# Differences in Maternal Circulating Fatty Acid Composition and Dietary Fat Intake in Women With Gestational Diabetes Mellitus or Mild Gestational Hyperglycemia

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**OBJECTIVE** — We investigated the relationship between maternal circulating fatty acids (FAs) and dietary FA intake in pregnant women with gestational diabetes mellitus (GDM; $n = 49$), women with hyperglycemia less severe than GDM (impaired glucose challenge test [GCT] non-GDM; $n = 80$), and normal control subjects ($n = 98$).

**RESEARCH DESIGN AND METHODS** — A case-control design was nested within a prospective cohort of healthy pregnant women. Fasting concentrations of serum total FAs (enzymatic assay) and FA composition (gas chromatography–mass spectrometry) were determined at entry and the third trimester. Dietary fat intake data were obtained from 24-h recalls.

**RESULTS** — There was a graded increase among groups (control subjects, impaired GCT non-GDM, and GDM) during the third trimester for total FAs and individual FAs, including myristic, palmitic, palmitoleic, oleic, linoleic, linolenic, arachidonic, eicosapentaenoic, and docosahexaenoic acids ($P$ for trend $<0.03$ to $P < 0.001$). Similar relationships were observed at entry in total FAs and for four FAs (myristic, palmitic, palmitoleic, and eicosapentaenoic acids). Women with impaired GCT non-GDM with BMI $\geq 25$ kg/m$^2$ had the highest levels of FAs at entry, whereas women with GDM with BMI $\geq 25$ kg/m$^2$ had the highest levels during the third trimester, and all grouped FAs were significantly different from lean women with impaired GCT non-GDM or control subjects ($P < 0.05$). Dietary intake of polyunsaturated FAs was decreased, but saturated FAs were increased in GDM compared with impaired GCT non-GDM or control subjects ($P < 0.05$).

**CONCLUSIONS** — Abnormalities in fat metabolism are present in both GDM and impaired GCT non-GDM women. Reducing pregravid weight and altering diet might prevent the associated elevation of circulating FAs.

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**M**any studies suggested that maternal circulating fatty acids (FAs) play important roles in fetal growth and development (1–2). However, elevated maternal circulating total FAs are associated with increased insulin resistance and β-cell dysfunction, which contribute to the development of gestational diabetes mellitus (GDM) and increase risk of adverse perinatal outcomes,

including preterm delivery (3–4). Less attention has been focused on the relationship between FA composition and GDM. Published data (5–6) are inconclusive on which individual FAs are altered in GDM and the importance of these changes, if any. Dietary saturated fat intake is associated with increased risk of type 2 diabetes and increased polyunsaturated fat intake with a reduced risk (7). Similar results have

been found in some, but not all, studies with GDM, with the difference in results probably being due to the effect of dietary counseling after GDM diagnosis (8–9).

Recent studies have reported that maternal glucose intolerance less severe than overt GDM is associated with an increased risk of adverse pregnancy outcomes (10). These observations raise important questions because ~9–19% of pregnant women have hyperglycemia during fasting or an oral glucose load but do not meet the diagnostic criteria for GDM (11). These patients generally are not provided the usual diabetes care. Consequently, there is little information on whether metabolic abnormalities in FA composition exist in these women and if their dietary fat intake differs from women with metabolically normal pregnancies.

Therefore, we used a nested case-control design to investigate whether elevated concentrations of serum FA and alerted FA composition were present not only in women with overt GDM but also in those with less severe glucose intolerance. In addition, we examined whether the corresponding dietary FA intake differed among groups and correlated with serum FA concentration.

## RESEARCH DESIGN AND
**METHODS** — We conducted a case-control study nested within the Camden Study (12), a prospective cohort study of pregnancy outcome and complications in young, generally healthy women residing in one of the poorest cities in the continental U.S. The institutional review board at the University of Medicine and Dentistry of New Jersey, School of Osteopathic Medicine, approved the study protocol. Informed written consent was obtained from each participant after explanation of the nature and purpose of the study.

