based on ADP from high-income countries, but there is little data available from middle- or low-income countries. By presenting *z* scores and centile reference charts for an urban Ethiopian infant population, this study represents a first step toward providing a useful reference tool on FM and FFM for an urban sub-Saharan African context, important for future clinical care and research.

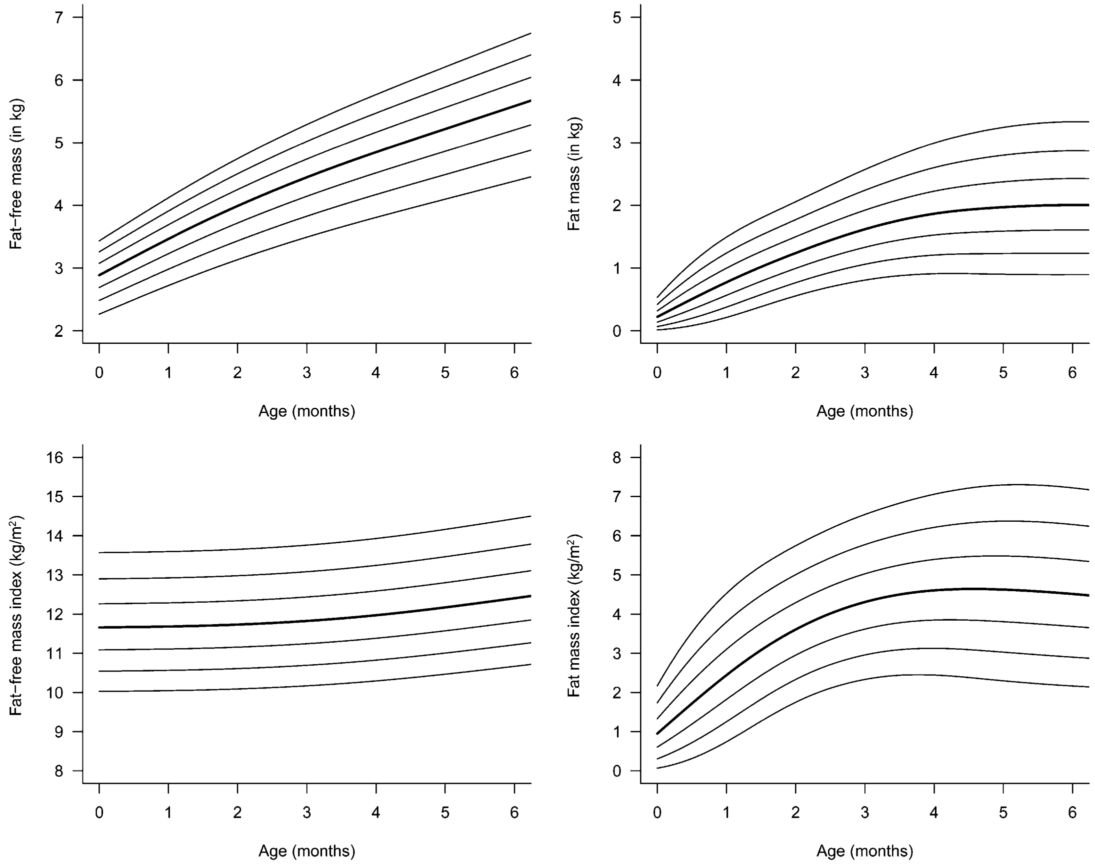

FIGURE 3. Percentiles of FM (kg), FFM (kg), FMI (kg/m^2), and FFMI (kg/m^2) from birth to 6 mo of age for boys. The 2nd, 9th, 25th, 50th, 75th, 91st, and 98th percentiles are given in ascending order. The *z* scores and percentiles were obtained with the LMS method (31). FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index; LMS, lambda-mu-sigma.

