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The Impact of Maternal Lower Body Fat on Infant Birth Weight across Body Types

Troy D Abell[1,2,3]*; Lisa C Baker[1,2]; Connor P Tompkins[1,3,6]; Gregory E Hoy[1,4]; Kathryn E Reilly[2]; Mark B Mengel[2,5]

[1]Baylor University, Honors College, Waco, TX United States.

[2]University of Oklahoma Health Sciences Center, Department of Family and Preventive Medicine, Oklahoma City, OK, United States.

[3]Baylor University, Department of Anthropology, United States.

[4]University of Michigan School of Medicine and School of Public Health, Ann Arbor MI, United States.

[5]University of Arkansas for Medical Sciences, Department of Family and Preventive Medicine, Little Rock, AR, United States.

[6]Baylor College of Medicine, Houston, TX, United States.

***Corresponding Author(s): Troy D Abell**
Baylor University, Honors College and
Department of Anthropology, Waco, Texas,
United States.
Email: troy_abell@baylor.edu

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Abstract

Objective: In prior research maternal upper-body fat is positively associated with infant birthweight, while lower-body fat is utilized for lactation; our goal was to ascertain if the utilization of body fat differs across body types. We hypothesized that only women with large lower-body fat stores accompanied by small upper-body adiposity will utilize their lower-body fat in fetal growth.

Study Design: In this prospective cohort study, 355 women initiated prenatal care during the first trimester of pregnancy at University of Oklahoma clinics during 1990 -1993. Maternal anthropometric measurements were assessed at the first clinic visit: height; weight; thigh circumference; and subscapular skinfolds.

Results: Infant birthweight was regressed on known major determinants to create the initial or foundational model. Women were separated into body types using two approaches: (a) a relative or ratio body type (lower-body/upper-body adiposity) operationalized into quartiles and (b) an absolute or median-cutoff body type (2x2 model) comparing lower- and upper-body adiposity. BMI in the foundational model was replaced by thigh circumference. In the relative approach, only the women in the quartile with the largest lower-to-upper body fat ratio manifested a significant association between thigh circumference and infant birthweight, (b = 18.2 g; z-score b = 142.3g; p = 0.0053). In the absolute approach, only the women categorized as 'above the median in lower-body fat and below the median in upper-body adiposity'

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i.e.‘pear-shape’) manifested a significant association between thigh circumference and infant birthweight, (b = 30.2g; z-score b = 236.5g; p = 0.0311). When a measure of upper-body adiposity was added to the model, the contribution of lower-body adiposity remained. As the ratio of lower-to-upper body adiposity increased across the quartiles, weight, BMI, thigh circumference, and subscapular skinfolds decreased. It is the lack of upper-body fat stores coupled with (a) a large ratio of lower-to-upper body fat or (b) a large absolute amount of lower-body adiposity that allows the body to use lower-body fat to fuel fetal growth, not simply an abundance of lower-body adiposity.

Conclusion: In the body type operationalized by a combination of large lower-body fat stores and small upper-body fat stores, lower body fat is a determinant of fetal growth; in other body types, only upper-body adiposity is a determinant.

Introduction

One focus of research in reproductive biology has been to better understand the role of maternal fat distribution and specialization in fetal growth [1,2]. It is hypothesized that upper-body fat stores tend to provide energy for the growing fetus [3-5], while lower-body adiposity is reserved to fuel lactation [1,3-7].

Various body types have been hypothesized to impact human health: android versus gynoid [8]; ‘apple’ versus ‘pear’ [9]; ‘rectangle’, ‘pear’, ‘apple’, and ‘hourglass’ [10]; central versus extremities adiposity [11,12]; lower versus upper body fat [13]; and, visceral versus subcutaneous fat [14,15]. This study focuses on lower- versus upper-body fat, which is similar to, but not identical with ‘apple’ and ‘pear’ body types.