Data regarding socioeconomic status, demographics, and lifestyle were obtained by interview at entry to care (~15 weeks of gestation) and updated at 20 and 28 weeks of gestation. Ethnicity was self-

defined. BMI was computed based on self-reported pregravid weight and measured height at entry to prenatal care (kg/m$^2$). Maternal obesity was defined as BMI $\geq$30 kg/m$^2$ (13). Fasting blood samples ($>$8 h) were obtained to measure serum FA concentrations and composition at entry to care (16.5 $\pm$ 0.16 weeks) and during the third trimester (30.76 $\pm$ 0.16 weeks) (means $\pm$ SE). Serum samples were centrifuged at 4°C and stored at −70°C for assay. After exclusions of women who had serious nonobstetric problems, the cohort of 2,379 participants enrolled between 1996 and 2006 were used to select case and control subjects.

## Case subject definition

Cases of GDM were selected from among participants with a positive glucose challenge test (GCT) at 28 weeks' gestation (27.7 $\pm$ 0.2 weeks) (means $\pm$ SE) (1-h plasma glucose concentration $>$140 mg/dl after a 50-g oral glucose load) and with two or more glucose values over the cut points of 95, 180, 155, and 140 mg/dl at fasting, 1, 2, and 3 h during a 100-g diagnostic oral glucose tolerance test (OGTT) (the Carpenter/Coustan conversion recommended by the American Diabetes Association) (14). All patients diagnosed with GDM (4.2% of the cohort) were treated with dietary counseling and/or insulin. Women with a positive GCT and fewer than two abnormal glucose values during an OGTT were identified as cases of impaired GCT non-GDM (7.1% of the cohort). Gravidae with GDM ($n = 49$), impaired GCT non-GDM ($n = 80$), and normal GCT (glucose $\leq$140 mg/dl at GCT) ($n = 98$) were randomly selected from the cohort to yield two control subjects per case subject of GDM and about one control subject per case subject of impaired CGT non-GDM (SAS Procedure, PROC SURVEYSELECT). The sample size is sufficient to detect a very small effect (0.05 SD units, equivalent to a correlation coefficient of $r = \sim$0.1), with a power of 85% (one-way ANOVA for groups of unequal size at $\alpha = 5\%$ and two-sided test).

## Analytic procedures

We measured the concentration and relative abundance of myristic, palmitic, stearic, palmitoleic, oleic, linoleic, linolenic, arachidonic, eicosapentenoic (EPA), and docosahexaenoic (DHA) FAs. Total lipids were extracted by a modified Folch method and analyzed by gas chromatography/mass spectrometry (GCMS) (5973 MS/6890 GC; Agilent Technologies, Santa Clara, CA) (15). Briefly, serum lipids were extracted by adding 5 ml of a mixture of 1 N HCl:heptane:propan-2-ol (1:10:40). The extracted lipids were dissolved in chloroform and separated by thin-layer chromatography. The FA band was cut out and FA methyl esters were prepared by esterification with 1 ml of 14% BF3/CH3OH. The resultant esters were redissolved in hexane and separated by GCMS using a fused-silica capillary column (Rtx-20; Restek, Bellefonte, PA). Peak retention times were identified by injecting known standards (Sigma-Aldrich, St. Louis, MO).

The peak area of FAs was identified as percentage of total area under the peaks, and absolute concentration of FAs was quantified by multiplying each individual FA in relative value (%) by the total FA concentration ($\mu$mol/l) determined by an enzymatic assay kit (Wako Chemicals, Richmond, VA). Total saturated FAs (SFAs) (the sum of myristic, palmitic, and stearic acids), total monounsaturated FAs (MUFAs) (the sum of palmitoleic and oleic acids), and total polyunsaturated FAs (PUFAs) (the sum of linoleic, linolenic, arachidonic, EPA, and DHA) were computed.

## Dietary data

A 24-h recall of the previous day's diet was obtained at entry to care and weeks 20 and 28 of gestation and were processed with databases from the Campbell Institute of Research and Technology (Campbell Soup Company) in Camden as described previously (16). The database generates data for $>$70 nutrients and 19 FAs using the U.S. Department of Agriculture Nutrient Database for Standard Reference (http://www.nal.usda.gov/fnic/foodcomp) and the Continuing Survey of Food Intakes by Individuals. The mean of three 24-h recalls was used to calculate the total daily intake of energy, fat, carbohydrate, protein, individual FAs, SFAs, MUFAs, and PUFAs, accordingly.

