# Dietary Variables and Glucose Tolerance in Pregnancy

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OBJECTIVE — To investigate relationships between dietary macronutrient intakes and glucose tolerance in pregnancy.

RESEARCH DESIGN AND METHODS — Nulliparous pregnant Chinese women diagnosed with gestational diabetes mellitus (GDM) ($n = 56$) were compared to age-, gestational age–, height-, and parity-matched groups with normal glucose tolerance ($n = 77$) and glucose intolerance (IGT) ($n = 38$) based on the results of an oral glucose tolerance test (National Diabetes Data Group criteria), performed between 24 and 28 weeks of pregnancy. A 24-h recall dietary assessment was also obtained at the time of screening.

RESULTS — Subjects with IGT and GDM were significantly heavier (66.1 ± 1.4 and 68.6 ± 1.2 kg, respectively, mean ± SEM) ($P < 0.0001$) than the normal group (61.2 ± 1.8 kg) and had a higher BMI. Overall energy intake was similar between groups, as were the intakes of each macronutrient (%kcal). However, there was a highly significant reduction in polyunsaturated fat intake in the IGT and GDM groups whether expressed as %kcal, % of total fat, or fat kcal. This effect was independent of body weight or BMI whether assessed by ordinal logistic regression or by analysis of a weight- and BMI-matched subgroup of the subjects ($P = 0.002$ for %kcal; $n = 47$ normal, 26 IGT, and 43 GDM subjects). In logistic regression analysis of the complete data set, increased body weight ($P < 0.0001$) and decreased polyunsaturated fat intake ($P = 0.0014$) were both independent predictors of glucose intolerance (IGT and GDM), as were increased body weight and a low dietary polyunsaturated to saturated fat ratio.

CONCLUSIONS — Increased polyunsaturated fat intake is associated with a reduced incidence of glucose intolerance during pregnancy. This finding may have major implications for dietary management of women with or at risk of developing GDM.

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Pregnancy is a stressor on the glucose regulatory system that exposes individuals at risk of type 2 diabetes. During normal pregnancy, glucose tolerance deteriorates in all women and 2–7% develop gestational diabetes mellitus (GDM) (1). While in the postpartum glucose metabolism generally returns to normal, women with GDM have a high risk of developing overt diabetes, mainly type 2 diabetes, later in life (2).

Dietary intervention is in the front line of management of type 2 diabetes and of GDM (3). Although there is a large body of work related to the dietary management of type 2 diabetes, there is still controversy over the optimal balance between carbohydrate and fat, and in turn, carbohydrate and fat subtypes (4,5). There is less information specifically related to the dietary management of GDM. Major et al. (6) have recently compared glucose metabolism during pregnancy and perinatal outcome in two groups of women with GDM placed on either a low- (<42% of calories) or high- (45–50%) carbohydrate diet. The group of women with a low-carbohydrate intake had lower postprandial glucose levels and reduced incidence of insulin treatment associated with significantly better perinatal outcomes (6). Concerning a separate but possibly related issue, recently Moses et al. (7) assessed the usual dietary intake in a group of women with or without recurrence of GDM. They showed that the group with recurrence of GDM had a higher overall intake of fat (as a percentage of energy) compared with those without recurrence of GDM. Interestingly, there was a trend for those without recurrence to have higher polyunsaturated and lower saturated fat intakes. Thus, recent studies on the influence of dietary macronutrients on GDM point to a beneficial effect of moderate increases in fat consumption (reduced carbohydrate) on glycemic control and perinatal outcomes, but a detrimental effect of increased fat intake on the recurrence of GDM. It seems clear that there is a need for a better understanding of the ways in which dietary macronutrients may influence the development and severity of GDM. In particular, the role of fat subtypes needs to be addressed in view of the substantial though varied information on the importance of fat quality in type 2 diabetes and related conditions (4). This study aimed to investigate relationships between dietary macronutrient intakes, particularly of fat subtypes, and the occurrence of glucose intolerance (IGT) and GDM in a large series of consecutive pregnancies in a Chinese urban population.

