Fat and Fat-Free Mass at Birth: Air Displacement Plethysmography Measurements on 350 Ethiopian Newborns

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ABSTRACT: LBW increases the risk of a number of noncommunicable diseases in adulthood. However, birth weight (BW) cannot describe variability in infant body composition (BC). Variability in fat mass (FM) and fat-free mass (FFM) at birth may be particularly important in low-income countries because they undergo nutritional transition. There is a need for data on birth BC and its predictors from low-income countries in transition. We assessed absolute FM and FFM at birth and examined the role of gender, parity, GA, and LBW as predictors of birth BC. FM and FFM were assessed within 48 h of birth on 350 Ethiopian newborns using air displacement plethysmography (ADP). Female gender and being an infant of primi- or secundiparous mothers predicted lower BW and lower birth FFM but not FM, compared with male gender and infants of multiparous mothers, respectively. There was a positive linear relationship between BW and relative amount of FM for boys and girls. This study presents reference data on birth FM and FFM from a low-income setting and provides background for further longitudinal mapping of the relationship between fetal BC, childhood growth, and adult disease. (*Pediatr Res* **70: 501–506, 2011**)

LBW is the predominant indicator of fetal growth restriction and has been linked to infant morbidity and mortality (1–3) and impaired cognitive development (4,5) in early life, as well as risk of the metabolic syndrome (6), type 2 diabetes (7), and cardiovascular diseases (CVD) (8) later in life. Although birth weight (BW) is easy to measure, it does not describe variation in the body composition (BC) and therefore does not index fetal growth or nutritional status. It was recently hypothesized that fat mass (FM) and fat-free mass (FFM), rather than weight, mediate the link between fetal nutritional experience and adult disease (9). In adults, FM is a predictor of metabolic disease outcomes and related to insulin resistance and markers of CVD (10). Thus, precise estimation of birth FM and FFM is important to assess the relationship between fetal growth restriction and disease.

Research on BC in early life has been limited by the lack of appropriate methods, because available methods have generally been either impractical or of unknown accuracy (11). However, recent development of equipment based on air displacement plethysmography (ADP) allows for assessment of infants from birth through 6 mo in a rapid-throughput, noninvasive, and comfortable environment (12). ADP assessment of infant BC has high validity when compared with a four compartment reference model (13). Currently, only few and relatively small studies using ADP have been done, and these were performed in high-income populations (9,13–19).

We performed ADP at birth on 350 Ethiopian infants. In this article, we present normative data on FM and FFM at birth and examine the predictive ability of gender, parity, GA, and LBW on birth FM and FFM.

METHODS

Study setting and participants. From January 2009 to April 2010, 350 mothers and their newborns were recruited at the Jimma University Specialized Hospital (JUSH), Ethiopia. Women were eligible and asked to participate if living in Jimma town and had given birth at the JUSH maternity ward to a child with a BW ≥1500 g without congenital malformation. 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. All measurements and questionnaires were performed by trained research nurses speaking local languages.

Maternal and infant data. Physical examination at birth included assessment of GA, infant length, weight, and FM and FFM, in addition to a questionnaire including information on maternal age and parity.

Infant length was measured twice to the nearest 0.1 cm using a SECA 416 Infantometer (SECA, Hamburg, Germany). Maternal weight was measured to the nearest 0.1 kg using Tanita 418 Bioimpedance analyzer (Tanita Corp.) and height to the nearest 0.1 cm using a SECA 214 stadiometer (SECA, Hamburg, Germany). The PeaPod, an infant air displacement plethysmograph developed by Life Measurements (LMI, Concord, CA), was used to assess infant BW, FM, and FFM. The PeaPod has been validated against deuterium dilution in the United States and has been shown to have good accuracy and high precision (13). It is suitable for use in infants weighing below 8 kg. In brief, ADP enables a two-component densitometry model, the compartments representing FM and FFM. Measurements of infant weight and volume (corrected for air in the lungs and isothermic air close to the skin) are used to estimate infant total body density (TBD). In accordance with Archimedes' principle, TBD will take a value between an age- and gender-specific refer-

Abbreviations: ADP, air displacement plethysmography; **BC,** body composition; **BW,** birth weight; **FM,** fat mass; **JUSH,** Jimma University Specialized Hospital; **FFM,** fat-free mass; **FFTD,** fat-free tissue density; **TBD,** total body density

ence value for fat-free tissue density (FFTD) (20) and a known constant fat tissue density (FTD). Higher TBD values indicate a higher proportion of FFM, and lower proportion of FM, in body weight, and *vice versa*. We used PeaPod Software version 3.0.1 and 3.1.0 in this study, as the reference values for FFTD for infants <6 d old are corrected for expected early life changes in hydration, from version 3.0.1 and onward. In this study, we used the reference value for FFTD as proposed by Fomon *et al.* (20).

