Decreased Insulin Requirement and Improved Control of Diabetes in Pregnant Women Given a High-Carbohydrate, High-Fiber, Low-Fat Diet

DENISE NEY, DOROTHY R. HOLLINGSWORTH, AND LARRY COUSINS

Five quantitative measures of diabetic control [HbA_{1c} determinations, mean 24-h plasma glucose values, mean amplitude of glycemic excursions (MAGE), mean 24-h urinary loss of glucose, and daily exogenous insulin requirement] were compared in 20 pregnant women who were randomly assigned to either a high-carbohydrate, high-fiber diet (HCF) that was low in fat or to a control diet commonly prescribed for pregnancy. Eleven women followed the HCF diet and nine subjects, the control diet, from baseline entry into the study until delivery. Dietary compliance was excellent, with 78% of the women in each group rated good or acceptable. HbA_{1c} values were similar in both groups at baseline (HCF: 11.0 ± 0.5% versus control: 10.2 ± 0.6%), with no different predelivery values (8.6 ± 0.4%). Mean 24-h plasma glucose levels improved in patients on both diets, with lower values noted in the HCF group at predelivery. MAGE values and standard deviations did not differ significantly in the two groups. Glycosuria decreased markedly in both dietary groups, but differences between groups were not significant. Improved control of diabetes on the HCF diet was achieved with significantly lower increments in insulin dose during gestation (HCF baseline: 32 ± 8 U/24 h to 66 ± 10 U/24 h versus control baseline: 27 ± 9 U/24 h to 108 ± 12 U/24 h, $P < 0.03$). Outcome of pregnancy did not differ in the two groups of patients, but women on the HCF diet gained less weight than those on the control diet (26 ± 3 lb versus 35 ± 5 lb, $P < 0.05$). Mean newborn gestational age was similar in the two groups (HCF: 37.2 ± 0.7 wk versus control: 36.5 ± 0.7 wk). Mean birth weight in infants of HCF mothers was 3809 ± 248 g versus 3313 ± 278 g in infants of control mothers ($P < 0.05$). We conclude that although marked improvement of diabetic control occurred on both regimens, patients on the HCF diet achieved better control of diabetes with significantly lower increments in exogenous insulin. DIABETES CARE 5: 529–533, SEPTEMBER–OCTOBER 1982.

Diabetes in pregnant women poses special problems since fetal growth and development occur in a setting of abnormal composition of metabolic fuels.[1] The long-term implications of the consequent abnormal fetal diet are unknown. Dietary recommendations for diabetic pregnant women have varied remarkably during the past century, as described in our recent historical review.[2] There has been renewed interest in the past few years in both the carbohydrate and dietary fiber content of the diabetic diet for nonpregnant patients with diabetes.

Kiehm et al.[3] have reported the beneficial effects of a high-carbohydrate, high-fiber, and low-fat diet on hyperglycemic diabetic men. Additional observations by others[4–10] have demonstrated decreased postprandial hyperglycemia and lower insulin requirements associated with a high-carbohydrate, high-fiber diet. Crapo et al.[11] and Coulston et al.[12] have shown that postprandial hormonal responses vary with the ingestion of different types of complex carbohydrates.

In this study we compared the effects of a control diet commonly prescribed for pregnancy with those of a high-carbohydrate, high-fiber, low-fat (HCF) diet on various quantitative criteria of diabetic control during pregnancy.

MATERIALS AND METHODS

Patients. Twenty diabetic pregnant women, 10 with type I insulin-dependent diabetes (IDDM) and 10 with type II non-insulin-dependent diabetes (NIDDM), were referred to the High Risk Obstetrics Clinic of the University of California, San Diego. This patient population was racially heterogeneous (Hispanic, black, Caucasian); most women were from a low socioeconomic class with multiple social, emotional, and economic problems. Type II subjects were older (32.2 ± 2.1 yr versus 26.6 ± 1.4 yr, $P < 0.02$) and heavier (body mass index: 34.5 ± 2.1 kg/M2 versus 21.8 ± 0.8 kg/M2, $P < 0.0001$) than type I patients.

