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The impact of maternal adiposity specialization on infant birthweight: upper versus lower body fat[☆,☆☆]

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ABSTRACT

Background: The specialization of human fat deposits is an inquiry of special importance in the study of fetal growth. It has been theorized that maternal lower-body fat is designated specifically for lactation and not for the growth of the fetus.

Objective: Our goal was to compare the contributions of maternal upper-body versus lower-body adiposity to infant birth weight. We hypothesized that upper-body adiposity would be strongly associated with infant birth weight and that lower-body adiposity would be weakly or negligibly associated with infant birth weight—after adjusting for known determinants.

Study design: In this prospective cohort study, 355 women initiated medical pre-natal care during the first trimester of pregnancy at The University of Oklahoma Health Sciences Center during 1990–1993. Maternal anthropometric measurements were assessed at the first clinic visit: (a) height; (b) weight; (c) circumferences of the upper arm, forearm, and thigh; and, (d) skin-fold measurements of the bicep, subscapular region, and thigh.

Results: Infant birth weight was regressed on known major determinants to create the foundational model. Maternal anthropometric variables subsequently were added one at a time into this multiple regression model. The highest contribution by a single anthropometric variable to infant birthweight was, in order: subscapular skin-fold, forearm circumference, and thigh circumference. With one upper-body (subscapular skin-fold) and one lower-body (circumference of the thigh) adiposity measure in the model, the z-score regression coefficient (s.e.) was 85.7 g (30.8) [$p = 0.0057$] for maternal subscapular skin-fold and 19.0 g (31.6) [$p = 0.5477$] for circumference of the thigh. When the second-best upper-body contributor to infant birthweight (circumference of the forearm) was entered with one lower-body measure into the model, the z-score regression coefficient (s.e.) was 77.5 g (38.5) [$p = 0.0451$] for maternal forearm circumference and 14.1 g (38.5) [$p = 0.7146$] for circumference of the thigh. When both subscapular skinfold and forearm circumference were added to the model in place of BMI, the explained variance ($r^2 = 0.5478$) was similar to the model using BMI ($r^2 = 0.5487$).

Conclusion: Upper-body adiposity – whether operationalized by subscapular skin-fold or circumference of the forearm – was a markedly larger determinant of infant birth weight than lower-body adiposity.

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Introduction

It has been known for some time that maternal pre-pregnancy fat stores modify the impact of gestational weight gain (GWG) on infant mortality [1]. In order to minimize infant mortality, women with little body fat must gain markedly more weight than heavier women, while obese women must gain less weight than women with lower adiposity. GWG recommendations made by the Institute of Medicine (IOM) to optimize pregnancy outcomes are based on maternal body mass index (BMI) [2,3]. The limitations of basing these recommendations on maternal BMI have been acknowledged [4,5], and probability of favorable pregnancy outcome varies markedly within the recommended GWG ranges [6–8].

GWG is one of the known modifiable determinants of maternal health and pregnancy outcome [7–10]. Excessive GWG is associated with adverse pregnancy outcomes such as preterm delivery, neonatal hypoglycemia, and large for gestational age (LGA) infants [7–9]. For mothers, excessive GWG leads to increased risk of cesarean delivery, adverse cardiometabolic sequelae, and increased body weight later in life [11–14]. Conversely, insufficient GWG is associated with preterm birth, small for gestational age (SGA) infants, neonatal seizures, and increased hospitalization time for neonates [8,9].

Several studies have explored how anthropometric measurements other than BMI may better evaluate the preparedness of a woman's body for gestation by assessing maternal fat compared to fat-free mass [15,16] and total maternal body fat [17]. These measurements, however, do not include information on fat distribution in the body.

In light of growing evidence of adipose depot specialization [18–22], assessing where fat is located on a mother's body prior to pregnancy and how that fat is utilized may be more fundamental in determining pregnancy outcome than measuring total body fat. Fat specialization through varying cell receptor concentration and transcription factor activity at different sites of the body is thought to be especially prominent during reproduction [18,20,21].

Past studies have suggested that upper body adiposity may be preferentially operationalized for fetal growth [23,24], with lower body adiposity primarily contributing to lactation [21]. Sidebottom et al., after evaluating the pattern of subcutaneous body fat change throughout gestation [25], concluded that fat was utilized differently at specific sites of the body. However, the study did not analyze how individual fat depots impact infant birthweight.