The overall hypothesis of this study is: women with large lower-body fat stores accompanied by small upper-body adiposity will utilize their lower-body fat to fuel fetal growth, while women with other body types will not.

Materials and methods

Study population

This prospective cohort study is described elsewhere in detail [16]. Three hundred and fifty-five women initiated prenatal care by the end of the first trimester of pregnancy between 1990 and 1993 at the University of Oklahoma Department of Family Medicine and Department of Obstetrics and Gynecology clinics in Oklahoma City. The Institutional Review Board of the University of Oklahoma approved all procedures, assessments, and method of obtaining written informed consent.

Exposure

Maternal body type constituted by variations in lower-body versus upper-body adiposity is the exposure.

Anthropometric characteristics were measured at the first prenatal visit, including: height (cm); weight (kg); circumference of the thigh (non-stretchable measuring tape); and (b) subscapular skinfold (Lange calipers, Cambridge Industries Inc., Cambridge, Maryland, USA).

Maternal body types were operationalized in two ways. (1) In the relative approach to fat distribution, the ratio between a measure of lower-body fat (thigh circumference [cm]) and a measure of upper-body fat (subscapular skinfold [mm]) was used as a continuous metric: the larger the ratio, the more lower-body adiposity in relation to upper-body adiposity. The study population was then divided into quartiles based on this metric. (2) In the absolute (or discrete) approach, thigh circumference and subscapular skinfold were each divided into two groups at the median. A fourfold operationalization of body type was created by comparing the lower-body measure with upper-body adiposity, resulting in the following groups: (a) ‘Thin’ – smaller lower-body adiposity and smaller upper-body adiposity; (b) ‘Pear-Shape’ – larger lower-body adiposity and smaller upper-body adiposity; (c) ‘Apple Shape’ – smaller lower-body adiposity and larger upper body adiposity; and (d) ‘Overweight/Obese’ – larger lower-body adiposity and larger upper-body adiposity. (Our use of the term ‘Apple Shape’ is used only for convenience and does not precisely fit the medical definition.)

The need for an absolute approach is evident: for example, a participant who is very thin could be categorized as being in ‘the largest lower-to-upper ratio’ quartile by the relative approach even though she has little lower-body adipose tissue – but she has even less upper-body fat stores.

Fetal growth outcomes

Birthweight of the infant was measured in grams. Length of gestation in weeks was abstracted from the medical record.

Assessment of covariates

Maternal Gestational Weight Gain (GWG) was calculated as: maximal maternal weight during pregnancy minus maternal weight at the first prenatal visit minus the birthweight of the infant. ‘Smokers’ were operationalized as those 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 trimesters.

Data analysis

All statistical analyses were carried out using SAS 9.4 statistical software (SAS Institute, Cary, North Carolina, USA). The univariate data for each mother-infant pair are reported elsewhere [16].

The initial or 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 gestational weight gain (GWG) (Table 1, Regression 1). Regression coefficients were presented in three forms: (1) the standard or ‘natural-unit’ coefficients (e.g., “each maternal gestational weight gain (GWG) of one kilogram was positively associated with 15.9g of infant birthweight”); (2) standardized regression coefficients, identical to the concept of correlation (e.g., “the correlation between GWG and infant birthweight was 0.1524”); and (3) z-score regression coefficients (e.g., “each z score of GWG is positively associated with 100.3g of infant birthweight”).

The strategy that follows involved two steps. First, BMI was replaced in the foundational regression model (Regression 1) with a measure of thigh circumference across two models of maternal body type: relative and absolute (Regressions 2 and 3); the goal was to see if there existed a subset of women in which lower-body fat contributed to fetal growth. Second, among that subset of women, a measure of upper-body adiposity was added to the regression model to see if lower-body adiposity still contributed to infant birthweight (Regressions 4 and 5).