A complete PeaPod examination including weighing and registration took approximately 10 min, including a 2-min PeaPod measurement. The infant was placed without clothes and wearing only a wig cap on a plastic bed in a closed compartment. The research nurses and the mother could watch the infant through a Plexiglas window at all times, and the compartment door could be opened at any time should the baby or mother feel uncomfortable.

The New Ballard Score (NBS) (21,22) assessment was performed to estimate GA at birth. NBS comprise a physical examination of six signs of neuromuscular maturity and seven signs of physical maturity and has been shown to have a error of prediction of 1.89 wk in a Zimbabwean population (23).

Ethics. Written informed consent was obtained from all participating women, and thorough information about the study and examinations was given orally and written in local language. Women were informed that they are free to retract from the study at any time. Any serious medical conditions observed by the research nurses during examination of the infants were addressed according to local recommendations. Ethical permission was granted from the Jimma University Ethical Review Committee.

Data handling. Mothers were categorized as primi- (first birth), secundi- (second birth), or multiparous (>2 births). Infants were categorized in four groups of BW (<2500 g, 2500–3000 g, 3000–3500 g, and >3500 g), and infants <2500 g were considered LBW. GA was grouped in three groups of similar sizes (<39 wk, 39 wk, and >39 wk).

Statistics. t tests and χ^2 tests were used to test for gender-specific differences in BC and anthropometry. Simple and multivariate linear regression models were used to analyze relationships between birth BC and gender, parity, GA, and BW in categories. In simple linear regression models, the mean value is presented for the reference category whereas the absolute difference from the reference category mean is presented for the other categories. In the multivariate linear regression models, only the difference from the reference category is given. A modified Hattori chart (24,25) was plotted to illustrate simultaneously, in each sex, the variability in FM and FFM. Fourteen negative FM measurements and one measurement >20% fat were removed from the Hattori chart analysis to allow plotting but remained in all other analyses. A *p* value <0.05 was considered significant in all analyses. All analyses were performed in Stata 11.0 (StataCorp, TX).

RESULTS

Of 387 eligible mothers, 350 accepted to participate and were examined together with their infants within 48 h after birth, of whom 94% (*n* = 328) were examined within 24 h after birth. A description of the study sample is presented in Table 1.

The 37 women refusing participation were on average slightly older (25.2 *versus* 23.8 y, *p* = 0.039) and gave, according to self-reported BW, birth to heavier babies (3.45 kg, *p* = 0.001). The main reasons for nonparticipation were lack of interest (30%), lack of time (24%), and long distance to the hospital (19%).

Mean infant age at examination was 14.2 ± 8.5 h. Mean BW was 3106 ± 407 g for boys and 2973 ± 414 g for girls, whereas length at birth was 49.6 ± 1.8 cm for boys and 49.0 ± 2.1 cm for girls. BW of the boys was distributed as 229 ± 163 g FM and 2876 ± 315 g FFM, whereas the girls had 235 ± 155 g FM and 2738 ± 325 g FFM (Table 2). There was a wide variability in FM and FFM proportions for a given BW (Fig. 1). For example, following the near-vertical 3.5 kg BW line in Figure 1 reveals that a 3.5 kg newborn may consist of anything between 170 to 580 g fat and 2890 to 3370 g FFM, yielding a range in fat percentage around 5 to 17%.

Table 1. *Description of the study sample*

	Mean ± SD (*N*) or % (*N*)
Maternal characteristics	
Maternal age, y	23.8 ± 4.5 (345)
Height, cm	158.1 ± 5.9 (302)
Weight, kg	56.6 ± 8.7 (305)
BMI, kg/m²	22.6 ± 3.0 (303)
Parity, (%)	
Para 1	55.9 (191)
Para 2	25.4 (87)
Para ≥3	18.7 (64)
Mode of delivery, (%)	
Vaginal delivery	93.1 (323)
Caesarean section	6.9 (24)
Infant characteristics	
Gender(%)	
Boys	47.7 (167)
Girls	52.3 (183)
GA at birth, wk	39 (30–42) (350)*
Age at examination, h	14.2 ± 8.5 (350)

* GA at birth are presented as median and range.

