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Maternal Dietary Fat Intake During Pregnancy and Newborn Body Composition

Ms. Natalie A. Damen, MS, RD, LD[1], **Melanie Gillingham, PhD, RD, LD**[2], **Joyanna G. Hansen, PhD, RD, LD**[2], **Kent L. Thornburg, PhD**[3], **Jonathan Q. Purnell, MD**[3], **Nicole E. Marshall, MD, MCR**[4]

[1]Graduate Programs in Human Nutrition, Oregon Health & Science University, Portland, OR, USA

[2]Department of Molecular and Medical Genetics, Oregon Health & Science University, Portland, OR, USA

[3]Knight Cardiovascular Institute, Oregon Health & Science University, Portland, OR, USA

[4]Department of Obstetrics and Gynecology, Oregon Health & Science University, Portland, OR, USA

Abstract

Objective—Increased infant birth weight and adiposity are associated with altered risk of adult chronic diseases. The objective was to investigate the association between maternal dietary fat intake during pregnancy and newborn adiposity.

Study Design—The study included 79 singleton pregnancies. Associations between maternal dietary fat intake during each trimester and infant adiposity at birth were assessed.

Result—Average total grams of maternal total dietary fat and unsaturated fat intake during pregnancy correlated with infant percent body fat after adjusting for potential confounding variables (r=0.23, p=0.045; r=0.24, p=0.037). Maternal average daily intake of total fat, saturated fat, and unsaturated fat during the second trimester of pregnancy were each associated with infant percent body fat (r=0.25, p=0.029; r=0.23, p=0.046; r=0.25, p=0.031; respectively).

Conclusion—The second trimester of pregnancy is a key time period for fetal adipose tissue metabolic programming and therefore a target for nutritional intervention.

Contact info: Nicole E. Marshall, MD, 3181 SW Sam Jackson Park Rd, Mail code L466, Portland, OR 97239. Telephone (503) 494-2101. Fax: (503) 494-5296. marshani@ohsu.edu.

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Supplementary information is available at JPER’s website.

INTRODUCTION

Increasing evidence links infant birth weight (BW) and early life development to later risk of chronic diseases. (1–6) However, BW alone does not indicate an infant's body composition (e.g., percent body fat), which may be a better predictor for adult-onset chronic diseases. (7, 8) Preclinical studies have consistently shown correlations between high-fat maternal diets during pregnancy, altered fetal body composition, and metabolic syndrome in the offspring. The syndrome is characterized by insulin resistance, hypertension, dyslipidemia, and increased central adiposity. (9, 10) In humans, studies have suggested that infants with a higher percent body fat (% body fat) at birth are predisposed to insulin resistance later in life.(6) Evidence has also shown that increased neonatal adiposity is associated with increased risk of being overweight or obese between two and six years old. (11)However, the role that maternal diet plays in determining human infant adiposity remains poorly understood. If altering maternal diet during pregnancy could impact infant adiposity and lower lifetime risk for chronic disease independently of BW, then improving dietary intake of pregnant mothers could be a tool to prevent chronic disease at the earliest stages of life.

The Healthy Start Study by Crume et al used the median value of multiple 24-hour dietary recalls to assess maternal intake and air displacement plethysmography to assess infant fat mass, and reported a positive correlation between neonatal adiposity and maternal intake of fat and carbohydrates.(12) However, the authors did not examine trimester-specific changes in maternal dietary intake, or the impact of fetal sex.

The goal of this investigation was to examine the association between maternal dietary fat intake across each trimester during gestation and infant adiposity at birth to uncover possible critical windows during gestation that set the foundation for infant adiposity. We tested the hypothesis that high maternal dietary fat intake during late pregnancy when fetal fat accretion is at its peak would be positively correlated with increased infant adiposity at birth as determined by % body fat. (12–15)

MATERIALS AND METHODS

Study Population.