Theory

In our earlier work [16] we found that lower-body fat had a positive association with infant birthweight. This relationship disappeared when a measure of upper-body adiposity was added to the regression model. This is consistent with the concept of confounding: the view that lower-body fat was related to the growth of the fetus was 'distorted' by the lack of a measure of upper-body fat being in the model.

The cause of this apparent association is a potential gap in the reproductive biology literature. Does the relationship exist because all measures of adiposity are highly correlated with each other, i.e., an issue of collinearity? Thus, the upper-body fat stores would be fueling fetal growth while the lower-body fat measures are correlatively but not causally related.

Another possibility is that there are certain individuals whose lower-body fat does fuel fetal growth: the relationship between lower-body fat and fetal growth is modified by body type.

The distinction of upper- versus lower-body fat coincides well with previous research in reproductive biology. We created a relative and an absolute approach (see Methods) in hopes that any discrepancies between the two would manifest more precisely the characteristics contributing to a body type that modifies the impact of lower- versus upper-body adiposity on infant birthweight.

Results

Descriptive Statistics

The mean (sd) infant birthweight was 3329.16g (658.08), and the average gestational age was 38.80 weeks (2.27). The mean (sd) maternal BMI at first prenatal visit was 26.1 kg/m^2 (6.28). Maternal and infant characteristics are presented in detail elsewhere [16]. Maternal BMI was only slightly correlated with maternal height (r = -0.00105) and thus was a good operationalization of height-independent weight.

Initial or Foundational Model

When infant birthweight was regressed on the known determinants in the foundational model (**Table 1**, Regression 1), the adjusted r^2 was 0.5487 (n=355, model df = 8). The regression coefficients reflect the impact of each variable on infant birthweight.

When maternal BMI was replaced in the foundational model with one anthropometric variable at a time, the results were: subscapular skinfold (overall r^2 = 0.5446, z-score b = 96.9g, p = 0.0001); and thigh circumference (r^2 = 0.5348, z-score b = 72.4g, p = 0.0046). In our prior research, the statistically significant contribution of thigh circumference to infant birthweight was eliminated when subscapular skinfold was added to the model [16].

Replacing BMI in our Foundational Model with a measure of Lower-body Adiposity

A Relative Measure of Body Type: the Ratio of Lower-to-Upper-Body Adiposity

Infant birthweight was regressed on thigh circumference adjusted for the major determinants in each of the four maternal body types based on the ratio of lower-to-upper body fat **(Table 2)**. In the quartile with the highest thigh/subscapular ratio, thigh circumference was directly associated with infant birthweight (z-score b = 142.3g, p = 0.0053). Thigh circumference did not manifest a significant relationship with infant birthweight in the other three quartiles.

An Absolute Measure of Body Type

When birthweight was regressed on thigh circumference adjusted for known determinants, thigh circumference was associated with infant birthweight for women in the 'Pear' body type **(Table 3)**. The z-score regression coefficient for thigh circumference (b = 236.5g, p = 0.0331) among the 'Pear' body type was large compared to the z-score coefficients of the other body types (b = -0.5g, -146.0g, and -88.4g) and was the only one that was statistically significant.

The Strongest Test of our Hypothesis: both Lower and Upper Measures of Adiposity in the Same Model across Body Types

A Relative Measure of Body Type: the Ratio of Lower-to-Upper-Body Adiposity

In **Table 4** we have only two groups: (a) the quartile with the largest ratio of lower-to-upper body adiposity compared to (b) the other three quartiles combined. Unlike in previous regressions, a variable representing lower-body adiposity and a variable representing upper body fat were included in the same regression model. In the quartile with the largest ratio of lower-to-upper body fat, thigh circumference manifested a strong association with infant birth weight (z-score b = 185.9g, p = 0.0071), and subscapular adiposity was not related to infant birthweight (z-score b = -228.0g; p = 0.3392). However, among the other three quartiles combined, subscapular skinfold was a strong determinant of infant birthweight (z-score b = 127.0g; p = 0.0012), while thigh circumference was not (z-score b = -27g; p = 0.4873).