## Statistical analysis

Univariate statistics were calculated for continuous variables, and $\chi^2$ test was used for categorical variables. ANOVA was used to assess the significance of the linear trends among groups with various degrees of hyperglycemia and the normal control subjects; pairwise contrasts were computed to compare case with control subjects. Data on dietary FA intake were adjusted for total fat and energy intake. A stratified analysis by maternal overweight and obesity (BMI $<$25 vs. BMI $\geq$25 kg/m$^2$) was performed to test if the differences in FA composition and hyperglycemia were independent of maternal adiposity. Potential confounding variables including maternal age, ethnicity, parity, and cigarette smoking were controlled in multivariable models. All statistical analyses were performed using SAS version 9.1 (SAS Institute, Cary, NC).

**RESULTS** — Maternal characteristics are shown in Table 1. As expected, patients with GDM or impaired GCT non-GDM were older and had higher pregravid BMI ($P$ for trend $<$0.001). In

**Table 1—Characteristics of participants**

| | GDM | Impaired GCT non-GDM | Normal GCT | $P$ for trend |
|---|---|---|---|---|
| $n$ | 49 | 80 | 98 | |
| Age (years) | 25.63 $\pm$ 0.81 | 24.48 $\pm$ 0.65 | 21.29 $\pm$ 0.54 | $<$0.001 |
| BMI (kg/m$^2$) | 30.76 $\pm$ 0.93 | 26.93 $\pm$ 0.71 | 25.40 $\pm$ 0.56 | $<$0.001 |
| Obese (BMI $\geq$30 kg/m$^2$) | 22 (44.9) | 21 (26.3) | 18 (18.4) | $<$0.01 |
| Parimipara | 15 (30.6) | 26 (32.5) | 46 (46.9) | 0.065 |
| Ethnicity | | | | |
| Hispanic | 30 (61.2) | 38 (47.5) | 35 (35.7) | |
| African American | 6 (12.2) | 31 (38.8) | 49 (50.0) | |
| Caucasian and other | 13 (26.5) | 11 (13.8) | 14 (14.3) | 0.001 |
| Cigarette smoking | 15 (30.6) | 23 (28.8) | 19 (19.4) | 0.21 |
| Medicaid | 49 (100) | 80 (100) | 96 (98.0) | 0.26 |
| Gestational age at delivery* | 38.09 $\pm$ 0.29 | 38.68 $\pm$ 0.22 | 38.90 $\pm$ 0.20 | 0.033 |
| Infant birth weight (g)† | 3,325 $\pm$ 67 | 3,210 $\pm$ 50 | 3,152 $\pm$ 47 | 0.047 |

Data are means $\pm$ SE or $n$ (%). *Adjusted for maternal age, BMI, and cigarette smoking. †Adjusted for maternal age, BMI, gestational age at delivery, and cigarette smoking.

addition, there were more Hispanic and fewer African American women in the GDM group ($P < 0.001$). The mean gestational age at delivery was significantly shorter and infant birth weight was significantly greater in the GDM group than in the control group ($P < 0.05$ for each).

## Serum FA composition

Maternal serum FA composition in absolute concentration and expressed as a percent of total FAs are given in Table 2, which compares FAs concentrations and distribution patterns for the three groups: control subjects, impaired GCT non-GDM, and GDM. We found a graded relationship between the severity of maternal hyperglycemia and concentrations of individual FAs at both entry and the third trimester (e.g., women with GDM had the highest and control subjects had the lowest FA concentration; the FA concentration was intermediate in the impaired GCT non-GDM group). During the third trimester, the absolute concentration of all individual FAs (except stearic acid) and the sum of SFAs, MUFAs, and PUFAs showed significant linear trends ($\mu$mol/l, means $\pm$ SE). The differences between the GDM and the control subjects were all significant ($P < 0.05$ for each). Only two differences were found between the GDM and impaired GCT non-GDM groups, the concentrations of palmitoleic acid and DHA.

At entry to care, the trends were less pronounced. Significance was only found with a few FAs (myristic acid, palmitic acid, palmitoleic acid, EPAs, SFAs, and total FAs) for GDM versus control subjects ($P < 0.05$ to $P < 0.01$). Additionally, palmitic acids and total SFAs were significantly higher in the impaired GCT non-GDM group than in control subjects (Table 2).