In this study, we hypothesize that maternal adiposity is specialized, with upper body adiposity theoretically being available for fetal growth, making that factor a strong predictor or marker of infant birthweight. This contribution is in contrast to lower body adiposity, which is hypothesized to contribute little or nothing to infant birthweight.

Materials and methods

Study population

This prospective cohort study enrolled consecutive participants from 1990 to 1993 who presented for their first medical prenatal visit at the Department of Family Medicine or the Department of Obstetrics & Gynecology clinics at the University of Oklahoma Health Sciences Center in Oklahoma City, Oklahoma. (Soon after the completion of this study, four of the authors took administrative jobs at different universities. Unfortunately for the research, it has taken a number of years to complete this particular analysis. The authors believe that the hypotheses are not impacted by the date of enrollment of the participants. The issue is still an important one in reproductive biology.)

Exclusions included multiple births, stillborn infants, spontaneous and elective abortions, and women who were incarcerated. Three hundred and fifty-five women initiated prenatal care by the end of the first trimester of pregnancy, met our inclusion criteria, and had complete information on all of the variables pertinent to the analysis. The Institutional Review Board of the University of Oklahoma Health Sciences Center approved all procedures and assessments, including the method of obtaining written informed consent.

Exposure: maternal upper-body versus lower-body adiposity

The height (cm) and weight (kg) of the participants were measured at their first prenatal visit, as well as (a) the circumference of the forearm, bicep, and thigh, (non-stretchable measuring tape) and (b) bicep, subscapular, and thigh skinfold measurements (Lange calipers, Cambridge Industries Inc., Cambridge, Maryland, USA). All skinfold measurements were taken three times and the average recorded.

The initial thigh skinfold measurement was of the hamstring (bottom of thigh). As the study progressed it became clear that some women were too large for the hamstring assessment with our Lange calipers; we decided to change the thigh skinfold measurements to the top of the thigh. During analysis we used z-transformations separately for the top of the thigh and hamstring skinfold measures. The resultant variable *thigh skinfold* is the z-score for the hamstring (hamstring skinfold $n = 146$) or the z-score for the top of the thigh (top of thigh skinfold $n = 200$). Thigh skinfold measurement is the one variable for which the sample size is less than 355 (thigh skinfold z-score $n = 346$).

Fetal growth outcomes

Birthweight of the infant was measured in grams. Length of gestation was abstracted from the mother's medical record as recorded by the physician at the last prenatal visit. In 1990–1993 in the U.S., before the use of ultrasound dating was the standard of care, physicians began their establishment of the estimated date of delivery (EDD) based on the patient's self-report of last normal menstrual period (LNMP). During the pregnancy that estimation was adjusted, if necessary, using clinical information such as fundal height and the date when fetal heart tones were first heard.

Assessment of covariates

Socio-demographic information was collected from the study participants at the first prenatal visit, including age, education, ethnicity, and parity. Maternal gestational weight gain (GWG) was calculated as follows: maximal maternal weight during the pregnancy minus maternal weight at the first prenatal visit minus the birthweight of the infant (GWG = (a) maximal weight − (b) weight at first visit − (c) infant birthweight). The use of maternal weight at first prenatal visit avoids the systematic distortion of weight gain that occurs when pre-pregnancy weight is measured by self-report.

Smoking status was operationalized as follows: "smokers" were those women who continued to smoke beyond the first trimester of pregnancy, and "non-smokers" were those women who did not smoke in the second or third trimester of pregnancy.

Data analysis

All statistical analyses were carried out using SAS 9.3 statistical software (SAS Institute, Cary, North Carolina, USA).

The univariate data for each mother–infant pair (mean and standard deviation for the continuous variables and proportions for the discrete variables) were presented to provide information for comparison with other clinical studies and with national data. We presented the U.S. 1991 national birth cohort using linked birth/infant death data [26] to allow clinicians and researchers to judge comparability of our clinic sample and of their own patients with national data.

The foundational model for the determinants of infant birthweight was developed: infant birthweight was regressed on length of gestation, sex of the infant, parity, maternal height, maternal BMI, ethnicity, smoking status, and GWG (Regression 1). Regression coefficients were presented in three forms: (1) the standard or 'natural-unit' coefficients (e.g., "each maternal gestational weight gain of one kilogram is positively associated with 15.9 g of infant birthweight"); (2) standardized regression coefficients, identical to the concept of correlation (e.g., "the correlation between maternal gestational weight gain and infant birthweight is 0.1524"); and, (3) z-score regression coefficients (e.g., "each maternal gestational weight gain of one standard unit, i.e., one z score, is positively associated with 100.3 g of infant birthweight").

