Maternal Weight and Body Composition during Pregnancy Are Associated with Placental and Birth Weight in Rural Bangladesh¹,²

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Abstract

Placental growth is a strong predictor of fetal growth, but little is known about maternal predictors of placental growth in malnourished populations. Our objective was to investigate in a prospective study the associations of maternal weight and body composition (total body water (TBW) estimated by bioelectrical impedance and fat and fat-free mass derived from upper arm fat and muscle areas (UAFA, UAMA)) and changes in these with placental and birth weights. Within a cluster-randomized trial of maternal micronutrient supplementation, a subsample of 350 women was measured 3 times across gestation. Longitudinal analysis was used to examine independent associations of ~10-wk measurements and ~10–20 wk and ~20–32 wk changes with birth outcomes. Weight, TBW, and UAMA, but not UAFA, at ~10 wk were each positively and independently associated with placental weight and birth weight (P < 0.05). Of the maternal ~10–20 wk changes in measurements, only TBW change and placental weight, and maternal weight and birth weight were positively associated (P < 0.05). Gains in weight, TBW, and UAMA from 20 to 32 wk were positively and UAFA gain was negatively associated with placental weight (P ≤ 0.01). Gains in weight and UAMA from 20 to 32 wk were positively associated with birth weight (P ≤ 0.01). Overall, higher maternal weight and measures of fat-free mass at ~10 wk gestation and gains from 20 to 32 wk are independently associated with higher placental and birth weight. J. Nutr. 142: 2010–2016, 2012.

Introduction

Low birth weight (<2.5 kg) continues to be a major public health issue, with a worldwide incidence of 15% and estimated incidence in Bangladesh of 30% (1,2). These infants have a higher rate of morbidity and mortality, extending to chronic disease in adulthood (3–5).

Placental weight is a strong predictor of infant weight at birth, as the capacity of the placenta to transfer nutrients and oxygen is the principle determinant of fetal growth (6–8). The majority of placental growth is completed by the end of the second trimester, preceding the large third trimester increases in fetal weight (8). Placental volume in mid-pregnancy is highly associated with birth weight independent of fetal size at mid-pregnancy, indicating that this important relationship and trajectory begins early (9). Sheep models where placental insufficiency is induced result in growth restriction of the fetus (10).

Maternal nutritional status is associated with improved placental growth, including higher periconceptional BMI and gestational weight gain (9,11,12) as well as micronutrient intake by diet and supplementation (13–15). Nutritional factors associated with poor placental growth include increased maternal carbohydrate intake in early and late pregnancy and decreased maternal protein intake in late pregnancy (16,17).

Weight gain and body composition changes in pregnancy involve components of the mother, including RBC mass, body water, fat, and uterine and breast tissue, and the products of conception, the fetus, placenta, and amniotic fluid (18). The maternal components contribute ~65% and the products of conception contribute ~35% of total gestational weight gain (19). Typically, the mother gains fat (3.3–4.1 kg) and body water (6–7 kg), while increases in fat-free mass are primarily due to the uterus, placenta, and fetus (19–21).

Consistently across studies of healthy pregnancies, maternal total body water (TBW)⁵ and fat-free mass (usually estimated from body water) are positively associated with birth weight (21–26). A study of uncomplicated pregnancies in the UK found TBW was ~12–15% lower at ~31, 34, and 37 wk of gestation for mothers delivering babies <25th percentile compared with

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５Abbreviations used: LMP, last menstrual period; MUAC, mid-upper arm circumference; TBW, total body water; UAFA, upper arm fat area; UAMA, upper arm muscle area.
>50th percentile (27). Although fat mass has typically not been associated with birth weight, U.S. studies have found that fat gain before wk 30 was positively associated with birth weight (28) and, conversely, a gain of >5 cm² in upper arm fat area (UAFA) after 28 wk was associated with a mean birth weight that was 123 g lower (29).

Weight, fat mass, and fat-free mass and their changes across pregnancy reflect maternal nutritional status and changes in status over the course of a nutritionally challenging reproductive event. Body composition and its changes across pregnancy have been associated with birth weight, but the relationship between these patterns and placental weight has not been well studied and data are scant in poor settings with high rates of malnutrition. This study aimed to identify the independent associations of longitudinal maternal anthropometry and body composition measurements taken during pregnancy with placental weight and birth weight in a rural setting in Bangladesh.