In contrast, the relationship between severity of maternal hyperglycemia and FA composition when expressed in relative values (percentage of total FAs) was not consistent. During the third trimester, women with GDM had a lower percentage of stearic acid and SFAs but a higher percentage of palmitoleic acid, oleic acid, and MUFAs than in control subjects ($P < 0.05$ for each) (Table 2). Similar results were found at entry for stearic and palmitoleic acids ($P < 0.05$ for each). Other FAs did not show differences between groups.

## Serum FAs, hyperglycemia, and BMI

We further examined the differences of serum FAs and hyperglycemia with and without overweight or obesity after adjusting for maternal covariates (Table 3). At entry, impaired GCT non-GDM women with BMI $\geq 25$ kg/m$^2$ had the highest concentrations of FAs among three groups. The differences were significant compared with lean women with impaired GCT non-GDM ($P < 0.05$ to $P < 0.01$ for each), and similar results were observed in comparison to lean control subjects ($P < 0.01$ for each).

During the third trimester, GDM women with BMI $\geq 25$ kg/m$^2$ had the highest concentrations of FAs among the groups, having SFAs, MUFAs, PUFAs, and total FAs that were higher than in lean control women ($P < 0.01$ for each), and SFAs, PUFAs, and total FAs were also higher than in lean women with impaired GCT non-GDM. In addition, control subjects with BMI $\geq 25$ kg/m$^2$ had higher MUFAs and PUFAs than in lean control women ($P < 0.05$ for each) (Table 3).

## Dietary fat and FA intake

The mean of dietary fat and corresponding FA intake for the three groups are shown in Table 4. The intake of FAs was adjusted for total energy and total fat intake. The total fat intake, expressed as grams per day (adjusted for energy intake) or as the percentage of energy, did not differ significantly among groups. There were significant trends for PUFA ($P < 0.01$), linoleic acid ($P < 0.01$), and DHA ($P < 0.05$) intake to be higher in the normal control subjects, whereas women with GDM had higher intakes of total SFAs ($P < 0.05$), palmitic acid ($P < 0.01$), and stearic acid ($P < 0.05$) than either impaired GCT non-GDM and/or control subjects.

## Correlations between serum FAs and dietary FA intake

We correlated serum individual FAs and grouped FAs (SFAs, MUFAs, PUFAs) (as a percentage of serum total FAs) with the corresponding dietary FA intake (as a percentage of total fat intake) adjusted for energy intake. A positive correlation was only observed between serum PUFAs with dietary PUFA intake ($r = 0.222$, $P < 0.05$ for GDM, $r = 0.247$, $P < 0.05$ for impaired GCT non-GDM and $r = 0.279$, $P < 0.01$ for control subjects). The correlations on other FAs were nonsignificant and negligible.

**CONCLUSIONS** — Our results show that the concentration of total FA, many individual FAs, and grouped FAs (SFAs, MUFAs, PUFAs) were elevated not only in women with GDM but also in women with impaired GCT non-GDM when compared with control subjects. There were also group-related differences in dietary intake. Maternal pregravid overweight or obesity (BMI $\geq 25$ kg/m$^2$) appears a significant contributor to an increased level of serum FAs. To our knowledge, ours is the first study of maternal serum FA composition in impaired GCT non-GDM subjects in young minority women from the U.S.

A growing body of evidence supports the concept that women with maternal hyperglycemia less severe than the overt GDM are also at an increased risk of adverse perinatal outcomes (10). Treatment for mild hyperglycemia reduces the associated risk (17). Chronic elevation in circulating FAs have been linked to increased insulin resistance and inflammation, which are associated with risk of type 2 diabetes and cardiovascular diseases (18–19). Increased maternal circulating FAs were found to be a significant pathogenic factor for GDM, preeclampsia, and risk of preterm delivery (3–4,20). However, little is known about whether FA concentrations are also elevated in women with mild or moderate hyperglycemia or if FA composition and/or dietary FA intake are altered in such cases. Our data showed a graded trend between the severity of maternal hyperglycemia and serum FA composition. Actual concentrations in 9 of 10 FAs and all grouped FAs (SFAs, MUFAs, and PUFAs) were significantly elevated in GDM women during the third trimester. Likewise several major SFAs were elevated at entry when compared with normal control subjects.