An Absolute measure of Body Type

Table 5, using an absolute measure of body fat, compared (a) the 'pear' shape body type to (b) all other body types combined. The results presented in Table 5 show that among the 'pear' shape body type, thigh circumference manifested a large impact on infant birthweight that was statistically significant (z-score b = 234.7g; p = 0.0389), while subscapular skinfold was not statistically significant (z-score b = 30.3g, p = 0.8818). Among the women with a 'non-pear' shape body type, subscapular skinfold was clearly a determinant of infant birthweight (z-score b = 117.5g; p = 0.0009), while thigh circumference was not (z-score b = -12.6, p = 0.7250).

What Characteristics are Responsible for this Modification of Fat Utilization across Body Types?

The impact of lower- versus upper-body fat on fetal growth differed by body type, but what precise combinations of weight, BMI, subscapular skinfold, and thigh circumference contributed to these body types in which lower body fat fuels fetal growth?

A Direct Comparison of the Relative (Ratio) Approach and the Absolute Approach to Body Type

A comparison of our relative and absolute categorizations is presented in **Table 6**. There were some obvious overlapping categories: the 'thin' and 'pear' body types tended to be categorized in the two quartiles with the largest lower-to-upper ratios; and the 'apple' and 'overweight/obese' body types tended to be categorized in the two quartiles with the smallest lower-to-upper ratios.

The Anthropometric Characteristics of the Lower-to-Upper Adiposity Ratio Quartiles

The comparisons in **Table 8** give insight into what contributed to the smaller and larger lower-to-upper adiposity ratios. Across quartiles, from smallest to largest, the values of maternal weight (83.5, 71.4, 65.8, 57.1 kg) decreased, as did BMI (31.4, 26.8, 24.9, 21.5 kg/m^2). The smallest bodies (as measured by weight or BMI) manifested the largest lower-to-upper fat ratios. The same trend was manifested with subscapular skinfold (36.8, 23.0, 17.0, 10.5 mm) and thigh circumference (56.4, 53.2, 51.0, 47.3 cm). The average lower-to-upper body fat ratio, of course, increased by quartile (1.6, 2.3, 3.0, 4.8). Thus, the ratio of lower-to-upper body adiposity increased as the four anthropometric measures decreased. The ratio increased because the subscapular measure of adiposity decreased.

The Absolute Approach to Body Types

In **Table 7** the anthropometric characteristics of the four absolute body types are presented. It is not surprising that the 'overweight/obese' body type manifested the largest anthropometric characteristics: weight, BMI, thigh circumference, and subscapular skinfold. Both the 'apple' and 'overweight/obese' body types had larger amounts of subscapular fat than 'pear' or 'thin' body types. The 'pear' body types did manifest the second largest thigh circumference. This demonstrates that the 'pear' body type is not defined solely by large amounts of lower body fat, but instead is defined by large amounts of lower body fat combined with small amounts of upper body adiposity.

Table 1: Regression 1. Foundational model: 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	0.464	0.464
Female infant	-104.3	47.2	-0.0794	-104.3	47.2	-2.21	0.0276	0.4693	0.0053
Primiparous	-99	51.8	-0.0727	-99	51.8	-1.91	0.0567	0.4679	-0.0014
Maternal height (cm)	11	3.4	0.1185	78	23.7	3.29	0.0011	0.4839	0.016
Maternal BMI (kg/cm^2)	17.6	4	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	0.013
Smoker	-204.5	50.6	-0.1513	-204.5	50.6	-4.04	0.0001	0.532	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	3549.1	48	-8.47	0.0001		

[a] Intercept z-score (t = 73.94; p < 0.0001); Table 1 reproduced from [16]

Table 2: Regression 2 a-d. Maternal body type quartiles based on a ratio of lower- to upper-adiposity.
Thigh circumference replacing BMI as a predictor of infant birthweight in the Foundational Model.