This was a sub-study of a prospective observational cohort study of 185 healthy pregnant women with a singleton gestation who underwent dietary recalls and body composition analysis as previously described.(16) The present cohort comprised the 101 women who enrolled in early pregnancy ("early enrollers," 12–16 weeks gestation) and were subsequently followed through delivery. Five women withdrew prior to delivery and 17 participants were excluded due to missing dietary or infant composition data, leaving complete measurements for 79 mother-baby pairs.

In brief, participants were recruited from Oregon Health & Science University (OHSU) outpatient clinics from October 2015 to April 2018. Exclusion criteria included active maternal infection, documented fetal congenital anomalies, substance abuse, chronic illness requiring regular medication use, maternal diabetes, chorioamnionitis, and significant medical conditions including active cancers, cardiac, renal, hepatic, and pulmonary diseases.

The OHSU institutional review board approved the study protocol and each participant provided signed informed consent prior to enrollment.

Following enrollment, assessment of maternal dietary intake over the previous 3 months by participants was completed using the 2005 Block food frequency online questionnaire (FFQ) at 12–16 weeks (1st trimester), 24–28 weeks (2nd trimester), and 37–38 weeks (3rd trimester). Maternal pre-pregnancy BMI was determined by measured maternal height and self-reported pre-pregnancy weight, which strongly correlated with first prenatal visit weight ($P < 0.0001$, $r2 = 0.98$). Infant anthropometrics were measured at birth.

Infant Measurements.

In infants under 2 years of age, there are no standard criteria for what constitutes a threshold of infant adiposity associated with increased risk for adult chronic diseases, and hence we included description of BW, % body fat, infant fat mass, abdominal circumference (AC), and ponderal index (PI). Following delivery, neonatal BW, length, AC, head circumference, and sex were recorded or collected from the infant's electronic medical record. Length was measured using Grafco paper tape measurers to the nearest half-centimeter. Infants were weighed using the scale inside the General Electric Panda iRES Bedded Warmer in the delivery rooms at OHSU. These measurements were also used to calculate PI = weight (kg) / height (m)^3. Infant flank skinfold thickness was measured by trained examiners within 24 hours of birth using Lange skinfold calipers. The flank skinfold was measured at the midaxillary line just above the crest of the ileum. The average of three measurements was used. Neonatal fat mass was calculated using the equation developed and verified by Catalano et al: neonatal fat mass (kg) = 0.39055 (BW in kg) + 0.0453 (Flank skinfold in mm) - 0.03237 (Length in cm) + 0.54657.(17) Infant fat mass was converted to percent body fat, which was used as the standard for infant adiposity throughout this study.

Data analysis.

Dietary fat intake, including total, saturated, and unsaturated, were calculated for each trimester, and then trimester intakes were averaged together to calculate average fat intakes over the entire gestational period. A multivariate test was used to compare fat intake across trimesters. Pearson's correlation coefficients (r) were used to quantify the linear association between each type of dietary fat intake and each of the following fetal variables: AC (cm), PI (kg/m^3), fat mass (kg), % body fat (%), and BW (kg). For statistically significant results, partial correlations (r_{part}) were used to adjust for total gestational weight gain (GWG), pre-pregnancy BMI, gestational age at birth (GA), and infant BW. These variables were selected for their known direct relationship with infant adiposity. For partial correlations that remained significant, the analysis was repeated again by fetal sex; only significant results are presented.

Average energy intake was not selected for the adjustment model because it is highly correlated with fat intake (r =0.942) and would have produced collinearity within the model. To further address energy intake, each of the correlation analyses and multiple regression analyses were repeated with each type of fat intake as a proportion of total energy intake (% of kilocalorie [kcal] from fat) as seen in Supplemental Tables 1, 2, and 3. Any significant correlation ($p<0.05$) was further analyzed in a multiple regression model, described above, to calculate a partial correlation. All statistical analyses were performed using STATA 15 software.