Table 2. *Birth body composition and anthropometry by gender*

	Boys (*n* = 167)	Girls (*n* = 183)
FM (g)	229 ± 163	235 ± 155
FFM (g)	2,876 ± 315	2,738 ± 325*
FM (%)	7.0 ± 4.5	7.6 ± 4.6
Weight (g)	3,106 ± 407	2,973 ± 414*
LBW (<2.5 kg), (%)†	5.4	12.6‡
Length (cm)	49.6 ± 1.8	49.0 ± 2.1‡
Ponderal index (kg/m3)	25.3 ± 2.3	25.3 ± 2.1

Values are mean ± SD.

* *p* < 0.01, significant values different from boys.
† For LBW proportions <2.5 kg are presented.
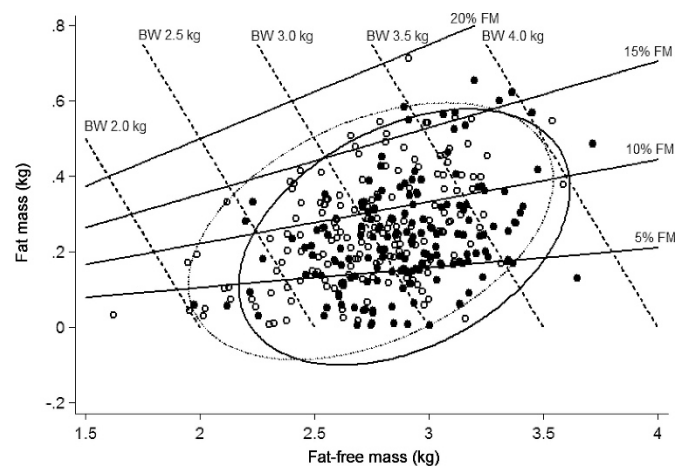‡ *p* < 0.05, significant values different from boys.

Figure 1. A modified Hattori chart, plotting FFM (kg) on the *x* axis and FM (kg) on the *y* axis. *Diagonal lines* represent constant total BW (*near-vertical lines*) or constant % FM (*near-horizontal lines*). The plot illustrates for boys (●) and girls (○) the wide variability in FM and FFM for a given BW. Fourteen negative FM measurements and one measurement >20% fat were removed to allow plotting, and measurements close to 0% FM may not represent plausible values. Bivariate normal ellipses (*p* = 0.95) for boys (—) and girls (---) are shown, and represent the area that 95% of the observations would fall within.

Boys were on average 49.6 cm at birth, whereas girls were on average −0.6 cm (95% CI, −1.1 to −0.2 cm) shorter. Girls were also born lighter as they had a −133 g (95% CI, −219

Table 3. *Simple linear regression models of the relation between infant body composition at birth and gender, birth weight in categories, parity, and GA*

	Birth FM (g)		Birth FFM (g)		Birth weight (g)		Birth length (cm)	
	B	95% CI	B	95% CI	B	95% CI	B	95% CI
Gender								
Girls	0.006	−0.028 to 0.039	−0.138	−0.206 to −0.071*	−0.133	−0.219 to −0.047*	−0.634	−1.054 to −0.214*
Boys	0.230		2.876		3.106		49.626	
Parity								
Primipara	−0.044	−0.089 to 0.001	−0.179	−0.271 to −0.088*	−0.223	−0.339 to −0.107*	−0.353	−0.922 to 0.215
Secundipara	−0.026	−0.077 to 0.029	−0.177	−0.281 to −0.072*	−0.203	−0.334 to −0.071	−0.576	−1.224 to 0.071
Multipara	0.263		2.949		3.212		49.634	
GA								
<39 wk	−0.026	−0.067 to 0.014	−0.102	−0.185 to −0.018†	−0.128	−0.233 to −0.023†	−0.521	−1.033 to −0.009†
39 wk	0.223		2.805		3.029		49.224	
>39 wk	0.052	0.013–0.091*	0.082	0.002–0.162†	0.134	0.034–0.234*	0.668	0.178–1.157*
Birth weight categories								
<2.5	−0.102	−0.151 to −0.054*	−0.461	−0.520 to −0.402*	−0.563	−0.621 to −0.505*	−2.408	−2.957 to −1.858*
2.5–3.0	0.165		2.619		2.784		48.448	
3.0–3.5	0.095	0.066–0.125*	0.332	0.296–0.368*	0.427	0.392–0.463*	1.563	1.221–1.905*
>3.5	0.274	0.231–0.316*	0.628	0.576–0.680*	0.901	0.850–0.953*	2.906	2.422–3.390*

Data are given as the mean for the reference categories (boys, multiparous mothers, 39 wk GA and BW 2.5–3.0) and the regression coefficient (B) (the difference from the mean) for the other categories, in addition to 95% confidence limits.