Protocol. All patients were hospitalized in the UCSD School of Medicine General Clinical Research Center (GCRC) at 10–30 wk gestation for an 8-day baseline evaluation and for metabolic studies and intensive dietary education. Written informed consent was obtained from each subject. On the morning following admission, an intravenous catheter with a heparin lock was inserted in a wrist vein. This permitted normal activity and was also satisfactory for blood sampling during hours of sleep. Hourly blood samples were obtained throughout a 24-h period for determinations of plasma glucose. Twenty-four-hour collections of urine were obtained daily in four fractions (0800–1200, 1200–1600, 1600–2000, and 2000–0800 h).

Plasma and urinary concentrations of glucose were measured by an automated glucose-oxidase method. MAGE values (mean amplitude of glycemic excursions) were determined by the method of Service et al.[13] HbA_{1c} determinations were performed using a column-exchange resin kit from Isolab (Isolab Inc., Akron, Ohio). During the initial 24-h study, each patient received her usual dose of insulin and a 2000-kcal control meal pattern with a standardized nutrient distribution, including three meals (at 0800, 1200, and 1700 h) and three between-meal snacks (at 1000, 1500, and 2200 h).

Following the baseline 24-h study the patients were randomly assigned to the control (6 type I and 3 type II patients) or HCF (4 type I and 7 type II patients) diet and each subject then followed the same diet throughout pregnancy. Dietary education was given during each day of hospitalization.

After discharge from the GCRC, each patient was seen weekly in the High Risk Obstetrics Clinic for medical supervision of pregnancy, nutritional counseling, and evaluation of dietary compliance. Glucose determinations were made on plasma obtained 2 h after breakfast, and quantitative urinary glucose values were determined in the four fractions from a 24-h collection of the previous day. Decisions regarding management strategy and insulin adjustment were made weekly following the clinic visit by assessment of clinical and laboratory data at a diabetes team conference attended by an obstetrician-perinatologist, internist, resident in obstetrics, nutritionist, and nurse-physician assistant. All patients were contacted the same day by telephone for personal counseling and changes in management.

Each subject was readmitted to the GCRC for 48 h at 25 wk gestation (if initially studied during the first trimester), 34–35 wk, and again 12 wk postpartum to assess 24-h plasma glucose excursions, quantitative urinary glucose loss, and HbA_{1c} values.

Diets. Table 1 presents the composition of the control and HCF diets used in this study. Both diets were individualized according to patient preferences and ethnic eating patterns. All patients were fed the control diet during the baseline 24-h study, but were then given their randomly assigned diet until delivery. The HCF diet was devised from specially developed exchange lists based on dietary fiber data published by Anderson et al.,[14,15] Paul and Southgate,[16] and Southgate et al.[17] To ensure a daily intake of 60–70 g of dietary fiber on the HCF diet, unprocessed wheat bran and/or muffins were prescribed three times daily.

TABLE 1
Composition of the control and HCF diets prescribed for diabetic women during pregnancy

Diet	Control (% kcal)	HCF (% kcal)
Carbohydrate*	40	65
Protein	20	20
Fat	40	15
Dietary fiber (g/day)	20	60–70
	Dietary fiber (g)	Dietary fiber (g)
Breads, cereals, and unprocessed wheat bran	13	39–46
Leafy vegetables and starchy vegetables	7	15–17
Fruits	2	5–7

* Total carbohydrate refers to available carbohydrate and does not include dietary fiber.

Total caloric intake was individualized according to weekly weight gain and activity levels and based on a projected total weight gain for pregnancy of 20–30 lb. Type I patients were instructed to eat three meals plus snacks at 1000 h, at 1500 h, and at bedtime, while type II patients were counseled to eat three meals with a bedtime snack.

Dietary compliance was assessed weekly based on a grading system of good, acceptable, or poor. Compliance was evaluated by a diet technician who used a standardized interview format and criteria that will be published as a separate report.[18]

Data were analyzed by group or paired *t* tests, as appropriate. Analysis of variance was also employed. In all cases random variation is given as standard error of the mean (SEM).

RESULTS

Assigned diets were maintained by each subject until delivery. For each of the two dietary groups, the mean length of dietary therapy was the same (HCF: 16 ± 2.3 wk; control: 16 ± 2.0 wk). Compliance in the two groups of subjects was also similar (HCF—good: 5, acceptable: 3, poor: 3; control—good: 4, acceptable: 3, poor: 2). All patients were in poor diabetic control at initial referral to the High Risk Obstetrics Clinic.