Two measures of explained variance (r^2 adjusted for degrees of freedom) were presented in the foundational model (Regression 1): (a) the explained variance for the overall model; and, (b) the incremental contribution of each predictor variable as it was added to the model.

The primary focus of the analysis involved replacing the overall maternal adiposity variable (BMI) in the foundational regression model (Regression 1) with measures of both upper- and lower-body fat (Regressions 2–9). In Regressions 2–4 (Table 4), BMI in the foundational model was replaced one at a time with individual anthropometric variables. In Regression 5, BMI was replaced with the best two anthropometric variables. In Regression 6, BMI was replaced with a composite measure of upper-body adiposity. In Regression 7, a major test of the upper/lower body adiposity hypothesis was accomplished by replacing BMI in the foundational model with the best upper body anthropometric variable (subscapular skinfold) and the best lower body measure (thigh circumference). In Regression 8, maternal BMI was replaced in the foundational model with the second-best upper body anthropometric variable (forearm circumference) and the best lower body measure (thigh circumference). In Regression 9, BMI in the foundational model was replaced with two composite variables: the composite of the best-two upper-body adiposity variables paired with the composite of the best-two lower-body adiposity variables.

Thus, the foundational model manifested in Regression 1 was repeated in the subsequent regression models; in Regressions 2–9, the overall adiposity measure of BMI was replaced by one or more anthropometric variables in order to evaluate the potential contributions of specific maternal adiposity sites.

Consequently, the regression models described above allowed for individual assessment of the strength of association of different anthropometric measures with infant birthweight while accounting for the contribution of the other covariates included in the foundational model (length of gestation, sex of the infant, parity, maternal height, ethnicity, smoking status, and GWG).

Results

Maternal characteristics are listed in Table 1; Table 2 summarizes infant characteristics. BMI was only slightly correlated with maternal height ($r = -0.00105$) and, thus, was a good overall operationalization of *height-independent weight*.

When infant birthweight was regressed on the known determinants in the foundational model (Table 3, Regression 1), the resultant coefficient of determination (adjusted r^2) was 0.5487 (n = 355, model df = 8). The regression coefficients revealed that, on average, each week of gestation was associated with 181.7 g in infant birthweight. Female infants weighed, on average, 104.3 g less than male infants. Primiparous women delivered infants who weighed, on average, 99.0 g less than infants of multiparous women. Taller women, on average, delivered larger infants, with each cm in height being positively associated with 11.0 g in infant birthweight. Maternal BMI was positively associated with infant birthweight, with each unit of increase in BMI adding 17.6 g to birthweight. African–American infants weighed, on average, 204.6 g less than their European–American counterparts. Smokers delivered infants that weighed 204.5 g less than infants born to non-smoking mothers. Finally, each kilogram of maternal GWG was positively associated with 15.9 g in infant birthweight.

The regression coefficients reflect the impact of each variable on infant birthweight. The standardized regression coefficients, the regression coefficients of the z-score transformation, and the incremental contributions to the adjusted r^2 are presented (Table 3) to allow comparison between the known determinants.

Length of gestation overwhelmingly was the largest determinant of infant birthweight (incremental contribution to adjusted $r^2 = 0.4640$). Smoking status was the second-largest contributor, while the other variables revealed smaller contributions to the

Table 1
Maternal characteristics (n = 355).

Maternal characteristic	Mean	Standard deviation
Maternal age (yrs)	24.6	4.79
Education (yrs)	11.5	1.9
Maternal height (cm)	162.9	7.07
Weight at first prenatal visit (kg)	69.4	17.6
BMI at first prenatal visit (kg/m^2)	26.1	6.28
Bicep circumference (cm)	27.6	4.6
Bicep skinfold (mm)	12.5	7.6
Forearm circumference (cm)	24.2	2.6
Subscapular skinfold (mm)	21.4	10.3
Thigh circumference (cm)	52.0	7.8
Thigh (top) skinfold (mm) (n = 200)	32.7	13.2
Thigh (hamstring) skinfold (mm) (n = 146)	36.9	14.6
		Proportion
Ethnicity		
African American		25.63%
European American		74.37%
Marital status		
Married and living with partner		39.72%
Unmarried, living with partner		16.06%
Never married, not living with partner		29.01%
Separated, divorced, or widowed		15.21%
Primiparous		36.90%
Smokers (past first trimester)		38.31%
Teens		16.90%
Greater than high school education		18.60%

Table 2
Infant characteristics (n = 355).