Regression	Quartiles	n	Regression coefficient	S.E.	Standardized regression coefficient	z-Score regression coefficient	z-Score S.E.	t	p Value	Model adjusted r^2
2a	Smallest Ratio	88	1.5g	9.1	0.0164	11.9g	70.9	0.17	0.8671	0.465
2b	2nd Smallest Ratio	89	5.0g	7.4	0.0536	39.2g	57.8	0.68	0.5001	0.5373
2c	2nd Largest Ratio	89	-0.007g	7.4	-0.00007	-0.05g	57.8	-0.0	0.9993	0.4852
2d	Largest Ratio	89	18.2g	6.3	0.2072	142.3g	49.7	2.87	0.0053	0.6304

Table 3: Regression 3 a-d. Maternal body types based on an absolute measure of lower- to upper-adiposity.
Thigh circumference replacing BMI as a predictor of infant birthweight in the Foundational Model.

Reg.	Body Type	n	Regression coefficient	S.E.	Standardized regression coefficient	z-Score regression coefficient	z-Score S.E.	t	p Value	Model adjusted r^2
3a	'Thin' / Moderate	136	-0.07g	9.8	-0.0004	-0.5g	76.9	-0.01	0.9946	0.6194
3b	'Pear'	37	30.2g	13.5	0.214	236.5g	105.5	2.24	0.0331	0.7169
3c	'Apple'	43	-18.6g	34.7	-0.0886	-146.0g	271.8	-0.54	0.5947	0.1278
3d	Overweight / Obese	139	-11.3g	6.9	-0.1072	-88.4g	54.2	-1.63	0.1055	0.4833

Table 4: Regression 4 a-b. Largest quartile of lower- to upper-adiposity ratio versus other quartiles combined. Thigh circumference replacing BMI as a predictor of infant birthweight in the Foundational Model.

Reg.	n	Body Type:	Regression coefficient	S.E.	Standardized regression coefficient	z-Score regression coefficient	z-Score S.E.	t	p Value	Model adjusted r^2
4a	89	**Largest Ratio Quartile** Subscapular	-20.8g	21.7	-0.0914	-228.0g	237.2	-0.96	0.3392	0.63
		Thigh cir	23.8g	8.6	0.2703	185.9g	67.3	2.76	0.0071	
4b	266	**Other Three Quartiles** Subscapular	11.6g	3.6	0.176	127.0g	38.9	3.27	0.0012	0.512
		Thigh cir	-3.5g	5.0	-0.0384	-27.0g	38.8	-0.7	0.4873	

Table 5: Regression 5 a-b. Pear shape body type versus other body types combined. Thigh circumference replacing BMI as a predictor of infant birthweight in the Foundational Model.

Reg.	n	Body Type:	Regression coefficient	S.E.	Standardized regression coefficient	z-Score regression coefficient	z-Score S.E.	t	p Value	Model adjusted r^2
5a	37	**Pear Shape** Subscapular	2.8g	18.4	0.0148	30.3g	201.6	0.2	0.8818	0.7067
		Thigh cir	30.0g	13.8	0.2123	234.7g	108.1	2.2	0.0389	
5b	318	**Other Three Body Types** Subscapular	10.7g	3.2	0.1837	117.5g	34.9	3.4	0.0009	0.534
		Thigh cir	-1.6g	4.6	-0.0197	-12.6g	35.9	-0.4	0.725	

Table 6: Comparison of Number of Women in Ratio versus Absolute Models of Maternal Body Type Absolute Model.

Ratio Model	Thin	Pear	Apple	Obese	Total
1 smallest ratio quartile	0	0	17	71	88
2	14	0	24	51	89
3	51	20	2	16	89
4 largest ratio quartile	71	17	0	1	89
Total	136	37	43	139	355

Table 7: Anthropometric characteristics across absolute body types.