* $p < 0.01$, significant values different from reference category.

† $p < 0.05$, significant values different from reference category.

to −47 g) difference to the boys BW of 3106 g. The weight deficit consisted purely of FFM, because girls had on average −138 g (95% CI, −206 to −71 g) FFM compared with boys (Table 3). In multivariate linear regression analyses of FM, FFM, and BW where the effect of gender was adjusted for length, parity, GA, BW categories, and age at examination, the relationship between gender and BW disappeared [−9 g (95% CI, −39 to 21 g)] whereas girls still had a significant deficit of FFM [−48 g (95% CI, −78 to −18 g)] and furthermore significantly more FM [39 g, (95% CI, 12–66 g)] compared with boys (Table 4). The gender-specific ellipses on Figure 1 illustrate that girls are overrepresented at the lower BW, as also seen in Table 2. The girls' ellipse is not only pushed to the left but also upward, underscoring the girls' surplus of FM, and indicate that this is particularly evident at the lower end of the BW scale (Fig. 1).

Infants to primi- or secundiparous mothers had weight differences of −223 g (95% CI, −339 to −107 g) and −203 g (95% CI, −334 to −71 g), respectively, compared with the average 3192 g for infants of multiparous mothers. These weight deficits comprised mainly FFM with differences being −179 g (95% CI, −271 to −88 g) and −177 g (95% CI, −281 to −72 g) FFM, respectively (Table 3), and nonsignificant differences in FM of −44 g and −26 g, respectively. In adjusted analyses, the effect of being born by primiparous [−54 g (95% CI, −94 to −14 g)] and secundiparous [−52 (95% CI, −98 to −7 g)] mothers on FFM persisted (Table 4). Maternal age did not explain infant BC in addition to the effect of parity (data not shown).

Infants with a GA > 39 wk were longer [0.7 cm (95% CI, 0.2–1.2 cm)] and heavier [134 g (95% CI, 34–234 g)] at birth than infants born at 39th week of gestation. This weight surplus was distributed as 52 g FM (95% CI, 13–91 g) and 82 g FFM (95% CI, 2–162 g). Infants with a GA below 39 wk

were shorter [−0.52 cm (95% CI, −1.03 to −0.01 cm)] and lighter [−128 g (95% CI, −233 to −23 g)] because of a deficit in FFM [−102 g (95% CI, −185 to −18 g)] (Table 3). However, in adjusted analyses, the effects of GA were no longer significant (Table 4).

Nine boys (5.4%) and 23 girls (12.6%) were less than 2500 g at birth and thus considered LBW (Table 2). None of these were born before the 37th week. LBW infants consisted on average of 63 g FM and 2158 g FFM, infants weighing 2500 to 3000 g had on average 165 g FM and 2619 g FFM, infants weighing 3000 to 3500 g comprised on average 260 g FM and 2951 g FFM, and infants weighing >3500 g consisted on average of 439 g FM and 3247 g FFM (Table 3). The 563 g weight deficit among LBW infants compared with those weighing 2500 to 3000 g consisted of 102 g (95% CI, 54–151 g) FM and 461 g (95% CI, 402–520 g) FFM. The FM proportion of the total BW significantly increased in a linear pattern across all four categories of BW, and FM in all categories was significantly different from the reference category, except for the difference between the <2.5 kg group and the reference group for boys that did not reach significance (Fig. 2). The linear trend was supported by a significant linear relationship between FM% and BW for both boys (FM% = −13.948 + 6.759 × BW, $p < 0.001$, $r^2 = 0.37$) and girls (FM% = −11.832 + 6.519 × BW, $p < 0.001$, $r^2 = 0.34$).

We recalculated the average FM% for boys and girls after excluding infants with an FM% ≤0 and an FM% ≤4%, respectively. When infants with <0% and <4% FM were excluded, the average FM% changed from 7.0 ± 4.5% to 7.5 ± 4.1% and 8.6 ± 3.5%, respectively, for boys and from 7.6 ± 4.6% to 8.2 ± 3.9% and 9.2 ± 3.3%, respectively, for girls.