RESULTS

The mean pre-pregnancy BMI of mothers was 27.4 kg/m^2, ranging from underweight to class 3 obesity (Table 1). Gestational diabetes mellitus (GDM), as diagnosed by the International Association of Diabetes and Pregnancy Study Group criteria,(18) affected 8.9% of pregnancies. Four women lost weight during their pregnancy, and 33 (41.8%) of the participants gained above the National Academy of Medicine (formerly known as the Institute of Medicine) GWG guidelines. The mean percent of calories from fat was 40.8% (range 28.5–51.6%), and there was a significant difference in unsaturated fat intake across trimesters (p=0.043), with the highest mean intake in the third trimester. There were no differences in intake of total calories consumed, total fat, or saturated fat between trimesters. The mean percent of calories from protein was 15.6% (range 11.5% to 21.1%), and the mean percent of calories from carbohydrate was 46.4% (range 34.4% to 58.6%).

The mean gestational age at delivery was 39.6 weeks, with one preterm infant born at 34.7 weeks gestation. The mean BW was 3.45 kg with a range of 2.35 kg to 5.00 kg. Three infants were classified as low BW (less than 2.5 kg). Two low BW infants (2.1 kg, 47.5 cm, and 2.29 kg, 49 cm) had negative fat mass calculations, and were excluded from analyses using fat mass and %body fat. The mean infant fat mass was 0.38 kg (range 0.09 kg to 0.97 kg) and mean % body fat was 10.6% (range 2.9% to 20.1%).

Total Dietary Fat.

Maternal total daily dietary fat intake in the second trimester, third trimester, and average intake throughout the entire pregnancy demonstrated a weak but significant correlation with newborn % body fat (Supplemental figures 1A, 1B, Table 2). After adjustment for potential confounding variables including GWG, pre-pregnancy BMI, GA, and BW, this relationship remained significant for total dietary fat intake during the second trimester and average total fat intake during the entire pregnancy (first, second, and third trimesters combined) (r_{part} =0.25, p=0.029; r_{part} =0.23, p =0.045, respectively). When stratified by sex, dietary fat intake in the second trimester correlated with male infant % body fat (r_{part} =0.346, p =0.039) but not with female infants (r_{part} =0.14, p =0.42). No other relationships between total dietary fat intake and infant measurements (AC, PI, fat mass, BW) were significantly related.

Dietary Saturated Fat.

Significant correlations were detected between maternal saturated fat intake in the second trimester, third trimester, and average intake during pregnancy and infant % body fat (r=0.25, p=0.030; r=0.23, p=.041; r=0.25, p=0.026; respectively, Table 2, Supplemental figures 2A and 2B). After adjustment for GWG, BMI, GA, and BW, associations between the second trimester saturated fat intake and infant adiposity remained significant (r_{part} =0.23 p=0.046). When stratified by infant sex, this relationship persisted for male infants (r_{part} =0.36 p=0.033), but not female infants (r_{part} =0.037, p=0.83). There were no other statistically significant relationships between maternal dietary saturated fat intake and infant measurements (AC, PI, fat mass, BW).

Dietary Unsaturated Fat.

Infant % body fat demonstrated significant relationships with maternal unsaturated fat intake during the second trimester, third trimester, and average overall intake during pregnancy (r =0.23, p=0.045; r =0.27, p=0.017; r =0.24, p=0.036; respectfully. Table 2). The crude relationships for the second trimester and entire pregnancy are shown in Supplemental figures 3A and 3B. After adjustment for GWG, BMI, GA, and BW, unsaturated fat intake during the second trimester and average intake over the entire pregnancy remained significant (r_{part} =0.25, p=0.031; r_{part} =0.24, p=0.037, respectfully) (Supplemental figures 3A, 3B). There were no significant differences by fetal sex. There were no other statistically significant relationships between maternal dietary unsaturated fat intake and infant measurements (AC, PI, fat mass, BW) after adjustment for confounders (GWG, BMI, GA, and BW).

DISCUSSION

Maternal average total, saturated, and unsaturated dietary fat intake across pregnancy were correlated with newborn % body fat. More specifically, we found that maternal dietary total, saturated, and unsaturated fat intake in the second trimester exhibited the strongest correlations with infant % body fat. Infant BW and fat mass was not associated with any type of dietary fat intake at any time point during pregnancy.