## RESEARCH DESIGN AND METHODS

— A total of 8,002 consecutive pregnant women presenting to The International Peace Maternity and Child Health Hospital of China Welfare Institute

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Abbreviations: GDM, gestational diabetes mellitus; IGT, glucose intolerance; NGT, normal glucose tolerance; OGTT, oral glucose tolerance test; P:S, polyunsaturated:saturated fat ratio; PUFA, polyunsaturated fatty acid.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

in Shanghai in the period September 1996 to September 1998 had a routine screening test for GDM at 24–28 weeks of gestational age. Gestational age was calculated from date of last menses, and most pregnant women had an ultrasound examination at the first trimester to confirm the age of gestation. At the same visit, these women attended a nutrition consulting clinic where they were interviewed by dietitians trained in assessing usual food patterns. The interview began with a recall of foods consumed the previous day, starting with breakfast. Portion sizes were described and then compared with food models and other support materials. Subjects were then asked if this pattern was usually followed throughout the week and if traditional recipes and cooking methods were followed. From this history the dietitian constructed a list of the amounts of foods consumed, which were then entered into a software program (Zhong Wen Huang, Shanghai Medical University, 1998) containing the Chinese nutrient database (Nutritional Evaluation and Dietary Prescription for Pregnant Women). All foods consumed by the study sample were contained in the database, as was information on all the nutrient variables of interest. The dietary methodology has been validated in previous research comparing interview data with weighed food records conducted in the homes of subjects. Reliability of the method was also assessed by conducting repeat interviews with one-third of the sample and comparing results (8). We performed a retrospective analysis of glucose tolerance and nutritional data from a sample of women extracted from this series according to criteria described below. This study was approved by the Human Ethics Committee of the University of Wollongong and by the Director of the International Peace Maternity and Child Health Hospital of the China Welfare Institute.

The definition of GDM was based on the recommendations of the National Diabetes Data Group (9) and involved a standard screening test for GDM using the 50-g 1-h oral glucose challenge. A value of $>7.8$ mmol/l in venous plasma indicated the need for a full diagnostic oral glucose tolerance test (OGTT). The 100-g oral glucose tolerance test was performed in the morning after an 8-h minimum fast. The time interval between screening test and OGTT was 1–2 weeks. Venous plasma glucose was measured in the fasting state and at 1, 2, and 3 h. GDM was diagnosed if $\geq 2$ venous plasma glucose concentrations met or exceeded the following values: fasting, 5.8 mmol/l; 1 h, 10.6 mmol/l; 2 h, 9.2 mmol/l; and 3-h, 8.1 mmol/l. For the purposes of analysis we categorized individuals as having IGT if only one venous plasma glucose concentration met or exceeded these values.

Height and weight were measured at the time of screening and BMI was calculated as weight in kilograms divided by height in meters squared.

Subject selection for this study was based on a sequential screening of hospital records from September 1996 and September 1998 for cases that matched our entry criteria (nulliparous women, screened for GDM at 24–28 weeks of gestational age and with a complete 24-h recall dietary assessment). This procedure identified 56 women with GDM who met these criteria. The remaining records were then screened sequentially for women with IGT or normal glucose tolerance (NGT) who met the inclusion criteria and who were age-matched to the GDM group. Age matching was achieved by setting recruitment targets for four age bands in proportion to the distribution of ages in the group of GDM women. Our aim was to select approximately equal numbers of women in the three groups resulting in a recruitment target of ~170 women divided among the three groups. However, only 38 women with IGT who met our inclusion criteria were identified. We therefore selected a total of 77 women with normal glucose tolerance, resulting in a total sample of 171 women for analysis. The resulting groups were well matched for age, gestational age at screening, parity, and height.

Relationships between dietary variables and diagnostic category (NGT, IGT, and GDM) were assessed initially by one-way ANOVA in the complete data set and also in a subset weighing 60–80 kg who were matched between categories for age, height, and BMI; differences between groups were localized using Scheffe's post hoc test. Selected relationships were further examined using either ordinal logistic regression, with diagnostic category the dependent variable (NGT = 0, IGT = 1, GDM = 2) and individual dietary variables with either body weight or BMI as independent variables, or by partial correlation analysis of the natural logarithm of the areas under the glucose curve during the OGTT against body weight and dietary intake measures. All analyses were performed using JMP software (version 3.1.6.2, SAS Institute, Cary, NC). All summary data are presented as means ± SEM.