'Thin' n = 136				**'Apple' n = 43**			
mean				mean			
ht	162.3	htz	-0.05	ht	160.3	htz	-0.34
wt	55.8	wtz	-0.77	wt	63.7	wtz	-0.33
bmi	21.1	bmiz	-0.8	bmi	24.8	bmiz	-0.22
thigh cir	45.4	thigh z	-0.84	thigh cir	47.6	thigh z	-0.56
subscap sf	12.8	scap z	-0.83	subscap sf	24.6	scap z	0.26
'Pear' n = 37			'Overweight' n = 139				
mean				mean			
ht	164.2	htz	0.23	ht	163.9	htz	0.18
wt	69	wtz	-0.01	wt	84.6	wtz	0.87
bmi	25.7	bmiz	-0.07	bmi	31.6	bmiz	0.87
thigh cir	55.5	thigh z	0.45	thigh cir	58.9	thigh z	0.88
subscap sf	15.2	scap z	-0.61	subscap sf	31.5	scap z	0.89

Discussion

The Data

Our prior research [16] left us with a gap in our understanding and two possible alternatives: (a) all measures of adiposity are highly correlated with each other and thus present a distorted view when a measure of lower-body fat is alone in a regression model; or (b) there exists a subgroup of women in which lower-body adiposity directly fuels fetal growth.

Tables 2 and 3 presented the impact of lower-body adiposity across body types. A measure of lower-body fat was a direct determinant of infant birthweight only among those women with large lower-body adiposity accompanied by small upper-body adiposity.

Tables 4 and 5 presented a stronger test. When measures of both lower-body adiposity and upper-body fat replaced BMI in the foundational model, lower-body fat manifested a significant association with infant birthweight among women of a certain body type: (a) large lower-to-upper fat ratio and (b) 'pear' shape body type (the absolute approach). A measure of upper-body fat manifested a significant association with infant birthweight in (a) the three combined quartiles with smaller lower-to-upper body fat ratios and (b) the 'non-pear' shape body types.

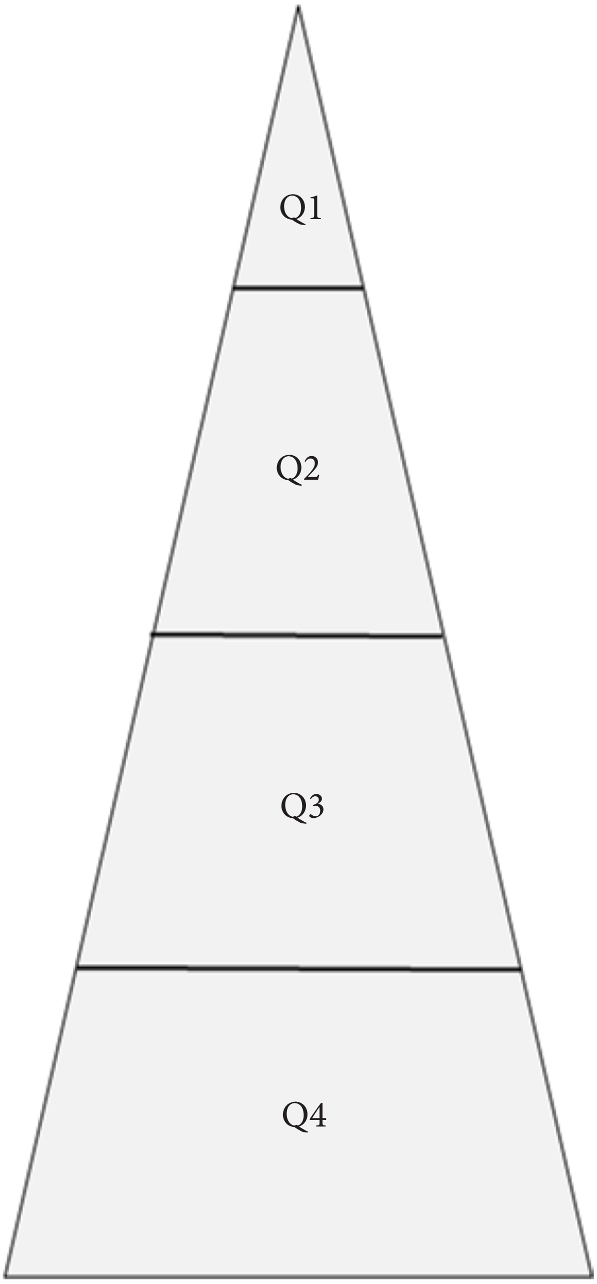
The results of our regression analyses (Tables 2-5) made it clear that there was a subset of women whose lower-body fat stores were utilized in fetal growth. A precise look at the characteristics of the women in that subset (Tables 6-8) revealed that it was a combination of two factors: a small amount of upper-body fat coupled with a large ratio of lower-to-upper body fat (or a large absolute amount of lower-body fat) that triggered