### Participants and Methods

Women were enrolled from an ongoing, community-based, cluster-randomized, controlled trial of maternal supplementation (n = 45,000) and received daily either an iron and folic acid (standard of care) or a 15-vitamin and mineral supplement from early pregnancy to 12 wk postpartum. The composition of the supplement follows the UN multiple micronutrient preparation (30), except with higher amounts as needed to meet the RDA from the Institute of Medicine. Details of the study were previously published (31). The parent trial is being conducted in rural northwestern Bangladesh where the ~435-km² study area was divided into 596 sectors used as the unit of randomization. We followed nonpregnant women in the study area and enrolled them in the trial if a pregnancy test was positive. Thereafter, women were visited once per week for tracking and supplement dosing.

A biochemical substudy was conducted in ~10% of the parent trial area and approximately one-half of this area (31 sectors) was selected for an intensive investigation that included placental weighing and cord blood collection. Women were enrolled from February 2009 to March 2010. Ethical approval for this study was granted by the Institutional Review Board at the Johns Hopkins School of Public Health, Baltimore, MD and the Bangladesh Medical Research Council, Dhaka, Bangladesh.

Five hundred and ten newly pregnant women were approached for consent and of these, 10 women declined. Of the 500 enrolled, there were 42 miscarriages, 27 induced abortions, and 12 stillbirths. We were not able to attend 63 (15%) of 419 live births, because some of these women traveled to a different home (n = 17), delivered in facilities we could not reach (n = 19), or delivered while being transported to a facility (n = 3). Some (n = 25) were missed because families did not notify us of labor or the team was attending another birth. Of women whose births were attended, those delivering twins (n = 3) were excluded from the analysis, as was one case of torn placenta and one case of the placenta being burned due to local custom. One woman was excluded due to live birth at 29 wk (before systematic visits began at 32 wk), leaving a final sample size of 350 singleton live births.

Women were measured at enrollment (~10 wk), mid-pregnancy (scheduled at 20 wk), and late pregnancy (scheduled at 32 wk) in their homes by technicians following standard methods (32). Weight was taken to the nearest 0.1 kg with a digital scale obtained from UNICEF homes by technicians following standard methods (32). Weight was scheduled at 20 wk, and late pregnancy (scheduled at 32 wk) in their labor or the team was attending another birth. Of women whose births body composition measurements taken during pregnancy associations of longitudinal maternal anthropometry and malnutrition. This study aimed to identify the independent studied and data are scant in poor settings with high rates of malnutrition. This study aimed to identify the independent associations of longitudinal maternal anthropometry and body composition measurements taken during pregnancy with placental weight and birth weight in a rural setting in Bangladesh.

### Statistical analyses

Variables of interest were normal or visually close to normal and none were transformed for analysis. Multivariate linear regression models were fit with early pregnancy BMI and height (in the same model) as exposures and placental weight and birth weight as outcomes.

To examine longitudinal changes in pregnancy, conditional linear regression models were fit according to methods for repeated measures of the same exposure and one outcome (38), which has similarly been applied to repeated maternal weights and birth weight (39). Interpretation involves 2 equations:

\[
E(PW) = \beta_0 + \beta_1W_1 + \beta_2W_2 + \beta_3W_3,
\]

\[
E(PW) = \beta_0 + (\beta_1 + \beta_2 + \beta_3)W_1 + (\beta_2 + \beta_3)(W_2 - W_1) + \beta_3(W_3 - W_1),
\]

where PW is placental weight (or birth weight) and \(W_1, W_2,\) and \(W_3\) are maternal weight (or other repeated exposure value) at times 1, 2, and 3, respectively. When you replace the actual weights at time 2 and 3 (Eq. 1) with the changes from the previous weight (Eq. 2), the coefficient for weight at time one \(W_1\) now estimates the effect on the outcome of a
shift starting at time one and across times 2 and 3 as well. Specifically, the coefficient for $W_1$ in Eq. 2 is the sum of the coefficients in Eq. 1 (i.e., $\beta_1 + \beta_2 + \beta_3$). Thus, each coefficient represents the “cumulative” effect on the outcome, because it accounts for how a person’s weight at one time affects subsequent weights (Fig. 1). Models based on Eq. 2 were fit for each repeated maternal anthropometry and body composition measurement with placental weight and birth weight as outcomes. Additionally, we repeated any models that included TBW with impedance alone to test the sensitivity of our results to the TBW equation, given that TBW estimates depended on weight and height measures, as we have previously done (31).