**RESULTS** — The three groups of subjects were well matched with respect to age (NGT 30 ± 1, IGT 30 ± 1, and GDM 31 ± 1 years), gestational age (NGT 27.5 ± 0.2, IGT 27.7 ± 0.4, and GDM 27.0 ± 0.4 weeks), and height (NGT 160 ± 1, IGT 160 ± 1, GDM 161 ± 1 cm); however, IGT (66.1 ± 1.4 kg) and GDM (68.6 ± 1.2 kg) subjects were significantly heavier than the normal pregnant group (61.2 ± 0.8 kg) and had higher BMI (Table 1). Table 1 also shows the reported dietary intake data for the three groups of women. Overall energy intake was similar between groups, as were the intakes of carbohydrate (%kcal), protein (% cal), and fiber (g). However, there was a tendency for a reduced fat intake (as %kcal) in the IGT and GDM groups, which was formally significant in the BMI-matched subset ($P$ = 0.05 by ANOVA). This group effect was much more pronounced when fatty acid subtypes were analyzed; particularly striking is the reduction, identified by ANOVA, in polyunsaturated fat intake in the IGT and GDM groups, which was present in both the full data set and the BMI-matched subgroup irrespective of the method of expression of the data (group effect, all subjects: percentage of fat, $P$ = 0.01; %kcal, $P$ = 0.003; fat kcal $P$ = 0.004; BMI-matched: percentage of fat, $P$ = 0.02; %kcal, $P$ = 0.002; fat kcal, $P$ = 0.004). A significant group effect was also seen on saturated fat intake (as percentage of fat, all subjects, $P$ = 0.03; weight-matched, $P$ = 0.03); however, this effect was not present when data were expressed as either %kcal or fat kcal. Scheffe's post hoc tests revealed significant difference between the NGT and GDM groups (Table 1), again regardless of how the data were expressed. Similarly, there was a suggestion of reduced monounsaturated fat intake in the BMI-matched IGT and GDM groups when expressed as %kcal ($P$ = 0.05) but this effect was not present in the full data set nor when the reported intake data was expressed as percentage of total fat or as kcal. As would be expected from the above data, IGT and GDM were associated with a significantly reduced polyunsaturated:saturated (P:S) ratio in both the full (ANOVA group effect, $P$ = 0.03) and weight-matched ($P$ = 0.02) data sets, with NGT and GDM subjects differing on an individual group basis.

Table 1—*Nutritional data obtained by 24-h recall dietary assessment for pregnant women with NGT, IGT, and GDM*