Table 4. *Multivariate linear regression models of the relation between infant body composition at birth and gender, birth weight in categories, parity, and GA*

	Birth FM (g)		Birth FFM (g)		Birth weight (g)	
	B	95% CI	B	95% CI	B	95% CI
Gender						
Girls	0.039	0.012–0.066*	−0.048	−0.078 to −0.018*	−0.009	−0.039 to 0.021
Boys	Ref.		Ref.		Ref.	
Parity						
Primipa	0.015	−0.022 to 0.051	−0.054	−0.094 to −0.014*	−0.039	−0.079 to −0.001
Bipara	0.028	−0.014 to 0.070	−0.052	−0.098 to −0.007†	−0.024	−0.070 to 0.021
Multipara	Ref.		Ref.		Ref.	
GA						
<39 wk	0.001	−0.033 to 0.034	−0.021	−0.057 to 0.016	−0.020	−0.057 to 0.017
39 wk	Ref.		Ref.		Ref.	
>39 wk	0.031	−0.001 to 0.063	0.003	−0.032 to 0.038	0.034	−0.001 to 0.069
Birth weight categories						
<2.5	−0.112	−0.167 to −0.057*	−0.340	−0.400 to −0.279*	−0.452	−0.512 to −0.392*
2.5–3.0	Ref.		Ref.		Ref.	
3.0–3.5	0.096	0.062–0.131*	0.253	0.215–0.291*	0.349	0.311–0.387*
>3.5	0.281	0.228–0.333*	0.466	0.409–0.524*	0.747	0.690–0.804*

Data are given as regression coefficients (B) and 95% confidence limits.
R^2 is 0.420 for the FM model, 0.839 for the FFM model, and 0.625 for the birth weight model. Ref. indicates the reference category.
* $p < 0.01$, significant values different from reference category adjusted for all explanatory variables in the model, infant length, and age at examination.
† $p < 0.05$, significant values different from reference category adjusted for all explanatory variables in the model, infant length, and age at examination.
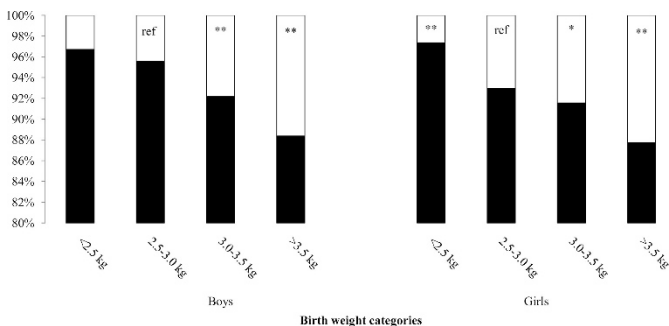

Figure 2. The proportions of FM and FFM across four groups of BW by gender. The FM proportion in the lowest and the two highest BW groups are all significantly different from the FM percentage in the reference group (2.5–3.0 kg), except for the difference between the <2.5 kg group and the reference group for boys, which did not reach significance. □, FM%; ■, FFM%. *Asterisks* indicate significant difference from reference category: *$p < 0.05$, **$p < 0.01$. Ref. indicates the reference group.

DISCUSSION

This study provides normative data on newborn FM and FFM from a low-income African setting. Female gender and being an infant of primi- or secundiparous mothers predicted lower BW and lower birth FFM but not FM. Higher BW was related to higher absolute FM and FFM and relatively higher FM but lower FFM.

Small-for-GA full-term newborns have been shown to have a lower FM% than appropriate-for-GA newborns in western populations (14,26), and our study confirms a similar pattern in a low-income African context. However, we found a wide variability in FM and FFM for a given BW. The consequences of restrained fetal growth for FM and FFM accretion are unclear, but it has been suggested that in particular, later FFM accretion may be constrained by LBW (27). Thus, future longitudinal follow-up of the effect of variability in FFM in infancy may establish an understanding of the role of early BC in growth and later disease.

The few studies that have examined birth BC with reliable methods are either small or performed in Caucasian populations. A study on 42 Australians reported higher FM% values for boys (9.42%) and girls (10.09%) (15), but these newborns were 403 g (boys) and 195 g (girls) heavier at birth than the infants in our study, and at least in this study, we find a linear relationship between BW and FM%. Thus, a lower FM% in our population is expected given the lower BW. Furthermore, the FM% values in the Australian study were based on 77 subjects only, and BW and BC measured within a margin of 72 h. Similarly, Other studies have reported higher FM% but also higher BW (28).