Based on evidence from bivariate analysis and other published studies, all models were adjusted for the following: gestational age at birth; woman’s education (years); parity (0 vs. ≥1); infant sex; mean number of dairy servings per week at 10 and 32 wk; betel nut chewing in late pregnancy (daily vs. <daily); tobacco chewing at 10 and 32 wk (any vs. none); and the living standard scale. Because participants were enrolled in a randomized micronutrient trial, the effect of treatment allocation (blinded, since trial is ongoing) was also included in models as a confounder. We presented regression coefficients based on untransformed variables and variables standardized to have a mean of 0 and SD of 1 to compare coefficients from early pregnancy status and gestational changes. We examined the relationship between early pregnancy BMI and 20–32 wk changes in UAMA and UFAA by chi-squared tests and linear regression. Analysis was conducted using STATA 11.1 (StatCorp) and associations were considered significant at $P < 0.05$. Results presented as mean ± SD, median (IQR), or mean (95%CI).

### Results

Of the 500 enrolled women, there were few baseline differences in women included in the analysis ($n = 350$) and those excluded. A lower percent of excluded women had paid jobs (28% vs. 41%) and women excluded were at an earlier gestational age at enrollment (median 8.7 vs. 9.6). Some of the gestational age difference was due to having more ultrasound-based gestational ages for those included and some was due to more women having induced abortions who were earlier in pregnancy.

In this rural, predominately Muslim population, women were young and poorly educated with few household resources (Table 1). In early pregnancy, the majority of women (58%) were of normal weight (BMI: 18.5–24.9 kg/m²) while 39% were underweight (BMI <18.5 kg/m²) and 23% were of short stature (≤145 cm). Women were measured at median (IQR) 9.7 (7.9, 11.9), 20.4 (20.0, 21.7), and 32.1 (31.7, 32.7) wk of gestation. Women gained weight and TBW between visits, but mean UAMA and UAMF did not change across gestation (Table 2).

Mean placental and birth weights were 346.0 ± 71.5 and 2681 ± 412 g, respectively, with one-third of infants born low birth weight (<2.5 kg); results did not differ by infant sex (data not shown). Mean gestational age at birth was 39.2 ± 1.6 wk and 7.3% were preterm (<37 wk gestational age). Placental weight was positively correlated with birth weight and gestational age at birth (Fig. 2). In simple linear regression (data not shown), each additional week of gestation, from 33 to 43 wk, was associated with a 13.0-g (95% CI: 7.9, 16.4) increase in placental weight and a 106.5-g (95% CI: 82.3, 130.6) increase in birth weight. Adjusted for each other and confounders, early pregnancy maternal weight and BMI were each positively associated with placental weight and birth weight (Table 3).

As described earlier, we used confounder-adjusted linear regression models for repeated measures and each coefficient in Table 4 represents an association “conditioned” on other measurements across time. Additionally, the coefficients for measurements at ~10 wk and the change from ~10 to ~20 wk represent a “cumulative” association, in that the estimates account for the total influence of the measurement at that time plus subsequent times in the pregnancy. Thus, maternal weight at ~10 wk was cumulatively associated with higher placental weight and higher birth weight (Table 4). Weight gain from ~10 to ~20 wk was cumulatively associated with higher birth weight. Finally, maternal weight gain from ~20 to ~32 wk was associated with higher placental weight and birth weight, independently of prior weight and weight gain.

For TBW, a higher measurement at ~10 wk was cumulatively associated with higher placental weight and birth weight, independently of TBW changes in mid- and late pregnancy (Table 4). Gains in TBW from approximately wk 10 to 20 were positively associated with placental weight but not birth weight, independently of prior TBW. Gains from ~20 to 32 wk were also positively associated with placental weight but not birth weight, independently of ~10 wk status and wk 10–20 changes. Using impedance alone (in place of TBW estimation) had no meaningful impact on the results (data not shown).