The concentrations of individual FAs and grouped FAs in women with impaired GCT non-GDM were moderately elevated and, for the most part, differed little from concentrations in gravidae with GDM. When compared against the control subjects, SFA (palmitate acid, total SFAs at entry, and myristic acid at the third trimester) levels were significantly higher (Tables 2). In contrast, prior studies showed no major differences in the individual FAs, including PUFAs (percentage of total FAs) between GDM and control subjects (5).

Obesity is an important pathogenic factor for diabetes and cardiovascular disease (18). In nonpregnant overweight or obese subjects, the total FA levels are commonly elevated, but FA composition, expressed as a percentage of total FAs,

**Table 2—Maternal serum FAs by glycemic group**

| | GDM (μmol/l) | Impaired GCT Non-GDM (μmol/l) | Normal GCT (μmol/l) | P for trend | GDM (%) | Impaired GCT Non-GDM (%) | Normal GCT (%) | P for trend |
|---|---|---|---|---|---|---|---|---|
| **Entry** | | | | | | | | |
| SFAs | | | | | | | | |
| Myristic acid (14:0) | 11.47 ± 0.86 | 9.79 ± 0.69 | 8.30 ± 0.62* | 0.003 | 3.09 ± 0.21 | 2.89 ± 0.17 | 2.69 ± 0.15 | NS |
| Palmitic acid (16:0) | 150.91 ± 9.91 | 144.80 ± 7.93 | 121.89 ± 7.08†‡ | 0.003 | 39.82 ± 1.26 | 39.61 ± 1.01 | 38.87 ± 0.90 | NS |
| Stearic acid (18:0) | 69.59 ± 4.05 | 68.17 ± 3.24 | 63.72 ± 2.90 | NS | 19.15 ± 0.99 | 19.98 ± 0.79 | 21.84 ± 0.71† | 0.019 |
| Total SFAs | 231.90 ± 13.91 | 222.76 ± 11.12 | 193.90 ± 9.94†‡ | 0.017 | 62.07 ± 2.07 | 62.49 ± 1.65 | 63.40 ± 1.48 | NS |
| MUFAs | | | | | | | | |
| Palmitoleic acid (16:1) | 10.90 ± 1.52 | 9.54 ± 1.20 | 7.41 ± 1.08† | 0.050 | 2.27 ± 0.18 | 2.07 ± 0.14 | 1.60 ± 0.13*‡ | 0.002 |
| Oleic acid (18:1) | 104.17 ± 11.07 | 96.03 ± 8.85 | 83.41 ± 7.91 | NS | 22.72 ± 1.27 | 22.22 ± 1.02 | 21.48 ± 0.91 | NS |
| Total MUFAs | 114.62 ± 12.45 | 105.45 ± 9.96 | 90.59 ± 8.89 | NS | 24.90 ± 1.42 | 24.26 ± 1.14 | 23.04 ± 11.02 | NS |
| PUFAs | | | | | | | | |
| Linoleic acid (18:2) | 53.72 ± 5.72 | 50.27 ± 4.26 | 45.29 ± 3.80 | NS | 11.96 ± 0.68 | 12.20 ± 0.54 | 12.44 ± 0.48 | NS |
| Linolenic acid (18:3) | 1.98 ± 0.22 | 1.64 ± 0.18 | 1.61 ± 0.16 | NS | 0.42 ± 0.03 | 0.39 ± 0.03 | 0.43 ± 0.02 | NS |
| Arachidonic acid (20:4) | 2.28 ± 0.24 | 2.01 ± 0.19 | 1.84 ± 0.17 | NS | 0.55 ± 0.05 | 0.53 ± 0.04 | 0.54 ± 0.04 | NS |