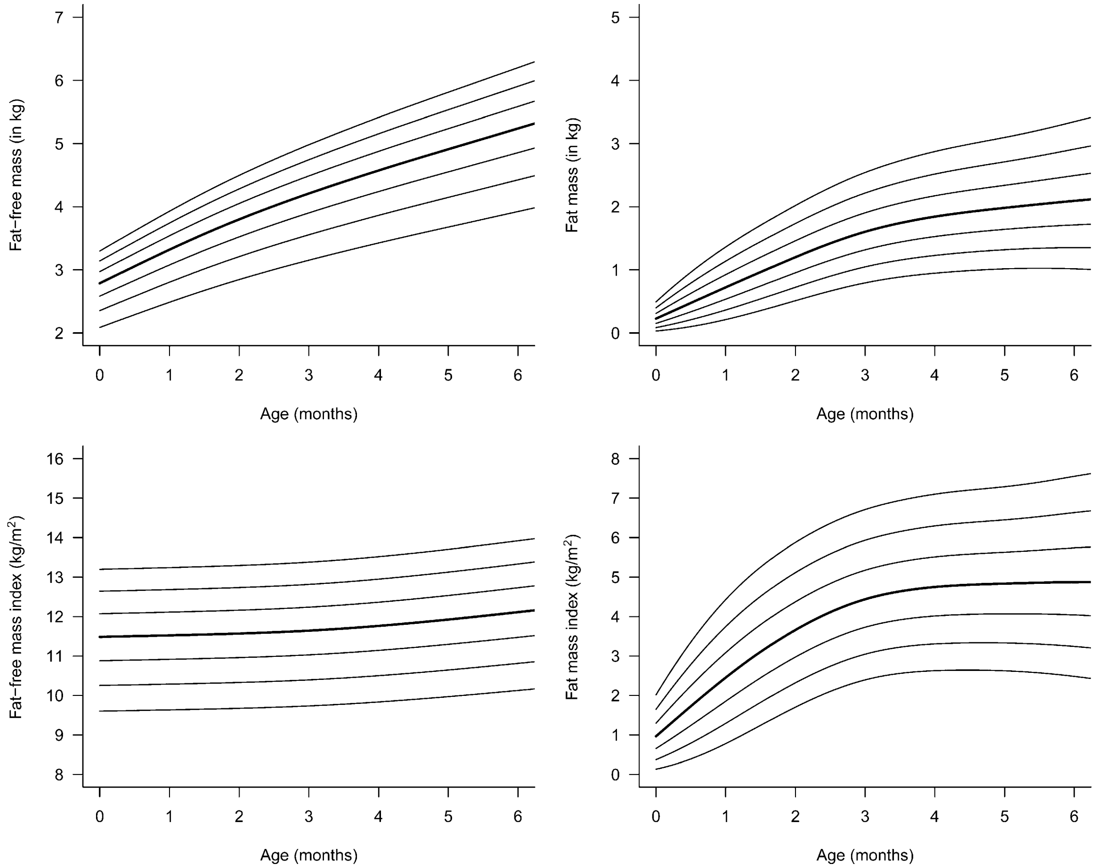

FIGURE 4. Percentiles of FM (kg), FFM (kg), FMI (kg/m^2), and FFMI (kg/m^2) from birth to 6 mo of age for girls. The 2nd, 9th, 25th, 50th, 75th, 91st, and 98th percentiles are given in ascending order. The *z* scores and percentiles were obtained with the LMS method (31). FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index; LMS, lambda-mu-sigma.

Three decades ago, Fomon et al (21) published reference data on FM and FFM from birth to 10 y of age. These data have provided the foundation for most subsequent infant and childhood body composition data. The FM and FFM growth curves in the present study follow a slope similar to that presented by Fomon et al (21) but with Ethiopian boys having slightly less FFM and Ethiopian girls having slightly more FM from 1 to 6 mo of age. Similar differences are seen when comparing our data with 2 recent studies of growth in FM and FFM in exclusively breastfed infants from the United States and Italy (12) and Australian infants of nonobese mothers (14). In comparison, the majority of infants in the present study are exclusively or predominantly breastfed at 6 mo of age, and maternal mean BMI (in kg/m^2) shortly after delivery is low at 22.7.