For UAMA, a higher measurement at ~10 wk was cumulatively associated with higher placental and birth weight. Also, ~20 to 32 wk gains were associated with higher placental and

### Table 1: Characteristics of women and their households at ~10 wk of gestation

<table>
<thead>
<tr>
<th>Nulliparous, n (%)</th>
<th>Age, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20, y</td>
<td>129 (36.9)</td>
</tr>
<tr>
<td>20–29, y</td>
<td>105 (30.0)</td>
</tr>
<tr>
<td>≥30, y</td>
<td>202 (57.7)</td>
</tr>
<tr>
<td>Education, n (%)</td>
<td>43 (12.3)</td>
</tr>
<tr>
<td>0–y</td>
<td>76 (21.7)</td>
</tr>
<tr>
<td>1–7, y</td>
<td>134 (38.3)</td>
</tr>
<tr>
<td>≥8, y</td>
<td>140 (40.0)</td>
</tr>
<tr>
<td>Chewed betel nut daily, n (%)</td>
<td>174 (49.7)</td>
</tr>
<tr>
<td>Chewed any tobacco, n (%)</td>
<td>24 (6.9)</td>
</tr>
<tr>
<td>Anemic (hemoglobin &lt;110 g/L)</td>
<td>50 (14.3)</td>
</tr>
<tr>
<td>Frequency of intake in past week</td>
<td>2</td>
</tr>
<tr>
<td>Meat</td>
<td>7.5 (4.0, 10.5)</td>
</tr>
<tr>
<td>Dairy</td>
<td>1.5 (0, 3.5)</td>
</tr>
<tr>
<td>Dark green leafy vegetables</td>
<td>1.5 (0.5, 2.0)</td>
</tr>
<tr>
<td>Home delivery, n (%)</td>
<td>306 (87.4)</td>
</tr>
<tr>
<td>Household asset ownership, n (%)</td>
<td>248 (70.9)</td>
</tr>
<tr>
<td>Clock</td>
<td>49 (14.0)</td>
</tr>
<tr>
<td>Television</td>
<td>132 (37.7)</td>
</tr>
<tr>
<td>Bicycle</td>
<td>121 (34.6)</td>
</tr>
<tr>
<td>Mobile phone</td>
<td>54 (15.4)</td>
</tr>
</tbody>
</table>

1 Values are n (%) or median (IQR); n = 350, except values were missing for betel nut (n = 1), meat (n = 15), dairy (n = 14), dark green leafy vegetables (n = 14), and clock (n = 1).

2 Women were asked how many times they ate specific foods in the past week; meat group is composed of goat, chicken, liver, fish, and eggs; dairy group is composed of milk and yogurt; dark green leafy vegetables was a single question.

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**FIGURE 1** Simplified path diagram of influences of repeated maternal measurements on placental weight.

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birth weights, independently of earlier UAMA status and gain. Standardized coefficients at \( \sim 10 \) wk were larger than those for wk 20–32 gains for weight and TBW associations with placental weight, and the standardized coefficient for wk 20–32 gains was larger than that for \( \sim 10 \) wk for UAMA and placental weight associations (Table 4). The standardized coefficients for associations between maternal weight and UAMA with birth weight at \( \sim 10 \) wk and 20–32 wk were similar.

For UAFA, the gain from approximately wk 20 to 32 was inversely associated with placental weight in adjusted models, although UAFA was not associated with birth weight. Of note, UAMA and UAFA were positively correlated at \( \sim 10 \) wk of gestation \((r = 0.32; P < 0.001)\), but gains during early and late pregnancy were not correlated \((P > 0.05)\), suggesting that different factors dictated changes in maternal arm muscle compared with fat across pregnancy. In particular, a higher proportion of underweight (<18.5 kg/m\(^2\)) compared with normal or overweight (18.5–29.9 kg/m\(^2\)) women in early pregnancy gained UAFA in late pregnancy (55 vs. 40%; \(P = 0.005\)). After adjustment for confounders, early pregnancy BMI and late pregnancy UAFA change had a negative linear association \([-0.2 \text{ cm per 1 kg/m}^2\, (95\% \text{ CI: } -0.4, -0.1)]\). Also, there was a non-linear relationship between early pregnancy BMI and 20–32 wk UAFA changes in confounder-adjusted models in which UAMA decreased with increasing BMI up to 18.5 kg/m\(^2\) \([-0.5 \text{ cm per 1 kg/m}^2\, (95\% \text{ CI: } -0.8, -0.1)]\) and leveled off thereafter \((P = 0.028\) for spline terms).