Infant characteristics	Mean	Standard deviation
Birthweight (g)	3329.16	658.08
Gestational age (wk)	38.80	2.27
		Proportion
Female infant		50.42%
Preterm		6.48%
Low birthweight		6.48%
Very low birthweight		2.50%

Table 3
Foundational model for birthweight regression (n = 355). Regression 1: infant birthweight regressed on major determinants.

Variable	Regression coefficient	S.E.	Standardized regression coefficient	z-Score regression coefficient	z-Score S.E.	t	p Value	Model adjusted r^2	Incremental r^2
Length of gestation (wks)	181.7	10.7	0.6269	412.5	24.4	16.92	0.0001	0.4640	0.4640
Female infant	−104.3	47.2	−0.0794	−104.3	47.2	−2.21	0.0276	0.4693	0.0053
Primiparous	−99.0	51.8	−0.0727	−99.0	51.8	−1.91	0.0567	0.4679	−0.0014
Maternal height (cm)	11.0	3.4	0.1185	78.0	23.7	3.29	0.0011	0.4839	0.0160
Maternal BMI (kg/cm^2)	17.6	4.0	0.1677	110.3	25.3	4.36	0.0001	0.4956	0.0117
African American	−204.6	56.4	−0.1359	−204.6	56.4	−3.62	0.0003	0.5086	0.0130
Smoker	−204.5	50.6	−0.1513	−204.5	50.6	−4.04	0.0001	0.5320	0.0234
Gestational weight gain (kg)	15.9	4.3	0.1524	100.3	26.9	3.73	0.0002	0.5487	0.0167
Intercept[a]	−5893.2	695.4	0.0	3549.1	48.0	−8.47	0.0001		

[a] Intercept z-score ($t = 73.94$, $p < 0.0001$).

explained variance. (Although primiparity did not add to the explained variance, it was kept in the equation, given that the estimate was in the hypothesized direction and made theoretical sense.)

When maternal BMI (an overall measure of adiposity) was replaced in the foundational regression model with each of the circumference and skinfold z-score variables one at a time (Table 4, Regressions 2–4), the single anthropometric variable that produced the highest explained variance was subscapular skinfold ($r^2 = 0.5446$, b = 96.9 g), followed by forearm circumference ($r^2 = 0.5401$, b = 88.1 g), and thigh circumference ($r^2 = 0.5348$, b = 72.4 g). (Data for other anthropometric variables not shown.)

When maternal BMI was replaced in the foundational regression model with two anthropometric variables (Table 4, Regression 5), the best two-variable replacement was subscapular skinfold and forearm circumference ($r^2 = 0.5467$, subscapular skinfold b = 71.5 g and forearm circumference b = 48.6 g).

With both (a) the best one-variable anthropometric measure and (b) the best two-variable measures in the foundational regression model, it was now possible to test the primary hypothesis of this analysis: maternal lower-body adiposity contributes little or nothing to infant birthweight when compared with upper-body adiposity, while adjusting for other known determinants. The inclusion of the best upper-body measure of adiposity (subscapular skinfold) with the best lower-body measure of adiposity (thigh circumference) into the foundational regression model resulted in the following (Table 5, Regression 7): model $r^2 = 0.5437$; subscapular skinfold b = 85.7 g ($p = 0.0057$); and, thigh circumference b = 19.0 g ($p = 0.5477$). The second-best upper-body measure of adiposity (forearm circumference) also was combined with the best lower-body measure of adiposity (thigh circumference) in the foundational regression model, with the following results (Table 5, Regression 8): model $r^2 = 0.5389$; forearm circumference b = 77.5 g ($p = 0.0451$); and, thigh circumference b = 14.1 g ($p = 0.7146$).