| EPA (20:5) | 0.45 ± 0.04 | 0.41 ± 0.03 | 0.33 ± 0.03† | 0.011 | 0.10 ± 0.01 | 0.10 ± 0.01 | 0.10 ± 0.01 | NS |
| DHA (22:6) | 0.27 ± 0.06 | 0.22 ± 0.05 | 0.34 ± 0.04 | NS | 0.07 ± 0.02 | 0.06 ± 0.02 | 0.10 ± 0.01 | NS |
| Total PUFAs | 58.42 ± 5.57 | 54.41 ± 4.60 | 49.24 ± 4.11 | NS | 13.03 ± 0.74 | 13.25 ± 0.59 | 13.56 ± 0.53 | NS |
| Total free FAs | 405.01 ± 29.53 | 379.63 ± 23.47 | 333.75 ± 21.11† | 0.039 | | | | |
| **Third trimester** | | | | | | | | |
| SFAs | | | | | | | | |
| Myristic acid (14:0) | 11.65 ± 0.77 | 10.08 ± 0.58 | 9.69 ± 0.52‡ | 0.001 | 2.99 ± 0.21 | 3.05 ± 0.16 | 3.34 ± 0.14 | NS |
| Palmitic acid (16:0) | 148.38 ± 9.46 | 128.56 ± 7.08 | 117.26 ± 6.36* | 0.008 | 36.87 ± 1.12 | 36.85 ± 0.84 | 37.71 ± 0.75 | NS |
| Stearic acid (18:0) | 62.73 ± 4.02 | 57.43 ± 3.01 | 55.49 ± 2.70 | NS | 15.71 ± 0.76 | 17.23 ± 0.57 | 18.49 ± 0.51* | 0.002 |
| Total SFAs | 222.76 ± 13.62 | 196.06 ± 10.2 | 182.44 ± 9.15* | 0.016 | 55.57 ± 1.75 | 57.12 ± 1.31 | 59.55 ± 1.17* | 0.045 |
| MUFAs | | | | | | | | |
| Palmitoleic acid (16:1) | 12.23 ± 1.22 | 8.89 ± 0.91† | 6.97 ± 0.82* | 0.0005 | 2.65 ± 0.17 | 2.24 ± 0.12 | 1.78 ± 0.11*§ | 0.001 |
| Oleic acid (18:1) | 119.98 ± 10.78 | 100.41 ± 8.07 | 88.42 ± 7.24† | 0.017 | 27.14 ± 1.10 | 26.24 ± 0.83 | 24.52 ± 0.74† | 0.03 |
| Total MUFAs | 132.21 ± 11.87 | 109.30 ± 8.89 | 95.39 ± 7.97† | 0.011 | 29.78 ± 1.22 | 28.48 ± 0.91 | 26.30 ± 0.82† | 0.011 |
| PUFAs | | | | | | | | |
| Linoleic acid (18:2) | 59.10 ± 4.84 | 48.47 ± 3.63 | 44.44 ± 3.25† | 0.017 | 13.54 ± 0.63 | 13.29 ± 0.47 | 13.16 ± 0.43 | NS |
| Linolenic acid (18:3) | 2.11 ± 0.22 | 1.68 ± 0.16 | 1.49 ± 0.14† | 0.021 | 0.47 ± 0.03 | 0.45 ± 0.02 | 0.42 ± 0.02 | NS |
| Arachidonic acid (20:4) | 1.95 ± 0.18 | 1.60 ± 0.14 | 1.28 ± 0.12* | 0.003 | 0.46 ± 0.05 | 0.48 ± 0.03 | 0.42 ± 0.03 | NS |
| EPA (20:5) | 0.45 ± 0.04 | 0.37 ± 0.03 | 0.33 ± 0.03† | 0.017 | 0.10 ± 0.01 | 0.10 ± 0.01 | 0.10 ± 0.01 | NS |
| DHA (22:6) | 0.33 ± 0.03 | 0.25 ± 0.02‡ | 0.21 ± 0.02* | 0.0004 | 0.08 ± 0.01 | 0.08 ± 0.01 | 0.07 ± 0.01 | NS |
| Total PUFAs | 63.94 ± 5.23 | 52.37 ± 3.92 | 47.70 ± 3.52* | 0.014 | 14.65 ± 0.69 | 14.40 ± 0.52 | 14.15 ± 0.47 | NS |
| Total free FAs | 418.91 ± 28.71 | 357.31 ± 21.34 | 325.53 ± 19.29* | 0.009 | | | | |

Data are means ± SE in umol/l or % of total FAs. *P < 0.01 vs. GDM; †P < 0.05 vs. GDM; ‡P < 0.05 vs. impaired GCT non-GDM; §P < 0.01 vs. impaired GCT non-GDM.