Interaction terms were not significant \((P > 0.05)\) for infant sex, parity, or early pregnancy BMI status in adjusted models (data not shown). In sensitivity analyses, the results did not differ meaningfully after excluding preterm births \((n = 25)\) or women who were overweight in early pregnancy \((n = 8)\).

### Discussion

This prospective study examined the longitudinal associations of maternal anthropometry and body composition with placental weight and birth weight in a rural setting in Bangladesh where we previously documented a 25–30\% prevalence of wasting malnutrition in early pregnancy (MUAC <22 cm) and a 50\% incidence of low birth weight (40,41). In this study, early pregnancy BMI and height were positively associated with placental weight and birth weight, independently of each other. Early pregnancy weight, TBW, and UAMA, but not UAFA, were also positively associated with placental and birth weight. Further, later gestational gains in weight, TBW, and UAMA were positively associated with placental weight, whereas gains in UAFA were negatively associated with placenta weight. Of these late pregnancy associations, only weight and UAMA gains were associated with birth weight.

As previously observed in healthy pregnancies, maternal weight, body water, and fat-free mass increase across gestation to term, but fat mass increases to 26–30 wk (18,42). Increases in body water across gestation have also been observed based on bioelectric impedance analysis measurements (22). Fat-free mass and body water increases are due to the expansion of blood volume; the growing uterus, placenta, and fetus; and amniotic fluid (18,43), while fat mass increases are “maternal reserves”

### TABLE 2 Maternal anthropometry and body composition across gestation

<table>
<thead>
<tr>
<th></th>
<th>10 wk ((n = 350))</th>
<th>(\Delta ) 10–20 wk ((n = 339))</th>
<th>(\Delta ) 20–32 wk ((n = 338))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, cm</td>
<td>148.8 ± 5.3</td>
<td>19.5 ± 2.5</td>
<td>3.2 ± 1.9</td>
</tr>
<tr>
<td>BMI, kg/m(^2)</td>
<td>23.7 ± 2.4</td>
<td>0.9 ± 1.0</td>
<td>1.1 ± 1.1</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>59.5 ± 4.7</td>
<td>-0.20 ± 2.35</td>
<td>-0.03 ± 2.16</td>
</tr>
<tr>
<td>TBW, kg</td>
<td>13.0 ± 6.5</td>
<td>0.18 ± 2.46</td>
<td>-0.20 ± 2.39</td>
</tr>
</tbody>
</table>

1 Values are mean ± SD. *\(P < 0.05\) for t test with \(H_0: \text{mean} = 0\). TBW, total body water; UAMA, upper arm muscle area.
2 \(\Delta 10–20 \text{ wk} = 20 \text{ wk value} – 10 \text{ wk value}; \Delta 20–32 \text{ wk} = 32 \text{ wk value} – 20 \text{ wk value}.

FIGURE 2 Locally weighted regression (line) of birth weight on placental weight (A), placental weight on gestational age (B), and infant weight on gestational age (C), \(n = 350\).
for the rapid fetal growth in late gestation (43). We observed similar results in this malnourished population, with maternal weight and TBW increasing across gestation. We did not observe mean changes in UAFA or UAMA; however, these measurements are only proxies for fat and fat-free body mass and may have not reflected changes occurring in the whole body to a detectable degree. Also, in other studies, thigh, subscapular, and suprailiac sites have shown the most change in skinfold thickness across pregnancy, with tricipital skinfolds (used for calculating UAMA and UAFA) showing little to no change (18,42,44,45). Thus, in retrospect, skinfold measures at other body sites may have been more sensitive to changes in s.c. fat depots.

Our body composition findings in relation to placental and birth weight outcomes is consistent with the pattern of changes typical of successful pregnancies observed by others. Gaining weight, TBW, and UAMA in late pregnancy were all associated with higher placental weight and birth weight, although gains in body water were not significantly associated with birth weight. Late pregnancy UAFA change was negatively associated with placental weight, potentially reflecting that the maintenance or loss of fat at that stage is needed to support placental growth. Moreover, it is possible that gains in body fat among the least well-nourished women reflected a prioritization of nutritional reserves to the mother rather than the offspring.