As a final comparison of upper- and lower-body adiposity, the two best upper-body adiposity measures – subscapular skinfold and forearm circumference – were transformed into z-scores and added together to form a one-variable measure of upper-body adiposity that we called *composite upper-body adiposity*. Replacing maternal BMI in the foundational model with *composite upper-body adiposity* produced an overall model with similar results to the model with maternal BMI (Table 4, Regression 6): model $r^2 = 0.5478$ (vs. 0.5487 in the BMI model); *composite upper-body adiposity* b = 120.5 g ($p < 0.0001$) (vs. 110.3 g for BMI, Table 3, Regression 1).

We then created a one-variable lower-body adiposity measure – *composite lower-body adiposity* – from the sum of the z-scores of thigh circumference and thigh skinfold. Replacing BMI in the foundational regression model with *composite upper-body adiposity* and *composite lower-body adiposity* resulted in the following (Table 5, Regression 9): model $r^2 = 0.5462$; *upper-body adiposity* b = 135.8 g ($p = 0.0027$); and, *lower-body adiposity* b = −22.0 ($p = 0.6129$).

In each of these pivotal analyses (Regressions 7, 8, and 9), upper-body measurements had a markedly higher association with infant birthweight than the statistically non-significant lower-body measures.

Comment

We conclude that maternal upper-body adiposity is strongly associated with infant birthweight and is consistent with the theoretical hypothesis that upper-body fat stores are more

Table 4
A series of regression models with infant birthweight regressed on known determinants and various measures of upper and lower body fat.

Anthropometric measurement/variable	Standardized regression coefficient	z-Score regression coefficient	z-Score S.E.	t	p Value	Model adjusted r^2[a]
Regressions 2–4. Infant birthweight regressed on known determinants with BMI replaced with single anthropometric variables (n = 355)						
Subscapular skinfold (mm)	0.1473	96.9	24.5	3.96	0.0001	0.5446
Forearm circumference (cm)	0.1339	88.1	25.3	3.49	0.0006	0.5401
Thigh circumference (mm)	0.1100	72.4	25.4	2.85	0.0046	0.5348
Regression 5. Infant birthweight regressed on known determinants plus two best anthropometric measurements (n = 355)						
Subscapular skinfold (mm)	0.1087	71.5	29.0	2.47	0.0140	0.5467
Forearm circumference (cm)	0.0738	48.6	29.8	1.63	0.1037	
Regression 6. Infant birthweight regressed on known determinants plus a composite of the two best anthropometric measurements (n = 355)						
Composite upper-body adiposity[b]	0.1619	120.5	28.2	4.27	0.0001	0.5478

[a] r^2 when infant birth weight was regressed on length of gestation (wks), sex of the infant (1 = female, 0 = male), parity (1 = primiparous, 0 = multiparous), maternal height (cm), ethnicity (1 = African American, 0 = European American), maternal smoking status (1 = smoker, 0 = non-smoker), GWG (kg), and stated anthropometric measurement.
[b] Composite upper-body adiposity was the sum of subscapular skinfold z-score and forearm circumference z-score.

Table 5
A series of foundational regression models with infant birthweight regressed on known determinants and comparing upper-body adiposity against lower-body adiposity.

Anthropometric measurement/variable	Standardized regression coefficient	z-Score regression coefficient	z-Score S.E.	t	p Value	Model adjusted r^2 [a]
Regression 7. Infant birthweight regressed on known determinants plus best upper-body adiposity measurement and best lower-body adiposity measurement (n = 355)						
Subscapular skinfold (mm)	0.1302	85.7	30.8	2.78	0.0057	0.5437
Thigh circumference (cm)	0.0289	19.0	31.6	0.60	0.5477	
Regression 8. Infant birthweight regressed on known determinants plus second best upper-body adiposity measure and best lower-body adiposity measure (n = 355)						
Forearm circumference (cm)	0.1178	77.5	38.5	2.01	0.0451	0.5389
Thigh circumference (cm)	0.0214	14.1	38.5	0.37	0.7146	
Regression 9. Infant birthweight regressed on known determinants plus composite upper body and composite lower body adiposity (n = 346)						
Composite upper-body adiposity[b]	0.1828	135.8	45.0	3.02	0.0027	0.5462
Composite lower-body adiposity[c]	−0.0302	−22.0	43.5	−0.51	0.6129	

[a] r^2 when infant birth weight was regressed on length of gestation (wks), sex of the infant (1 = female, 0 = male), parity (1 = primiparous, 0 = multiparous), maternal height (cm), ethnicity (1 = African American, 0 = European American), maternal smoking status (1 = smoker, 0 = non-smoker), GWG (kg), and stated anthropometric measurement.
[b] Composite upper-body adiposity was the sum of subscapular skinfold z-score and forearm circumference z-score.
[c] Composite lower-body adiposity was the sum of the thigh circumference z-score and thigh skinfold z-score.

available for fetal growth than lower-body fat stores (that manifest a negligible and non-significant association with infant birthweight). This finding supports the concept of adipose tissue specialization. The distinction of maternal upper- and lower-body fat may explain some of the disparities in infant birthweight between mothers with similar pre-gestational BMI and GWG.