Five criteria (HbA_{1c}, mean 24-h plasma glucose, MAGE, mean 24-h urinary glucose loss, and 24-h insulin requirement) were used to assess overall management of diabetes.

HbA_{1c}. Women who were assigned to the HCF diet had a baseline HbA_{1c} level (11.0 ± 0.5%) somewhat higher than that of the subjects assigned to the control diet (10.2 ± 0.6%), while at the conclusion of the study mean HbA_{1c} values were identical in both groups (8.6 ± 0.4%). Thus, the mean reduction in HbA_{1c} level was greater in the HCF subjects (2.3 ± 0.5%, $P < 0.0003$) than in subjects of the control group (1.5 ± 0.7%, $P < 0.07$).

Following delivery all patients returned to their usual medical care facilities, and weekly dietary counseling and compliance evaluations were no longer provided. By 3 mo postpartum, mean HbA_{1c} levels in both groups had returned to approximately their original levels (HCF: 10.7 ± 0.5% versus control: 11.0 ± 0.7%).

Table 2 shows mean 24-h plasma glucose values, mean 24-h urinary glucose loss, and mean insulin dose per 24 h in patients on the HCF and the control diets at the time of the initial baseline study, at the conclusion of the dietary trial (predelivery), and 3 mo postpartum.

Mean 24-h plasma glucose. Mean 24-h plasma glucose levels improved in patients on both diets. Although there was a significant decrease in mean 24-h plasma glucose values for the two groups ($P < 0.02$), the magnitude of the decrease was not significantly different between groups.

MAGE values decreased in both dietary groups (HCF: 55–50 mg/dl; control: 76–70 mg/dl), but the decrease was approximately the same in both groups. Despite the marked improvement in mean 24-h glucose values, the standard deviation of 24-h glucose measurements decreased only 10% on the HCF diet and 9% on the control diet.

By 3 mo postpartum, women who received both diets had marked hyperglycemia throughout the 24-h day (mean 24-h plasma glucose: HCF: 207 ± 57 mg/dl versus control: 212 ± 30 mg/dl, P = NS).

Mean 24-h urinary loss of glucose. As expected, improvement in urinary loss of glucose reflected reduced hyperglycemia. From baseline to predelivery there was a significant decrease in mean 24-h urinary glucose values in both groups ($P < 0.0001$). However, the amount of decrease was not significantly different between groups. Three months postpartum, mean 24-h glucose loss was higher in both groups (HCF: 23 ± 9 g versus control: 32 ± 12 g, P = NS).

Insulin requirements. Figure 1 (top panel) depicts the mean daily dose of insulin reported for the baseline prepregnancy period (solid bars), at the conclusion of the diet (open bars), and 3 mo postpartum (notched bars) in all HCF and control patients. Baseline insulin doses were not significantly different between the women on the HCF and those on the control diet (HCF: 32 ± 8 U/24 h versus control: 27 ± 9 U/24 h).

As expected during the course of pregnancy, the mean dose of insulin from baseline to predelivery increased in women on both diets. At predelivery, however, the daily insulin requirements were significantly lower in the HCF group than in the control group (66 ± 10 U/24 h versus 108 ± 12 U/24 h, $P < 0.03$). Thus, the incremental insulin requirement during the course of pregnancy was significantly lower

TABLE 2
Comparison of quantitative measures of diabetic control in pregnant women receiving a high-carbohydrate, high-fiber, low-fat (HCF), or a control diet at baseline study, before delivery, and 3 mo postpartum

	Mean 24-h plasma glucose (mg/dl)*			Mean 24-h urinary glucose (g/24 h)†			Insulin mean dose (U/24 h)‡		
	B§	PD§	PP§	B	PD	PP	B	PD	PP
HCF (11)¶	154 ± 8 (7)	112 ± 4 (7)	207 ± 57 (11)	34 ± 6 (10)	5 ± 2 (10)	23 ± 9 (11)	32 ± 8 (11)	66 ± 10 (11)	23 ± 6.2 (11)
Control (9)	179 ± 19 (8)	142 ± 15 (8)	212 ± 30 (9)	71 ± 16 (9)	16 ± 5 (9)	32 ± 12 (9)	27 ± 9 (9)	108 ± 12 (9)	37 ± 7.8 (9)

* P (B versus PD for both HCF and control) < 0.02.
† P (B versus PD for both HCF and control) < 0.0001.
‡ P (HCF versus control for PD) < 0.03.
§ B, baseline; PD, predelivery; PP, 3 mo postpartum.
¶ Number of subjects in each group given in parentheses.