Notably, when we standardized variables for comparisons, initial weight and body water were more important (i.e., had higher coefficients) than gains of each in later pregnancy for improving placental weight. Conversely, gaining muscle area was more important for placental weight than a woman’s starting value. Nutritional status or BMI at the beginning of pregnancy is undoubtedly linked to pregnancy outcomes and may be more important for fetal health than gestational weight gain (19). On the other hand, for UAMA, improving nutritional status enough to actually have a positive gain in arm muscle could be more important than how much muscle area a woman has at the beginning of pregnancy, thereby signaling improvements in nutritional status over the course of pregnancy that allow for improved availability of nutrients to the offspring.

It is unclear why TBW gains were associated with higher placental weight but not higher birth weight. Perhaps in these undernourished women, additional gains in body water are less important than the starting volume. We have found that underweight women gain more body water than normal-weight women (31), so the women starting at a lower value may be gaining more

### TABLE 3

<table>
<thead>
<tr>
<th>Maternal measurements</th>
<th>Placental weight, g</th>
<th>Birth weight, g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta$ (95% CI)</td>
<td>Standardized $\beta$</td>
</tr>
<tr>
<td>Height, cm</td>
<td>2.07 (0.65, 3.48)</td>
<td>0.15</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>4.40 (1.41, 7.40)</td>
<td>0.16</td>
</tr>
</tbody>
</table>

1. $n = 331$. Adjusted for height and BMI plus gestational age at birth, parity (1 vs. $\geq2$), woman’s age (y), infant sex, dairy intake (mean number of times per week in early and late pregnancy), betel nut chewing in late pregnancy (daily vs. $<€/daily$), tobacco chewing in early and late pregnancy (any vs. none), woman’s education (y), a living standards scale, and supplement allocation in parent trial.

2. Standardized $\beta$: regression coefficient calculated by first standardizing all variables to have a mean of 0 and a SD of 1.

### TABLE 4

<table>
<thead>
<tr>
<th>Maternal measurements</th>
<th>Placental weight, g</th>
<th>Birth weight, g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta$ (95% CI)</td>
<td>Standardized $\beta$</td>
</tr>
<tr>
<td>Weight, kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 wk</td>
<td>2.74 (1.28, 4.20)</td>
<td>0.25</td>
</tr>
<tr>
<td>10–20 wk²</td>
<td>3.34 (−0.60, 7.28)</td>
<td>0.09</td>
</tr>
<tr>
<td>20–32 wk³</td>
<td>7.08 (3.17, 11.0)</td>
<td>0.19</td>
</tr>
<tr>
<td>TBW, kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 wk</td>
<td>7.55 (3.61, 11.5)</td>
<td>0.26</td>
</tr>
<tr>
<td>10–20 wk²</td>
<td>8.03 (0.24, 15.8)</td>
<td>0.11</td>
</tr>
<tr>
<td>20–32 wk³</td>
<td>14.79 (8.30, 21.3)</td>
<td>0.23</td>
</tr>
<tr>
<td>UAMA, cm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 wk</td>
<td>1.85 (0.06, 3.64)</td>
<td>0.12</td>
</tr>
<tr>
<td>10–20 wk²</td>
<td>2.51 (−1.08, 6.11)</td>
<td>0.08</td>
</tr>
<tr>
<td>20–32 wk³</td>
<td>6.72 (3.11, 10.3)</td>
<td>0.20</td>
</tr>
<tr>
<td>UAFA, cm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 wk</td>
<td>0.80 (−0.61, 2.21)</td>
<td>0.07</td>
</tr>
<tr>
<td>10–20 wk²</td>
<td>−0.45 (−3.87, 2.97)</td>
<td>−0.02</td>
</tr>
<tr>
<td>20–32 wk³</td>
<td>−4.18 (−7.33, −0.03)</td>
<td>−0.14</td>
</tr>
</tbody>
</table>

1. Using conditional linear regression models for absolute value in early pregnancy (10–wk) plus changes by interval. Adjusted for height, gestational age at birth, parity (1 vs. $\geq2$), woman’s age, infant sex, dairy intake (mean number of times per week in early and late pregnancy), betel nut chewing in late pregnancy (daily vs. $<€/daily$), tobacco chewing in early and late pregnancy (any vs. none), woman’s years of education, a living standards scale, and supplement allocation in parent trial, $n = 322$. TBW, total body water; UAFA, upper arm fat area; UAMA, upper arm muscle area.