A lower FFM among boys in the present study is perhaps not surprising, as body weight and length are also lower in Ethiopia

TABLE 5

FFM (kg) reference data for boys and girls by *z* score and percentile based on 2026 ADP measurements of FFM and length performed on 378 infants followed between birth and 6 mo of age[1]

	z Scores													
	Boys							Girls						
Age	−2.0	−1.33	−0.67	0	0.67	1.33	2.0	−2.0	−1.33	−0.67	0	0.67	1.33	2.0
0 mo	2.27	2.48	2.69	2.88	3.07	3.26	3.43	2.09	2.35	2.58	2.79	2.97	3.14	3.30
1 mo	2.72	2.98	3.23	3.46	3.69	3.91	4.12	2.49	2.80	3.08	3.32	3.54	3.74	3.93
2 mo	3.13	3.43	3.72	3.99	4.25	4.50	4.75	2.85	3.21	3.52	3.80	4.05	4.28	4.50
3 mo	3.49	3.83	4.14	4.45	4.74	5.02	5.29	3.15	3.56	3.90	4.21	4.49	4.74	4.98
4 mo	3.81	4.17	4.52	4.85	5.17	5.47	5.77	3.43	3.86	4.24	4.58	4.88	5.16	5.41
5 mo	4.10	4.49	4.86	5.22	5.56	5.89	6.21	3.68	4.15	4.55	4.91	5.24	5.54	5.81
6 mo	4.39	4.81	5.20	5.58	5.95	6.30	6.64	3.92	4.43	4.86	5.24	5.59	5.91	6.20

[1] Equivalents for *z* scores in percentiles are as follows: −2 = 2.3%, −1.33 = 9.2%, −0.67 = 25.2%, 0 = 50%, 0.67 = 74.8%, 1.33 = 90.8%, and 2 = 97.7%. The *z* scores were obtained with the LMS method (31). ADP, air-displacement plethysmography; FFM, fat-free mass; LMS, lambda-mu-sigma.

TABLE 6

FM (kg) reference data for boys and girls by *z* score and percentile based on 2026 ADP measurements of FM performed on 378 infants followed between birth and 6 mo of age[1]

	z Scores													
	Boys							Girls						
Age	−2.0	−1.33	−0.67	0	0.67	1.33	2.0	−2.0	−1.33	−0.67	0	0.67	1.33	2.0
0 mo	0.01	0.07	0.14	0.22	0.32	0.42	0.53	0.03	0.08	0.15	0.23	0.31	0.40	0.49
1 mo	0.21	0.38	0.56	0.77	1.00	1.24	1.49	0.21	0.36	0.53	0.72	0.92	1.14	1.36
2 mo	0.55	0.77	0.99	1.24	1.50	1.77	2.06	0.51	0.72	0.95	1.20	1.46	1.73	2.02
3 mo	0.81	1.06	1.33	1.62	1.92	2.24	2.57	0.79	1.05	1.32	1.60	1.90	2.22	2.54
4 mo	0.91	1.21	1.53	1.87	2.22	2.60	2.99	0.95	1.23	1.53	1.84	2.17	2.52	2.88
5 mo	0.90	1.23	1.59	1.97	2.37	2.80	3.24	1.02	1.32	1.64	1.98	2.34	2.71	3.10
6 mo	0.89	1.24	1.61	2.00	2.43	2.87	3.33	1.02	1.35	1.71	2.09	2.49	2.91	3.35

[1] Equivalents for *z* scores in percentiles are as follows: −2 = 2.3%, −1.33 = 9.2%, −0.67 = 25.2%, 0 = 50%, 0.67 = 74.8%, 1.33 = 90.8%, and 2 = 97.7%. The *z* scores were obtained with the LMS method (31). ADP, air-displacement plethysmography; FM, fat mass; LMS, lambda-mu-sigma.

than the other settings. However, the additional body fat among girls is less intuitive and suggests that at the level of the whole population, deficits in lean mass at birth are not resolved during early infancy; rather, any catch-up growth affects adiposity, which therefore becomes slightly greater than in industrialized settings in girls. In a comparison of Indian and UK neonates, Yajnik et al (4) showed that the Indians, despite being smaller than UK neonates, preserved fat during intrauterine development at the expense of a deficit in nonfat tissues. We see a similar pattern among girls in the present study, but in the early months after delivery rather than during the fetal development. UK-born South Asian infants were recently shown to have a deficit in FFM compared with Europeans (10). Furthermore, a preference for catch-up of fat in infancy and childhood among neonates that were growth restricted in the fetal stage has also previously been described and linked to later risk of obesity, type 2 diabetes, and cardiovascular disease (33). However, the population differences presented in the present study are mostly not large, and with the exception of a lower FFM in boys, the present study presents relatively similar patterns of fat and lean gain during the first 6 mo compared with findings from high-income countries.