Our findings are in agreement with previous studies (12–14) despite using different methods for assessing infant adiposity. However there are important differences including our trimester specific findings and focus on infant % body fat, which takes into account fat mass as a proportion of BW rather than fat mass alone. In our study, maternal dietary saturated fat intake during the second trimester showed the greatest association with infant % body fat at birth. A link between infant adiposity and maternal dietary fat intake during the second trimester of pregnancy is biologically plausible as fetal fat accretion begins between 14 and 23 weeks gestation, and between 23 and 29 weeks gestation fat lobules increase in size and expand their surrounding capillary network. Our findings suggest that the fetus may be more sensitive to maternal dietary fat intake during the second trimester with the potential result of altering fetal fat globule development and programming, thus presenting an opportunity for nutritional intervention prior to adipocyte hypertrophy in the 3rd trimester. Our study supports the existing hypothesis that maternal diet determines maternal circulating lipids, which plays a role in fetal adipogenesis and affects subsequent risk for neonatal, childhood, and adult obesity. (11, 19, 20) Crume et al. also demonstrated a positive association between maternal saturated fat intake and neonatal fat mass, (12) and Horan et al. concluded a positive relationship between infant abdominal circumference at birth and maternal saturated fat intake during the third trimester of pregnancy.(15) Blumfield et al. did not assess fat intake by trimester, but did not find a relationship between maternal saturated fat intake and infant mid-thigh or abdominal fat. (13)

Animal studies support the relationship between maternal saturated fat intake and infant adiposity. Rat offspring of mothers fed a high saturated fat diet have increased body mass, visceral fat, adipocyte hypertrophy, and insulin resistance.(21) These affects are hypothesized to occur through adipocytes promoting insulin resistance, increased leptin levels, and increased oxidative stress thus interfering with cell-signaling pathways involved in fetal development.(21)

We also found evidence to support a weak relationship between maternal unsaturated fat intake in the second trimester and throughout pregnancy and infant % body fat at birth. Our findings are in accord with Crume et al. who demonstrated a positive correlation between maternal unsaturated fat and infant fat mass.(12) In contrast, Blumfield suggested a protective affect against infant adiposity with increased maternal polyunsaturated fatty acid intake.

Nutrition during fetal growth is vital to laying the foundation for body composition at birth. Maternal diet, along with liver and adipose stores, determines the fatty acid composition of maternal plasma triglycerides that are then available for transport to the fetus and eventually delivered to adipose deposits to be stored as triglycerides.(7, 20–22) Cord blood concentrations of triglycerides and free fatty acids have been positively associated with infant fat mass. Since maternal diet affects circulating lipids, which are known to impact infant body composition, maternal diet may provide an opportunity to influence infant adiposity. However, specific recommendations for maternal diet composition to optimize infant outcomes remain unclear. We found consistent statistically significant relationships between maternal dietary fat intake and newborn % body fat, which may have the potential to impact risk for obesity later in childhood. Other longitudinal studies have demonstrated that increased neonatal adiposity is associated with increased risk of being overweight or obese between two and six years old, and each standard deviation increase in neonatal adiposity is associated with a 0.12 kg/m^2 higher BMI.(11) Our study provides preliminary evidence to support dietary interventions during pregnancy as even modest benefits may play a role in breaking the cycle of generational obesity. Our findings that maternal dietary fat intake is particularly worrisome for males aligns with Chen et al., who concluded that addition of maternal dietary fat (while keeping other macronutrients constant) was associated with higher total abdominal fat in males but not females.(14) They also found that an isocaloric substitution of protein for fat intake was associated with decreased adipose tissue in males only.(14) These sex differences may be accounted for by differences in placental size and function known to occur between male and female babies and differing responses to maternal hormones depending on the sex of the offspring, as male fetuses make smaller placentas for body weight and take up nutrients at a higher rate.(23–25)

Strengths and limitations.