2. Represents the mean change in outcome associated with a 1-unit increase in the maternal measurement at that time plus subsequent measurements. Standardized $\beta$: regression coefficient calculated by first standardizing all variables to have a mean of 0 and a SD of 1.

3. Difference in measurement from 10 to 20 wk or 20 to 32 wk.
to normalize their body composition and yet not deliver a larger infant. It is a substantial advance to have a region-specific TBW equation from an isotope dilution study (36), especially in a context where such direct measures of body water in women of reproductive age do not exist. Although our TBW equation was developed with postpartum women, changes in the distributions of impedance measures across pregnancy in this setting reflect pregnancy weight gains, and impedance distributions at first trimester and 3 mo postpartum are nearly identical, demonstrating that impedance reflects expected changes in body water across a reproductive event (46). As well, our previous study (31) and other studies have used body water equations from nonpregnant populations for pregnant women (47).

Despite the longitudinal design of this study, we cannot be certain of the directionality between maternal and offspring status; conceivably, a well-growing placenta and fetus may be “causing” the late pregnancy weight and body water changes we observed, because the placenta and fetus are directly contributing to maternal measurements, especially later in gestation. Thus, when TBW increases, we cannot delineate to what extent it reflects changes in maternal body composition, plasma volume, intra- vs. extracellular water, amniotic fluid, or water in the conceptus, all of which may change in response to malnutrition, infection, etc. As such, TBW may be too general a measure compared with the maternal-specific measures of UAMA and UAFA to yield consistent associations with placental/infant outcomes.

In this setting, mothers, placentas, and infants were similar in size to data observed in some other developing countries but among the lowest mean values reported in a large WHO analysis spanning 20 countries (48), making this is an important population in which to examine maternal nutritional status and fetal growth. We do not have total gestational weight gain but found that maternal weight at ~5 mo gestation (45.2 kg) was comparable with Pune, India (44.0 kg) and rural Nepal (43.1 kg) and otherwise lower than most countries in the WHO report by ~5–15 kg. Maternal weight at 32 wk of gestation was also very low compared with other countries. Mean birth weight in our study (2681 g) was furthermore among the smallest worldwide, comparable with Pune, India (2633 g), but much lower than a U.S. white (3355 g) or black (3144 g) population (48).

This study is limited in not having maternal measurements that span the entire pregnancy, i.e., at conception or at the time of birth. However, there is evidence, albeit from a well-nourished population, that maternal weight and body composition are unchanged in the first trimester (49), allowing our ~10 wk measurements to be considered similar to pre-pregnancy values. Furthermore, our final maternal measurement at ~32 wk coincides well with the completion of the majority of placental growth that occurs by the end of the second trimester. Second trimester weight gain and body composition have actually been most important for birth outcomes in studies with repeated measures (22,50).

Ideally, we would have been able to better assess the nutritional inputs to provide a more comprehensive picture of the partitioning of macronutrients between mother and fetus. However, this would have also required a rigorous exploration of energy expenditure and physical activity, all beyond the scope of our field collection capabilities and our current analytic intent. A major strength of this study was the longitudinal analysis of several anthropometric and body composition measurements concurrently. Also, our study was unique in examining true placental weight (trimmed of the cord and fetal membranes) and true birth weight (immediately at delivery) in predominantly home births in poor, malnourished women. As such, it is an important contribution in a region of the world where ~70% of the population lives in rural settings and may have poor to no access to health care during pregnancy.

In this undernourished population, the initial nutritional status of the pregnant woman, and later changes, were both important when estimated by both whole body measures (weight and TBW) and upper arm measurements (muscle and fat area) in relation to positive placental and birth weight outcomes. Early pregnancy weight and TBW status seem to be more important than later gains of each in influencing placental growth, whereas gains in UAMA appear to be more important than initial status for this outcome. Future studies should examine these longitudinal associations in other settings. Maternal weight should continue to be given importance in monitoring the health of pregnancies and bioelectrical impedance analysis and arm measurements should be further investigated as another simple way to track appropriate body composition changes across gestation, especially in resource-limited settings. Although challenging, public health efforts should continue working to improve the nutritional status of women of reproductive age before they conceive as an apparent way to improve birth outcomes.

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Literature Cited