Although lower FFM might indicate a less healthy pattern of growth in this population, adults in east African populations tend to have lower FFM than Europeans (34). One possible explanation for this difference is adaptation to heat stress (35), and this adaptive process may begin in fetal life and continue through infancy (36, 37). Thus, further work is required to ascertain if different rates of FFM deposition indicate adaptation to the thermal environment or exposure to contrasting levels of nutrition or infectious disease.

In the present longitudinal study, we closely followed a sample of 378 Ethiopian infants during the critical months following birth. This period is known to be very important for both short-term survival and longer term health. ADP is a validated and objective method that, unlike anthropometrics, provides data on both the fat and fat-free components of body weight. As there are little other data available on infant body composition from low-income settings measured in a large sample with reliable methods and little infant body composition reference data available at all, these data add valuable information to the current understanding of infant growth. However, to obtain values on FM and FFM from ADP alone, it is assumed that the age-specific D_{FFM} in the study population were in accordance with values presented by Fomon et al (21). FFM contains muscle, organs, bones, and water, each with discrete densities. Consequently, the presented data on FM and FFM are valid only if the ratio between these components in

TABLE 7

FFMI (kg/m^2) reference data for boys and girls by *z* score and percentile based on 2026 ADP measurements of FFMI and length performed on 378 infants followed between birth and 6 mo of age[1]

	z Scores													
	Boys							Girls						
Age	−2.0	−1.33	−0.67	0	0.67	1.33	2.0	−2.0	−1.33	−0.67	0	0.67	1.33	2.0
0 mo	10.03	10.54	11.09	11.66	12.26	12.90	13.57	9.60	10.25	10.88	11.49	12.07	12.64	13.20
1 mo	10.05	10.57	11.11	11.68	12.29	12.92	13.59	9.63	10.29	10.92	11.52	12.11	12.68	13.24
2 mo	10.09	10.61	11.16	11.73	12.34	12.98	13.65	9.67	10.33	10.96	11.57	12.16	12.74	13.30
3 mo	10.17	10.69	11.25	11.83	12.44	13.08	13.76	9.73	10.39	11.03	11.64	12.24	12.82	13.38
4 mo	10.30	10.83	11.38	11.97	12.59	13.24	13.93	9.84	10.50	11.14	11.76	12.37	12.95	13.52
5 mo	10.47	11.01	11.57	12.17	12.80	13.46	14.16	9.97	10.65	11.30	11.93	12.53	13.13	13.70
6 mo	10.67	11.22	11.80	12.40	13.05	13.72	14.43	10.13	10.81	11.47	12.11	12.73	13.33	13.92

[1] Equivalents of *z* scores in percentiles are as follows: −2 = 2.3%, −1.33 = 9.2%, −0.67 = 25.2%, 0 = 50%, 0.67 = 74.8%, 1.33 = 90.8%, and 2 = 97.7%. The *z* scores were obtained with the LMS method (31). ADP, air-displacement plethysmography; FFMI, fat-free mass index; LMS, lambda-mu-sigma.

TABLE 8

FMI (kg/m^2) reference data for boys and girls by *z* score and percentile based on 2026 ADP measurements of FM and length performed on 378 infants followed between birth and 6 mo of age[1]

	z Scores													
	Boys							Girls						
Age	−2.0	−1.33	−0.67	0	0.67	1.33	2.0	−2.0	−1.33	−0.67	0	0.67	1.33	2.0
0 mo	0.02	0.25	0.56	0.91	1.30	1.71	2.15	0.13	0.37	0.65	0.96	1.30	1.65	2.01
1 mo	0.83	1.35	1.92	2.53	3.18	3.86	4.57	0.78	1.29	1.85	2.45	3.08	3.74	4.43
2 mo	1.92	2.48	3.07	3.68	4.32	4.98	5.67	1.70	2.32	2.98	3.66	4.38	5.12	5.88
3 mo	2.32	2.96	3.63	4.33	5.06	5.81	6.58	2.39	3.05	3.73	4.44	5.17	5.93	6.71
4 mo	2.41	3.10	3.84	4.60	5.40	6.23	7.08	2.63	3.31	4.02	4.75	5.51	6.30	7.10
5 mo	2.19	2.94	3.75	4.60	5.49	6.41	7.36	2.63	3.33	4.07	4.84	5.63	6.45	7.29
6 mo	2.13	2.87	3.65	4.47	5.33	6.22	7.14	2.48	3.24	4.04	4.88	5.74	6.63	7.55