| | All subjects ($n$ = 171) | | | BMI-matched ($n$ = 116) | | |
|---|---|---|---|---|---|---|
| | Normal | IGT | GDM | Normal | IGT | GDM |
| $n$ | 77 | 38 | 56 | 47 | 26 | 43 |
| BMI (kg/m$^2$) | 24.2 ± 0.31 | 25.7 ± 0.5* | 26.4 ± 0.4*† | 25.4 ± 0.3 | 26.1 ± 0.4 | 26.2 ± 0.4 |
| Total energy (kcal) | 2,133 ± 42 | 2,223 ± 75 | 2,134 ± 61 | 2,135 ± 54 | 2,304 ± 99 | 2,156 ± 72 |
| Fat (%kcal) | 32.4 ± 0.8 | 30.6 ± 1.0 | 30.0 ± 1.0 | 33.2 ± 1.2 | 30.4 ± 1.3 | 29.1 ± 1.3*† |
| Protein (%kcal) | 16.3 ± 0.3 | 17.2 ± 0.5 | 16.2 ± 0.4 | 16.4 ± 0.4 | 17.1 ± 0.7 | 16.3 ± 0.5 |
| Carbohydrate (%kcal) | 51.7 ± 0.9 | 52.3 ± 1.3 | 53.8 ± 1.2 | 51.1 ± 1.2 | 52.6 ± 1.6 | 54.6 ± 1.5 |
| Fat profile (% total fat) | | | | | | |
| Polyunsaturated | 31.6 ± 0.7 | 29.5 ± 1.0 | 28.2 ± 0.9*† | 31.7 ± 0.9 | 30.0 ± 1.2 | 28.1 ± 1.0*† |
| Monounsaturated | 26.3 ± 0.6 | 28.8 ± 1.0 | 25.7 ± 0.8 | 27.2 ± 0.8 | 28.1 ± 1.2 | 26.0 ± 0.9 |
| Saturated | 42.1 ± 1.0 | 41.8 ± 1.6 | 46.1 ± 1.4*† | 41.1 ± 1.3 | 41.9 ± 1.9 | 45.9 ± 1.3*† |
| Fat profile (% total kcal) | | | | | | |
| Polyunsaturated | 10.2 ± 0.3 | 8.9 ± 0.4 | 8.5 ± 0.4*† | 10.5 ± 0.5 | 9.0 ± 0.5 | 8.2 ± 0.5*† |
| Monounsaturated | 8.6 ± 0.3 | 8.7 ± 0.4 | 7.8 ± 0.4 | 9.1 ± 0.5 | 8.4 ± 0.5 | 7.6 ± 0.4*† |
| Saturated | 13.7 ± 0.5 | 13.0 ± 0.8 | 13.8 ± 0.6 | 13.7 ± 0.7 | 13.0 ± 1.0 | 13.3 ± 0.7 |
| Fat profile (kcal) | | | | | | |
| Polyunsaturated | 218 ± 8.9 | 195 ± 9.2 | 177 ± 8.4*† | 227 ± 13.1 | 204 ± 11.7 | 173 ± 9.6*† |
| Monounsaturated | 182 ± 7.7 | 192 ± 10.2 | 163 ± 8.6 | 194 ± 10.9 | 193 ± 12.5 | 162 ± 9.5 |
| Saturated | 291 ± 11.3 | 288 ± 22.2 | 291 ± 14.1 | 291 ± 14.8 | 297 ± 28.9 | 282 ± 13.6 |
| P:S ratio | 0.81 ± 0.04 | 0.77 ± 0.05 | 0.67 ± 0.04*† | 0.83 ± 0.05 | 0.77 ± 0.06 | 0.65 ± 0.04*† |
| Other nutrients | | | | | | |
| Fiber (g) | 14.1 ± 0.8 | 14.4 ± 1.3 | 13.2 ± 0.7 | 13.5 ± 1.0 | 15.7 ± 1.7 | 13.4 ± 0.8 |

Data are $n$ or means ± SEM. *Significantly different from NGT pregnant group (Scheffe's $F$ test, $P < 0.05$); †significant effect across all groups by analysis of variance ($P < 0.05$).

To further investigate the body weight–fat subtype relationships, we investigated the dependence of glucose tolerance status on measures of polyunsaturated fat intake and body weight or BMI in the complete data set using ordinal logistic regression (see RESEARCH DESIGN AND METHODS). In all analyses, BMI or body weight were approximately equivalent independent predictors of glucose tolerance status, such that higher body weight or BMI were associated with IGT and GDM. Increased polyunsaturated fat intake (as %kcal or kcal) were significantly protective against IGT and GDM independently of BMI or body weight. These analyses are illustrated in Fig. 1, where the percentages of subjects with IGT or GDM are plotted against tertiles of body weight and polyunsaturated fat intake (as kcal). Across all weight tertiles, the lower, middle, and upper polyunsaturated fat intake tertiles were associated with 70%, 54%, and 44% incidence, respectively, of abnormal glucose tolerance. Although there appears in Fig. 1 to be a tendency for differences in the effect of polyunsaturated fat across weight tertiles, with no effect in the lowest weight tertile and an increased minimal effective dose in the highest tertile, there were no statistically significant interactions between body weight and polyunsaturated fat intake in any analyses. Similar results were obtained if the P:S ratio was used instead of polyunsaturated fat intake, with an association between increased P:S ratio ($P$ = 0.03) and a decrease in IGT. Similar results were also obtained using partial correlation analysis of area under the glucose curve during the OGTT against body weight and polyunsaturated fat intake (kcal/day). Both body weight (partial $r$ = 0.24, $P$ = 0.003) and polyunsaturated fat intake (partial $r = -0.20$, $P$ = 0.02) showed significant independent relationships with glucose area such that increased weight and decreased polyunsaturated fat intake were each predictive of a deterioration in glucose tolerance (IGT and GDM).