In addressing potential *systematic error* we look at our foundational regression model: the coefficient of determination (adjusted $r^2 = 0.5487$) is high when compared with similar research and the list of determinants is a solid one. (Maternal age was not a significant determinant when parity was added to the model; primiparous women tended to be younger. Our judgment was that parity captured the clinical issue better than maternal age.)

All of the anthropometric variables are highly correlated with each other. The initial association between thigh circumference and infant birthweight (b = 72.4 g, p = 0.0046, Regression 4) was markedly reduced when an upper-body measure of adiposity was entered into the regression model (b = 19.0 g, p = 0.5477, Regression 7). In comparison, the addition of a second upper-body measure of adiposity did *not* eliminate the association between infant birthweight and the first upper-body variable (Regression 5).

Regarding *random error*, in spite of a relatively small sample size of 355, the p-values for the significant covariates are small; the p-values for the upper-body adiposity variables in the final regression model are small; and, the p-values for the lower-body adiposity values are large.

Concerning *construct validity*, each of the anthropometric variables was measured by full-time researchers during the clinical course of the pregnancy. The use of maternal measurements at the first prenatal visit avoids the potential bias of self-report pre-pregnancy weight and improves the trust in gestational weight gain (GWG).

A limitation of the validity of the gestational length data is that the gestational ages were not determined/confirmed by ultrasound, as this was not yet the standard of care in Oklahoma in 1990 to 1993.

The similar coefficients of determination of the foundational regression model ($r^2 = 0.5487$) using BMI and the regression model replacing BMI with a measure of only upper-body adiposity (subscapular skinfold and forearm circumference composite variable) ($r^2 = 0.5478$) reinforce the hypothesis that it is upper-body adiposity that primarily provides the fat stores for fetalgrowth. (To belabor the point: a measure of *upper-body adiposity* based on two variables provides a model with almost the same explained variance in infant birthweight as a model using BMI—a measure of *overall* maternal adiposity; and, the z-score regression coefficient of upper-body adiposity is 120.5 g versus 110.3 g for BMI.)

It could be hypothesized that the lower-body variables were poorly measured compared to those for the upper body. A correlation matrix of the anthropometric variables (Supplemental Table 1) reveals that the correlation between thigh circumference (lower body) and bicep circumference (upper body) (r = 0.82046) is *the highest correlation* between any two of the anthropometric variables. Any lack of association between thigh circumference and infant birthweight is *not* a result of poor measurement of thigh circumference.

To address *generalizability* we compared our sample to the national data set for the U.S. for the year 1991, a year in the middle of our clinical study. Given that sex and ethnicity of the infant are marked determinants of infant birthweight and length of gestation [27–30], we presented comparisons of birthweight and gestational age sorted by sex and ethnicity of infant (Supplemental Tables 2 and 3). The mean birthweights for the European-American infants were slightly less than the national averages, whereas the mean birthweights for the African American infants in the clinical study were higher. Our results seem generalizable to African–American and European–American women in the U.S. who present at university medical clinics.

Generalizability across *time periods* is a potential limitation of this study. The U.S. population continues to become more obese [31]. How well the *upper*- versus *lower-body adiposity* distinction holds up in a population of ever-increasing adiposity is open to future research.

In summary, these findings do not seem to be distorted by potential confounders; random error is unlikely to be the source of these results. The face validity of the various anthropometric variables is sound, and the results of this clinic sample from a mid-western city seems generalizable to African–American and European–American women in the U.S.

With the growing understanding of maternal fat specialization, future research has the potential to more precisely describe the relationship between upper body fat and fetal growth, to more accurately identify women at risk for adverse pregnancy outcomes, and to better tailor GWG recommendations to maternal body type with the goal of optimizing pregnancy outcome.

Conflict of interest

The authors report no conflict of interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ejogrb.2016.09.007.

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