[1] Equivalents for *z* scores in percentiles are as follows: −2 = 2.3%, −1.33 = 9.2%, −0.67 = 25.2%, 0 = 50%, 0.67 = 74.8%, 1.33 = 90.8%, and 2 = 97.7%. The *z* scores were obtained with the LMS method (31). ADP, air-displacement plethysmography; FM, fat mass; FMI, fat mass index; LMS, lambda-mu-sigma.

Ethiopian infants is similar to that presented by Fomon et al (21). This is of particular importance in studies of infants, as chemical maturation occurs during infancy. Thus, to evaluate the Fomon et al values, we assessed D_{FFM} in a subsample of 29 infants from 1.5 to 6 mo of age and found values very similar with those presented by Fomon et al and therefore, we found their reference values on D_{FFM} valid to use in the present study (21). In the subsample presented here, we were unable to assess D_{FFM} at birth and our validation was done in a small sample. Thus, studies are needed to confirm Fomon's and our values of D_{FFM} with multi-component models in larger samples from various low-income populations.

A total of 209 infants of the 595 recruited at baseline were lost during follow-up. In the first 350 infants recruited for the study, the reasons for loss to follow-up were recorded. The main reasons were: moving away from the study site (69%), mother reported lack of time (12%), mother or father disliked the study (9%), and the infant got sick or died (5%). Yet there were no differences in body composition at birth between infants followed and infants lost to follow-up.

Thirty PeaPod assessments of body composition at birth and 3 measurements at later time points were invalid and yielded no result. Retrieving and manually analyzing the details of these 33 measurements from the PeaPod database revealed that 31 of the invalid results were caused by calculations of negative FM values and 2 were caused by extremely high values of FM. As we have previously shown, the average % fat at birth is lower in the present study compared with other ADP studies from high-income settings (3). In 1-wk-old Swedish infants, birth weight, length, and % fat was lower among infants who experienced invalid ADP measurements (38), and the 31 with negative measurements in the present study were on average smaller at birth compared with the 348 with valid body composition at birth. However, the overall effect of including these infants on the average birth weight in the population was marginal at <50 g. Still, this could indicate that the D_{FFM} as proposed by Fomon et al (21) does not apply to the smallest neonates. An alternative explanation could be that the PeaPod does not correctly estimate body volume in small neonates, possibly through inaccurate estimation of lung volume or body surface area. Further, fluctuations in hydration in the first days of life could affect the measurements. We measured most children within the first 24 h after birth, and although the PeaPod has been shown to be relatively robust to minor changes in FFM hydration (9), this could also explain invalid measurements. Medical conditions involving edema may also affect estimation of FM, but infants in this study were generally found to be healthy during clinical examination and there was no overrepresentation of infants with negative FM among the few that were referred to further clinical care following a clinical examination. A recent validation of infant ADP with a porcine model showed less precision in the low % fat range (39). Thus, it is likely that such error affects all studies that measure body composition by ADP but is possibly more pronounced in populations with a high proportion of individuals that are of smaller size at birth. So, although we believe our study provides valid data on infant body composition in a low-income context, absolute values of FM and FFM at birth should be interpreted with caution.

Based on a large longitudinal sample measured with validated methods, we present *z* score and centile reference charts on FM and FFM for a healthy urban Ethiopian infant population. Although there are still issues to resolve on valid body composition assessment of newborns, this study represents a first step toward providing a useful reference tool on FM and FFM from an urban sub-Saharan African context, important for clinical care and research.

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The authors' responsibilities were as follows—GSA, JCKW, PK, TG, KFM, and HF: designed the study; GSA, PK, A-LH, and TG: conducted the study; GSA, JCKW, ML, and HF: analyzed data and performed the statistical analyses; and GSA: wrote the first draft of the manuscript and had primary responsibility for final content. All authors read, approved, and contributed to the final version. None of the authors had any conflicts of interest.

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