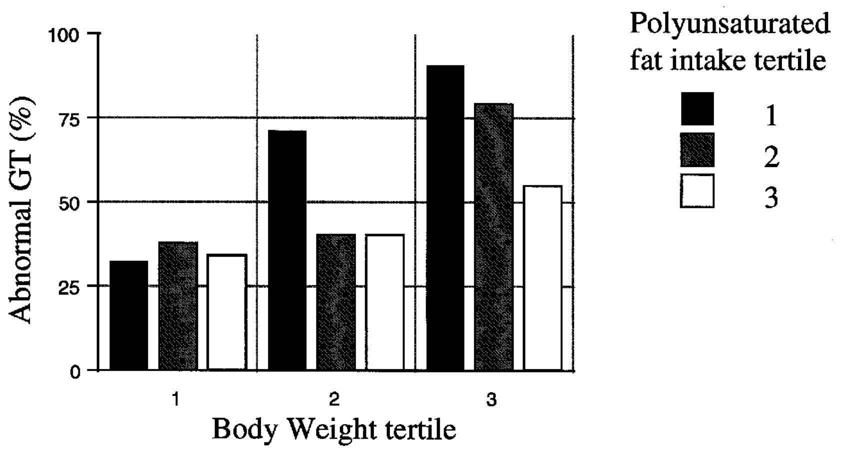

Figure 1—*Polyunsaturated fat intake and abnormal glucose tolerance: relationships between body weight, dietary polyunsaturated fat intake, and abnormal glucose tolerance (IGT+GDM). Subjects were assigned to tertiles (1 = lowest) of body weight and polyunsaturated fat intake (kcal/day). Polyunsaturated fat intake had no apparent effect on the low incidence of abnormal glucose tolerance in the lowest body weight tertile, but was negatively associated with abnormal glucose tolerance in the higher body weight tertiles.*

For each of the NGT, IGT, and GDM groups, soy oil contributed ~67% of the total polyunsaturated fatty acid (PUFA) intake, with soybeans, pork, and eggs contributing lesser amounts. Fish contributed to only ~1% of the total PUFA intake in all groups. When reported intakes of the different fat subtypes were correlated across individuals, monounsaturated and polyunsaturated intakes were closely related ($r$ = 0.69, $P < 0.0001$). In contrast, saturated fat intake was only modestly related to monounsaturated ($r$ = 0.28, $P < 0.001$) and to polyunsaturated ($r$ = 0.25, $P <$ 0.001) fat intake.

There were no significant dietary correlates of body weight or BMI variation within these subjects. In particular, there were no significant relationships between BMI (or body weight) and energy intake, total fat intake, or saturated fat intake ($r <$ 0.11, $P > 0.16$).

**CONCLUSIONS** — The present study investigated in a cross-sectional manner the relationship between diet and glucose tolerance in pregnancy. The salient results were that glucose intolerance and gestational diabetes were associated as expected with increased body weight and BMI, but unexpectedly and independently were associated with a reduced intake of polyunsaturated fats.

The study did not suffer from many of the measurement problems associated with dietary studies in other settings, largely because there was less variation in the food supply and traditional eating patterns were still the norm. For example, only two types of oil were used, soybean and vegetable, and the vast majority of people used soybean oil. Food patterns were relatively stable, that is, subjects rarely ate out of the home, rice remained a staple item for each day, protein-rich foods invariably comprised pork and fish, and the greatest variation in consumption was seen in the use of vegetables and condiments, such as soy sauce. Neither of these last two food items had a large impact on the study's nutritional variables. Because of the smaller range of foods usually consumed, the database was also quite adequate for analyzing nutrient profiles. With changes to the local food supply and the introduction of more Western-style takeaway restaurant foods, however, this may not remain the case. One of the limitations of our study was that weekend variation was less likely to be detected, but at this stage it was not considered to be largely influential on the overall results.