Our study has several strengths, including use of Block FFQs as the diet assessment method, which has been validated in women and for dietary assessment of macronutrients,(26, 27) and uniquely allows for trimester-specific assessment of maternal diet. The Block FFQ has a moderately strong correlation with assessment from 24-hour recalls (r= 0.50, r= r=0.70(27)) and is estimated to be within 20% of estimates produced by the average of three four-day diet records. In addition, we focused on maternal fat intake rather than overall diet patterns and food groups as done in other studies. (28) Our study population included women with a wide range of maternal pre-pregnancy BMI (17.9 to 50.1 kg/m^2) and dietary fat intake (28.5–51.6%), which increases the generalizability of the results.

Limitations to our study include sample size, infant measurements including restrictions of the Catalano equation, and dietary recall limitations. As the interaction between second trimester energy intake and newborn percent body fat neared significance, future larger studies are needed to better explore this relationship. Although the Block FFQ is a validated diet assessment tool for women, all FFQs are subject to recall bias and underreporting.(26, 27, 29) Some women reported low dietary intake, however despite this the range of calories from fat remained within standard dietary intake ranges. Pregnant women with lower educational status or higher BMI are more likely to underreport their dietary intake.(30) Although this study adjusted for BMI, it was limited in its ability to adjust for educational status or another proxy for socioeconomic status. In contrast to BMI classification for adults, there are not currently any health category standards for newborns based on adiposity to categorize an infant’s % body fat at birth on the basis for risk of harm from excessive fat mass or inadequate fat mass for growth and health. However, other studies have produced growth references based on normative distributions of infants and have reported similar mean % body fat values to our study.(12, 31, 32) Neonatal fat assessment is challenging as there is no recognized gold standard measurement technique. Varying correlations have been reported to compare neonatal fat assessment methods and skinfolds including a moderate to strong correlation of 0.55–0.84 with ADP in multiple studies, (33–35) and a strong correlation of 0.84 with total body electrical conductivity. The study that originally validated the Catalano equation excluded infants under two kg, infants admitted to the neonatal intensive care unit, and infants with congenital anomalies. These limitations of the Catalano study most likely contributed to the exclusion of two infants in our study weighing 2.1 kg and 2.29 kg with negative fat mass per the Catalano equation, suggesting that the Catalano model may be less predictive of neonatal fat mass in low birthweight infants. It is important to note that these two infants had lengths within the normative range for infants, which suggests their low birth weight may explain the negative fat mass, although measurement error cannot be excluded. Use of the newborn length measurement obtained in the delivery room by the primary nurse rather than use of a length board may have contributed to errors in the length assessment, which would have then affected the percent body fat determination. However, our measurements were within the expected range for newborn length established by normative values.

Research implications.

Our work confirms the importance of taking into account sex as a biological variable in future studies of maternal nutrition and newborn body composition. Future studies comparing isocaloric high fat and low fat maternal diets, especially during the 2nd trimester, are needed to assess the long-term effect of maternal diet on neonatal body composition as well as childhood growth trajectories. In addition to maternal fat intake, evaluating the role of added sugars on neonatal adiposity is another important area of study.

Conclusion.

The results of this study expand our current knowledge about the role of maternal dietary fat intake during each trimester of pregnancy and infant adiposity. It also suggests that altering maternal dietary fat intake during pregnancy, particularly during the second trimester, in an effort to optimize infant adiposity at birth may be a viable strategy to potentially decrease the risk for chronic disease later in life.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1.