**Table 3—Serum FAs (μmol/l) in three groups stratified by overweight or obesity***

| | BMI ≥25 kg/m² | | | BMI <25 kg/m² | | |
| --- | --- | --- | --- | --- | --- | --- |
| | GDM | Impaired GCT non-GDM | Control subjects | GDM | Impaired GCT non-GDM | Control subjects |
| $n$ | 10 | 36 | 53 | 39 | 44 | 45 |
| Entry | | | | | | |
| SFAs | 227.02 ± 16.27 | 244.13 ± 15.32 | 206.65 ± 14.83 | 243.50 ± 32.62 | 196.37 ± 16.60† | 184.91 ± 14.47‡ |
| MUFAs | 116.07 ± 14.36 | 133.66 ± 13.52 | 108.79 ± 13.91 | 105.37 ± 28.78 | 73.92 ± 14.65‡§ | 73.41 ± 12.78‡§ |
| PUFAs | 58.09 ± 6.66 | 66.87 ± 6.27 | 56.17 ± 6.07 | 59.78 ± 13.35 | 40.37 ± 6.79‡ | 42.17 ± 5.92‡ |
| Total free FAs | 401.85 ± 34.15 | 444.83 ± 32.16 | 371.59 ± 31.15 | 407.53 ± 68.51 | 306.86 ± 34.43‡ | 299.86 ± 30.41‡§ |
| Third trimester | | | | | | |
| SFAs | 235.71 ± 16.80 | 197.31 ± 14.60 | 189.90 ± 14.21 | 198.02 ± 28.56 | 200.34 ± 15.21§ | 169.29 ± 13.33‖ |
| MUFAs | 149.80 ± 14.30 | 118.81 ± 12.42 | 113.78 ± 12.10 | 85.40 ± 24.31 | 102.61 ± 12.92† | 75.90 ± 11.34‡‖¶ |
| PUFAs | 69.47 ± 6.31 | 56.07 ± 5.48 | 55.98 ± 5.33 | 45.80 ± 10.72 | 49.84 ± 5.7§ | 39.95 ± 5.00†‖¶ |
| Total free FAs | 455.10 ± 35.00 | 372.28 ± 30.39 | 359.66 ± 29.59§ | 329.41 ± 59.47 | 351.74 ± 31.1§ | 285.17 ± 27.76†‖ |

Data are means ± SE. *Models were adjusted for age, ethnicity, parity, and cigarette smoking; †$P < 0.05$ vs. impaired GCT non-GDM with BMI ≥25 kg/m²; ‡$P < 0.01$ vs. impaired GCT non-GDM with BMI ≥25 kg/m²; §$P < 0.05$ vs. GDM with BMI ≥25 kg/m²; ‖$P < 0.01$ vs. GDM with BMI ≥25 kg/m²; ¶$P < 0.05$ vs. control subjects with BMI ≥25 kg/m².

was not different from lean control subjects (19). We found that at entry to care, overweight or obese women with impaired GCT non-GDM had significantly higher concentrations of SFAs, MUFAs, PUFAs, and total FAs as compared with lean impaired GCT non-GDM and lean control subjects, whereas GDM women with BMI ≥25 kg/m² had the highest FAs during the third trimester. These data suggest that in addition to a mild hyperglycemia, gravidae with impaired GCT non-GDM, especially in those who are overweight or obese, have abnormalities in fat metabolism. It is likely that, in these women, increased insulin resistance gives rise to a reduction in insulin suppression of lipolysis as it does in GDM (3,21).

Dietary fat intake, especially the essential FAs, which cannot be synthesized by humans, are particularly important in pregnancy, because the essential FAs required by the fetus must come from the mother across the placenta (1). They play critical roles in the development of fetal membrane structures and oxidative substances (2). Data on relation of dietary fat or FA intake to GDM remain controversial. Early gestational intakes of total fat, SFAs and PUFAs do not seem to be associated with risk of GDM (22). Data suggest that intake of SFAs or PUFAs was decreased or that there was no difference during the third trimester between GDM women and control subjects (8–9). We used the mean of three 24-h recalls to evaluate dietary nutrient intake and found a significant graded trend in total PUFAs, linoleic acid, and DHA intake, which was the lowest in the GDM group and highest in the control subjects, with the impaired GCT non-GDM group falling in the middle ($P < 0.05$ for all) (Table 4). The reverse was observed with SFA, palmitic acid, and stearic acid intake, in agreement with a prior report (23).