It is not clear whether the lower FM values in our study compared with other studies is explained by genetic or environmental differences between the populations or whether it is a result of diverging neonatal hydration in this study population when compared with the Fomon *et al.* reference child. Indian infants have been shown to preserve fat despite being smaller when compared with UK infants (29). Comparing groups of LBW with others within our study population showed a similar pattern but not when comparing our study population with other populations. The lower FM values in our population could reflect a high incidence of IUGR. As only seven infants were born before the 37th week, it is most likely that some IUGR occurred. In a multicenter study, it was shown that geographical differences in neonatal phenotype were mainly accounted for by maternal BC and size (30). Thus, maternal nutritional status could also account for the lower FM values. Finally, diverging BC values may occur if the reference data on FFTD (20) does not reflect the actual FFTD in the study population. This may in particular be the case when abnormal neonatal hydration is frequent. In this study, 14 ADP measurements yielded negative FM results. The negative ADP measurements were included in the presented analyses, lowering the average FM% in this study.

Other neonatal BC studies have used or suggested a lower plausible neonatal FM% limit of 3 to 4% (13,31). To allow comparison, we recalculated FM% after excluding infants with a FM% ≤0 and ≤4%, respectively. Although these exclusions increased the average FM% for boys and girls, it may not fully explain the lower FM values reported from this study.

To avoid selective exclusion of participants, we did not exclude negative or low measurements of FM%. The inclusion of measurements with implausible values is not likely to affect the ranking of newborns in terms of FM and FFM. All BC data are subject to imprecision, and negative FM values are merely particularly visible through violating the feasible range of adiposity. The Fomon *et al.* reference on FFTD may not perfectly match this population, but to our knowledge, there are no reference data on the density of FFM for African newborns. Butte *et al.* (32) has presented an alternative reference for FFTD, but it does not include suitable reference data for infants <14 d, and a recent Swedish study confirmed the Fomon *et al.* FFTD reference (33).

Girls were born lighter and shorter with a weight deficit accounted for by decreased FFM only. Adjusting for length and other factors removed the differences in weight but the female FFM deficit persisted and was confirmed by a significant surplus in FM. These results indicate that girls have a higher proportion of FM to FFM than boys even at birth, which cannot be explained by shorter female stature or a higher proportion of LBW girls. Thus, there seem to be some genetic determination of neonatal BC. Carrberry *et al.* showed a similar effect of gender on FFM, but reported no additional FM in girls (15). Fields *et al.* (34) showed a gender effect on FM%, but this was at the age of 1 mo, and the effect had disappeared at 6 mo of age.

First- and second-born infants had less FFM compared with babies of multiparous mothers, even after adjustment for birth length, BW, gender, GA, and age at measurement. A relationship between parity and BW has previously been demonstrated in high-income countries (35) and in African populations (36); but to our knowledge, there is no previous evidence for an effect particularly on FFM. We cannot determine whether this could relate to changed fetal environment *per se* or reflects an effect of maternal anthropometric changes. Interestingly, a recent study from Brazil showed that first borns carry a higher metabolic risk in early adulthood (37). As FFM may be considered an index of metabolic capacity (38), we speculate that decreased FFM among first- and second-born infants in this study could be an early representation of a programmatic link between parity and adult metabolic risk.

GA > 39 wk at birth was related to increased FM compared with a GA of 39 wk at birth. In fact, in the unadjusted analyses, high GA at birth resulted in a 23% increase in birth FM compared with GA at 39 wk but only a 3% increase in birth FFM. However, these effects disappeared in adjusted analyses. Furthermore, because GA in this study was based on the relatively crude Ballard score assessment of GA, this finding should be interpreted cautiously. It does, however, support that late growth *in utero* is related primarily to FM accretion, which is in congruence with previous studies of prenatal fat accretion (39,40).

LBW infants had a deficit in both FM and FFM compared with infants with a BW of 2500 to 3000 g. In absolute terms, the majority of the deficit pertained to FFM because the total weight deficit consisted of 18% (102 g/563 g) FM and 81% (461 g/563 g) FFM. However, in relative measures, there is a substantial FM deficit as LBW infants lacked 62% (102 g/165 g) of the FM in the reference group, but only 18% (461 g/2619 g) of the FFM in the reference group. The different deficits may have different implications for short- and long-term outcomes. Reduced fatness may impact adversely on early survival, but the deficit in FFM, which may be considered an index of metabolic capacity (38) may have greater effects on long-term risk of chronic diseases (41).

Living conditions differ between urban and rural Ethiopia, and in the rural parts, the majority of women give birth at home (42), whereas there is an estimated 28.5% home births in Jimma town (43). It is therefore not clear whether these findings are generalizable to a rural population.