Participant Baseline Characteristics and Dietary Intake

Characteristic	All Participants [1–3] N=79
Maternal Baseline Characteristics	
Age, years	32.9 ± 4.42 (23–43)
Height, cm	165.2 ± 6.24 (147.3–182.9)
Pre-pregnancy weight, kg	75.1 ± 18.50 (46.3–145.2)
Pre-pregnancy BMI, kg/m^2	27.4 ± 6.16 (17.9–50.1)
Total gestational weight gain, kg	12.1 ± 6.32 (−5.2–23.5)
Parity	
Nulliparous	44 (56%)
Multiparous	35 (44%)
Race[3]	
White/Caucasian	63 (80%)
Black	5 (6%)
Asian	5 (6%)
Other	10 (13%)
Ethnicity	
Hispanic	7 (9%)
Non-Hispanic	67 (85%)
Unknown/Declined	5 (6%)
Smokes tobacco	
Never smoked	59 (75%)
Previous smoker	20 (25%)
Gestational Diabetes	
Yes	7 (9%)
No	72 (91%)
Maternal Dietary Intake Throughout Pregnancy	
Energy per day, kcal	1666.5 ± 502.62 (650–2825)
Fat per day, grams	75.7 ± 25.44 (31.7–138.2)
Percent calories from fat, %	40.8 ± 4.64 (28.5–51.6)
Carbohydrate per day, grams	193.3 ± 60.68 (62.0–345.6)
Percent calories from carbohydrate, %	46.4 ± 5.65 (34.4–58.6)
Protein per day, grams	64.4 ± 20.41 (29.9–126.0)
Percent calories from protein, %	15.6 ± 1.99 (11.5–21.1)
Infant at Birth	
Gestational age, weeks	39.6 ± 1.31 (34.7–42.1)
Weight, kg	3.5 ± 0.51 (2.3–5.0)
Length, cm	51.4 ± 2.480(45.5–58.0)
Head circumference, cm	34.6 ± 1.35 (30.5–37.5)
Abdominal circumference, cm	33.6 ± 2.35 (27.5–39.5)

Characteristic		All Participants [1–3] N=79
Ponderal index, kg/m^3		25.3 ± 2.74 (18.8–34.9)
Fat mass, kg		0.4 ± 0.18 (0.1–1.0)
Body Fat Percentage, %		10.6 ± 3.57 (2.9–20.1)
Sex		
	Male	40 (51%)
	Female	39 (49%)

Abbreviation: BMI, body mass index; cm, centimeter; kcal, kilocalorie; kg, kilogram; m, meter.

[1]Values expressed as mean ± standard deviation (min-max).

[2]Values expressed as N (percent).

[3]Participants reported all groups that apply.

Table 2.

Infant Body Fat Percent and Maternal Dietary Intake

Variable	1st Trimester				2nd Trimester				3rd Trimester				Total Pregnancy			
	Crude[1]		Partial[2]		Crude[1]		Partial[2]		Crude[1]		Partial[2]		Crude[1]		Partial[2]	
	r	*p*[3]	*r*	*p*[3]	*r*	*p*[3]	*r*	*p*[3]	*r*	*p*[3]	*r*	*p*[3]	*r*	*p*[3]	*r*	*p*[3]
Total fat (g)	0.163	0.151	-	-	0.243	**0.031**	0.252	**0.029**[4]	0.260	**0.021**	0.159	0.172	0.249	**0.027**	0.233	**0.045**
% of kcal	0.124	0.278	-	-	0.194	0.087	-	-	0.148	0.192	-	-	0.186	0.100	-	-
Saturated fat (g)	0.193	0.088	-	-	0.245	**0.030**	0.231	**0.046**[4]	0.231	**0.041**	0.112	0.339	0.250	**0.026**	0.201	0.083
% of kcal	0.158	0.164	-	-	0.222	0.050	-	-	0.121	0.286	-	-	0.189	0.095	-	-
Unsaturated fat (g)	0.139	0.223	-	-	0.227	**0.045**	0.250	**0.031**	0.269	**0.017**	0.184	0.114	0.236	**0.036**	0.241	**0.037**
% of kcal	0.067	0.555	-	-	0.106	0.352	-	-	0.142	0.213	-	-	0.127	0.263	-	-
Energy (kcal)	0.133	0.242	-	-	0.213	0.059	0.227	0.050	0.221	0.050	0.215	0.065	0.210	0.063	-	-

Abbreviation: cm, centimeter; g, gram; kg, kilogram; *p*, p-value; *r*, Pearson's correlation coefficient; %, percent.

[1]Crude correlation analysis without any adjustment models.

[2]Partial correlation analysis adjusting for maternal total gestational weight gain, pre-pregnancy BMI, infant gestational age at birth, and infant birth weight.

[3]P-Value <0.05 is considered statistically significant, indicated by bold type.

[4]When analyzing males and females separately, this relationship persisted for males only with p<0.05