Table 8: Anthropometric characteristics across quartiles of lower- to upper-adiposity ratio quartiles.

Smallest Thigh/Subscap Ratio (Quartile 1)			
n= 88	mean		
ht	162.9	htz	0.03
wt	83.5	wtz	0.81
bmi	31.4	bmiz	0.84
thigh cir	56.4	thigh z	0.56
subscap sf	36.8	scap z	1.37
thigh/scap ratio	1.6		
Quartile 2			
n= 89	mean		
ht	163.2	htz	0.09
wt	71.4	wtz	0.11
bmi	26.8	bmiz	0.1
thigh cir	53.2	thigh z	0.16
subscap sf	23	scap z	0.11
thigh/scap ratio	2.3		
Quartile 3			
n= 89	mean		
ht	162.5	htz	-0.02
wt	65.8	wtz	-0.2
bmi	24.9	bmiz	-0.19
thigh cir	51	thigh z	-0.12
subscap sf	17	scap z	-0.44
thigh/scap ratio	3		
Largest Thigh/Subscap Ratio (Quartile 4)			
n= 89	mean		
ht	162.9	htz	0.04
wt	57.1	wtz	-0.7
bmi	21.5	bmiz	-0.74
thigh cir	47.3	thigh z	-0.6
subscap sf	10.5	scap z	-1.03
thigh/scap ratio	4.8		

lower-body fat stores to be used to fuel fetal growth. Surprisingly, these women were smaller overall (smaller weight, BMI, subscapular skinfold, and thigh circumference).

We addressed the issues of systematic error, random error, construct validity, and generalizability elsewhere [16]. In our regression models, we regressed infant birthweight on weeks of gestation using linear regression; we know that the relationship between birthweight and gestation age is not linear. We supplemented our analysis by modeling the relationship between birthweight and length of gestation using (a) a cubic model and (b) a model utilizing splines. Neither of these more complex models changed the results of our main focus – the impact of maternal lower body fat on infant birthweight across body types (results not shown). Thus, for the sake of clarity, we presented our linear regression models.



Future Research

Concerning future research, we hope that researchers with larger clinical samples will invest effort in creating models that will test the results presented here. Given our sample size, we did not attempt to explore various possible combinations of lower- and upper-body fat to reach an 'optimal' operationalization; we used quartiles in the relative approach and medians in the absolute approach.

Conclusion

Given our data, we conclude that: (1) on average, upper-body adiposity fuels fetal growth and lower-body fat is saved for lactation; (2) for a subgroup of pregnant women, lower-body fat is a determinant of infant birthweight; and (3) it is the lack of upper-body fat stores coupled with (a) a large ratio of lower-to-upper body fat or (b) a large absolute amount of lower-body adiposity that results in the body using lower-body fat to fuel fetal growth, not simply an abundance of lower-body adiposity.

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