In conclusion, we present data from the first large study on birth BC from a low-income setting measured with ADP. Apart from being a reference for future studies, this study identifies a number of important predictors of birth FM and FFM. Lower BW among girls and infants of primi- and secundiparous mothers was related to differences in FFM rather than FM. It has been suggested that birth BC could be a better proxy for fetal growth than BW, and these data may provide the background for future longitudinal studies on the link between birth BC, childhood growth and later markers of adult disease.

REFERENCES

1. Ashworth A 1998 Effects of intrauterine growth retardation on mortality and morbidity in infants and young children. Eur J Clin Nutr 52:S34–S41
2. McCormick MC 1985 The contribution of low birth weight to infant mortality and childhood morbidity. N Engl J Med 312:82–90
3. Shrimpton R 2003 Preventing low birthweight and reduction of child mortality. Trans R Soc Trop Med Hyg 97:39–42
4. de Bie HM, Oostrom KJ, Delemarre-van de Waal HA 2010 Brain development, intelligence and cognitive outcome in children born small for gestational age. Horm Res Paediatr 73:6–14
5. van Soelen IL, Brouwer RM, Peper JS, van Beijsterveldt TC, van Leeuwen M, de Vries LS, Kahn RS, Hulshoff Pol HE, Boomsma DI 2010 Effects of gestational age and birth weight on brain volumes in healthy 9 year-old children. J Pediatr 156:896–901
6. Barker DJ, Hales CN, Fall CH, Osmond C, Phipps K, Clark PM 1993 Type 2 (non-insulin-dependent) diabetes mellitus, hypertension and hyperlipidaemia (syndrome X): relation to reduced fetal growth. Diabetologia 36:62–67
7. Hales CN, Barker DJ, Clark PM, Cox LJ, Fall C, Osmond C, Winter PD 1991 Fetal and infant growth and impaired glucose tolerance at age 64. BMJ 303:1019–1022
8. Osmond C, Barker DJ, Winter PD, Fall CH, Simmonds SJ 1993 Early growth and death from cardiovascular disease in women. BMJ 307:1519–1524
9. Hull HR, Dinger MK, Knehans AW, Thompson DM, Fields DA 2008 Impact of maternal body mass index on neonate birthweight and body composition. Am J Obstet Gynecol 198:416.e1–416.e6

10. Gómez-Ambrosi J, Salvador J, Páramo JA, Orbe J, de Irala J, Diez-Caballero A, Gil MJ, Cienfuegos JA, Frühbeck G 2002 Involvement of leptin in the association between percentage of body fat and cardiovascular risk factors. Clin Biochem 35:315–320

11. Wells JC, Chomtho S, Fewtrell MS 2007 Programming of body composition by early growth and nutrition. Proc Nutr Soc 66:423–434

12. Ma G, Yao M, Liu Y, Lin A, Zou H, Urlando A, Wong WW, Nommsen-Rivers L, Dewey KG 2004 Validation of a new pediatric air-displacement plethysmograph for assessing body composition in infants. Am J Clin Nutr 79:653–660

13. Ellis KJ, Yao M, Shypailo RJ, Urlando A, Wong WW, Heird WC 2007 Body-composition assessment in infancy: air-displacement plethysmography compared with a reference 4-compartment model. Am J Clin Nutr 85:90–95

14. Giannì ML, Roggero P, Taroni F, Liotto N, Piemontese P, Mosca F 2009 Adiposity in small for gestational age preterm infants assessed at term equivalent age. Arch Dis Child Fetal Neonatal Ed 94:F368–F372

15. Carberry AE, Colditz PB, Lingwood BE 2010 Body composition from birth to 4.5 months in infants born to non-obese women. Pediatr Res 68:84–88

16. Lee W, Balasubramaniam M, Deter RL, Hassan SS, Gotsch F, Kusanovic JP, Gonçalves LF, Romero R 2009 Fetal growth parameters and birth weight: their relationship to neonatal body composition. Ultrasound Obstet Gynecol 33:441–446

17. Moyer-Mileur LJ, Slater H, Thomson JA, Mihalopoulos N, Byrne J, Varner MW 2009 Newborn adiposity measured by plethysmography is not predicted by late gestation two-dimensional ultrasound measures of fetal growth. J Nutr 139:1772–1778

18. Roggero P, Giannì ML, Orsi A, Amato O, Moioli C, Mosca F 2010 Neonatal period: body composition changes in breast-fed full-term newborns. Neonatology 97:139–143

19. Eriksson B, Löf M, Forsum E 2010 Body composition in full-term healthy infants measured with air displacement plethysmography at 1 and 12 weeks of age. Acta Paediatr 99:563–568