Sun et al. (24) observed a moderate to strong correlation between n-3 FAs of marine origin in erythrocytes and corresponding dietary intake. Others reported correlations between dietary intake of linolenic and linoleic acids and plasma concentrations in fasting whole blood, plasma, or adipose tissue (25). We found a moderate correlation between some of the essential fatty acids—serum total PUFAs and dietary PUFAs—in each group ($P < 0.05$) but did not find significant correlations with other FAs. It is known that SFAs and MUFAs can be synthesized endogenously, thus correlations between tissue levels and diet would not be anticipated (9,24–25). In addition, the distribution of FAs (including PUFAs) could vary substantially in tissues because of metabolic changes and different physiologic roles of FAs (25). Larger samples size may be required to detect small to

**Table 4—Dietary fat/FA intake (g/day) by glycemic group***

| | GDM | Impaired GCT non-GDM | Normal GCT | $P$ for trend |
| --- | --- | --- | --- | --- |
| Total fat | 84.16 ± 2.70 | 86.66 ± 7.10 | 86.80 ± 1.91 | NS |
| Total fat percentage of energy | 32.70 ± 1.00 | 32.69 ± 0.78 | 34.14 ± 0.70 | NS |
| Carbohydrate | 294.54 ± 8.52 | 288.01 ± 6.57 | 287.65 ± 5.96 | NS |
| Protein | 91.14 ± 3.83 | 93.46 ± 2.96 | 93.25 ± 2.68 | NS |
| Mysteric acid (14:0) | 3.25 ± 0.18 | 3.03 ± 0.14 | 3.02 ± 0.12 | NS |
| Palmitic acid (16:0) | 18.35 ± 0.28 | 17.61 ± 0.21‡ | 17.36 ± 0.19† | 0.005 |
| Stearic acid (18:0) | 8.64 ± 0.29 | 8.22 ± 0.22 | 7.86 ± 0.20‡ | 0.027 |
| Total SFAs | 34.14 ± 0.79 | 32.63 ± 0.61 | 32.04 ± 0.55‡ | 0.037 |
| Palmitoleic acid (16:1) | 2.08 ± 0.08 | 1.85 ± 0.06‡ | 1.84 ± 0.05‡ | 0.028 |
| Oleic acid (18:1) | 29.95 ± 0.41 | 29.79 ± 0.32 | 29.60 ± 0.29 | NS |
| Total MUFAs | 32.84 ± 0.42 | 32.41 ± 0.32 | 32.23 ± 0.29 | NS |
| Linoleic acid (18:2) | 10.58 ± 0.69 | 12.63 ± 0.53‡ | 13.25 ± 0.48† | 0.003 |
| Linolenic acid (18:3) | 1.21 ± 0.10 | 1.34 ± 0.08 | 1.34 ± 0.07 | NS |
| Arachidonic acid (20:4) | 0.15 ± 0.02 | 0.17 ± 0.02 | 0.18 ± 0.01 | NS |
| EPA (20:5) | 0.02 ± 0.01 | 0.03 ± 0.01 | 0.04 ± 0.01 | NS |
| DHA (22:6) | 0.05 ± 0.01 | 0.07 ± 0.01 | 0.09 ± 0.012‡ | 0.021 |
| Total PUFAs | 12.15 ± 0.78 | 14.40 ± 0.60‡ | 15.03 ± 0.54† | 0.005 |

Data are means ± SE. *FA intake was adjusted for energy and total fat intake; total fat, carbohydrate, and protein intakes were adjusted for total energy intake; †$P < 0.01$ vs. GDM; ‡$P < 0.05$ vs. GDM. NS, not significant.

moderate correlations for individual PUFAs.

In summary, our study suggests that the absolute concentrations, as opposed to relative proportions, of fasting serum FAs were elevated not only in women with GDM but also in gravidae with less severe hyperglycemia. In addition, gravidae with impaired GCT, non-GDM, and especially those who were overweight or obese have abnormalities in fat metabolism that parallel their hyperglycemia. The differences are largely dependent on maternal adiposity. Thus, reducing pregravid weight and altering diet to include more polyunsaturated fat and less saturated fat might reduce circulating FAs, decrease insulin resistance and inflammation, and lower future maternal risk of type 2 diabetes and cardiovascular disease.

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