The present results are in pleasing congruence with the emerging literature on fat subtypes, type 2 diabetes, and obesity (4). Saturated fat intake is associated with increased insulin resistance measures and increased prevalence of diabetes and obesity in population studies. In contrast, as in the current results, polyunsaturated fat intake is either neutral or protective in relation to these variables. In the current study we did not find a relationship between saturated fat intake and obesity. This result may be consistent with underreporting of fat by the heavier subjects. However, underreporting is an unlikely explanation for the apparent protective effect of polyunsaturated fat intake, given that when the analyses of polyunsaturated fat intake were performed with weight matched between groups, the relationships were not affected.

Unfortunately, our nutrient database was not capable of separating n-6 and n-3 PUFAs; thus the data do not speak directly to the controversial issue of n-6 to n-3 ratio (4). The analysis of food sources of PUFA, however, indicates little likelihood of a difference between groups in n-6:n-3 ratio, because the same foods in similar proportion accounted for the PUFA intake in all groups.

The apparently beneficial effects of monounsaturated fatty acid intake, as exposed in the weight-matched analysis, was interesting. Short-term intervention studies have shown improved glucose control on diets emphasizing high monounsaturated fat intake compared with a high-carbohydrate diet (10), whereas population-based studies have shown either neutral or adverse effects of monounsaturated fat intake on measures of insulin action and glycemic control (11). Those population studies were done in countries where the monounsaturated fat intake was largely in association with saturated fat intake in meat and dairy products. In our study population, however, soy oil was a major contributor to both monounsaturated and polyunsaturated fat. Apparent inconsistencies in the literature on monounsaturated fats may relate to different modes and correlates of consumption in different populations and cultures.

Although these data and our previous observations of dietary relationships with recurrence of GDM (7) both point to an influence of dietary fat intake, the two studies differ in their specific findings and in their design. Specifically, in the present study, with diet measured at the time of diagnosis, reduced polyunsaturated intake was the strongest predictor of IGT. In contrast, with the diet measured retrospectively (7), recurrence of GDM appeared to be related to increased total fat intake. There were, however, nonsignificant trends toward higher saturated fat and lower polyunsaturated fat consumption in the group with recurrence. It therefore seems possible that these two results may be consistent with each other, with apparent differences perhaps arising from differences in the ways that fat subtypes are incorporated into the diets in the two different populations. In the present study, PUFA intake was not associated with saturated fat intake, whereas in the population studied by Moses et al. (7), there is an association between PUFA and saturated fat intakes similar to that described in European populations (11). Together with differences in design and methods of dietary assessment, this differing aspect of PUFA intake could account for differences in the detailed findings of the two studies.

Individuals with GDM or IGT were heavier than the normal control subjects on weight taken at GDM screening. We did not have pre-gravid weight; however, there were no differences between groups in birth weight of offspring. Neither total caloric intake nor percentage or total fat intake appeared to account for the body weight differences. If anything, fat intake was lower in the heavier women. In this context it is interesting that saturated fat intake is associated with increased adiposity while polyunsaturated fat intake may even be protective, a pattern consistent with the present results. This literature and the potential mechanistic underpinnings of these observations have been reviewed recently (12).

Of course, we have measured food intake as associated with pregnancy. It is of interest for future work to determine if this pattern occurs as well in the nonpregnant state.

The present results are relevant to the question of carbohydrate–fat dietary balance. The reasoning behind reducing fat intake is the assumption that this will reduce body weight. As discussed, this assumption may not hold in at least the present study group and dietary fat quality may be much more important. In contrast to the proponents of a low-fat approach, the argument for reducing carbohydrate intake (and relaxing mono- and polyunsaturated fat intake guidelines) is that there is, via both insulin resistance and impaired insulin secretion, a major problem in handling carbohydrate during pregnancy. Thus, the present results are consistent with the observations of Major et al. (6), in that better outcomes were associated with a higher fat intake.

In summary, a higher intake of polyunsaturated fats resulting in a dietary fatty acid profile with a high P:S ratio appeared to protect against IGT and GDM. This result may have major implications for dietary management of women with, or at risk of, developing GDM. An intervention study aimed at increasing the dietary P:S ratio with concomitant antioxidant supplementation in pregnant women would appear warranted.

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