20. Fomon SJ, Haschke F, Ziegler EE, Nelson SE 1982 Body composition of reference children from birth to age 10 years. Am J Clin Nutr 35:1169–1175

21. Ballard JL, Novak KK, Driver M 1979 A simplified score for assessment of fetal maturation of newly born infants. J Pediatr 95:769–774

22. Ballard JL, Khoury JC, Wedig K, Wang L, Eilers-Walsman BL, Lipp R 1991 New Ballard Score, expanded to include extremely premature infants. J Pediatr 119:417–423

23. Feresu SA 2003 Does the modified Ballard method of assessing gestational age perform well in a Zimbabwean population? Cent Afr J Med 49:97–103

24. Wells JC 2000 A Hattori chart analysis of body mass index in infants and children. Int J Obes Relat Metab Disord 24:325–329

25. Hattori K, Tatsumi N, Tanaka S 1997 Assessment of body composition by using a new chart method. Am J Hum Biol 9:573–578

26. Saenger P, Czernichow P, Hughes I, Reiter EO 2007 Small for gestational age: short stature and beyond. Endocr Rev 28:219–251

27. Wells JC 2007 The programming effects of early growth. Early Hum Dev 83:743–748

28. Wells JC 2010 The Evolutionary Biology of Human Body Fatness: Thrift and Control. Cambridge University Press, Cambridge, pp 95–99

29. Yajnik CS, Fall CH, Coyaji KJ, Hirve SS, Rao S, Barker DJ, Joglekar C, Kellingray S 2003 Neonatal anthropometry: the thin-fat Indian baby. The Pune Maternal Nutrition Study. Int J Obes Relat Metab Disord 27:173–180

30. Leary S, Fall C, Osmond C, Lovel H, Campbell D, Eriksson J, Forrester T, Godfrey K, Hill J, Jie M, Law C, Newby R, Robinson S, Yajnik C 2006 Geographical variation in relationships between parental body size and offspring phenotype at birth. Acta Obstet Gynecol Scand 85:1066–1079

31. Koo WW, Walters JC, Hockman EM 2004 Body composition in neonates: relationship between measured and derived anthropometry with dual-energy X-ray absorptiometry measurements. Pediatr Res 56:694–700

32. Butte NF, Hopkinson JM, Wong WW, Smith EO, Ellis KJ 2000 Body composition during the first 2 years of life: an updated reference. Pediatr Res 47:578–585

33. Eriksson B, Löf M, Eriksson O, Hannestad U, Forsum E 2011 Fat-free mass hydration in newborns: assessment and implications for body composition studies. Acta Paediatr 100:680–686

34. Fields DA, Krishnan S, Wisniewski AB 2009 Sex differences in body composition early in life. Gend Med 6:369–375

35. Regnault N, Botton J, Forhan A, Hankard R, Thiebaugeorges O, Hillier TA, Kaminski M, Heude B, Charles MA 2010 Determinants of early ponderal and statural growth in full-term infants in the EDEN mother-child cohort study. Am J Clin Nutr 92:594–602

36. Friis H, Gomo E, Nyazema N, Ndhlovu P, Krarup H, Kaestel P, Michaelsen KF 2004 Maternal body composition, HIV infection and other predictors of gestation length and birth size in Zimbabwe. Br J Nutr 92:833–840

37. Siervo M, Horta BL, Stephan BC, Victora CG, Wells JC 2010 First-borns carry a higher metabolic risk in early adulthood: evidence from a prospective cohort study. PLoS ONE 5:e13907

38. Wells JC 2009 Historical cohort studies and the early origins of disease hypothesis: making sense of the evidence. Proc Nutr Soc 68:179–188

39. Koo WW, Walters JC, Hockman EM 2000 Body composition in human infants at birth and postnatally. J Nutr 130:2188–2194

40. Ziegler EE, O'Donnell AM, Nelson SE, Fomon SJ 1976 Body composition of the reference fetus. Growth 40:329–341

41. Singhal A, Wells J, Cole TJ, Fewtrell M, Lucas A 2003 Programming of lean body mass: a link between birth weight, obesity, and cardiovascular disease? Am J Clin Nutr 77:726–730

42. Central Statistical Agency, ORC Macro 2006 Ethiopia Demographic and Health Survey 2005. Central Statistical Agency and ORC Macro, Addis Ababa, Calverton, MD. Available at: http://www.measuredhs.com/pubs/pdf/FR179/FR179.pdf. Accessed June 6, 2011

43. Girma T, Hailu N 2008 Traditional newborn care in Jimma Town, Southwest Ethiopia. Ethiop J Health Sci 18:79–86