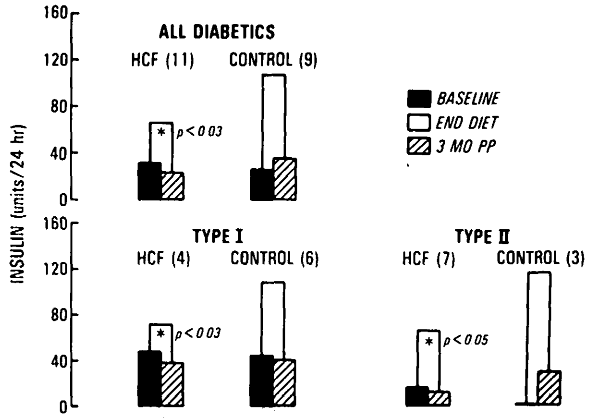

FIG. 1. *Mean daily insulin requirement in all diabetic women (top panel) who received either a high-carbohydrate, high-fiber diet (HCF) or the control diet at baseline (dark bars), predelivery (open bars), and 3 mo postpartum (notched bars). The bottom panel compares insulin requirements of type I and type II diabetic women on the two diets during the same time periods.*

in the HCF group than in the control group (35 ± 10 U/24 h versus 72 ± 15.7 U/24 h, $P < 0.01$).

Women with type I diabetes (IDDM) had a significantly lower ($P < 0.05$) mean increment in insulin dosage during pregnancy (39 ± 7%) than those with type II diabetes (NIDDM) (68 ± 19%), reflecting the greater insulin resistance in the older, more obese subjects. Of particular interest was the observation that the HCF diet reduced the insulin requirement in both type I and type II patients.

Figure 1 (bottom panel) depicts increases in insulin dose in type I versus type II subjects on the two diets. Four type I patients on the HCF diet increased their mean insulin dose only 24 ± 8 U during pregnancy compared with an increase of 65 ± 8 U for six women on the control diet ($P < 0.03$). In seven type II women on the HCF diet, there was an increment in insulin dose of 58 ± 14 U/24 h compared with an increase of 119 ± 29 U/24 h in three subjects who received the control diet ($P < 0.05$). The predelivery mean 24-h plasma glucose value of 142 ± 15 mg/dl (Table 2) indicates that women on the control diet had inadequate glycemic control for pregnancy despite higher doses of insulin. At 3 mo postpartum both groups were on inadequate insulin therapy as reflected by significant hyperglycemia and glycosuria (Table 2).

Outcome of pregnancy. Maternal weight gain during pregnancy was lower in the HCF patients than in women on the control diet (26 ± 3 lb versus 35 ± 5 lb, $P < 0.05$). Mean gestational age was similar in the two groups (HCF: 37.2 ± 0.7 wk versus control: 36.5 ± 0.7 wk, P = NS). Mean birth weight was higher in infants of HCF mothers (HCF: 3809 ± 248 g versus control: 3313 ± 278 g, P = NS). Birth weights correlated with gestational age, but not with maternal prepregnancy weight or weight gain during gestation. Infant neonatal morbidity was negligible, with no babies experiencing respiratory distress syndrome or major congenital malformations.

DISCUSSION

Dietary therapy is an important adjunct to insulin administration in maintaining normal plasma glucose levels in diabetic pregnancies.[19,20] Previous studies in nonpregnant patients have shown improved control of diabetes in subjects receiving a high-fiber diet.[3–10] Our report provides the first investigation of the use of an HCF diet in a longitudinal study of diabetic pregnant women. We found good or acceptable dietary compliance in 78% of the patients in each group. This positive result was attributed to the high motivation diabetic women expressed for a good outcome to a high-priority pregnancy. On the HCF diet, some women experienced more frequent stools, occasional abdominal pain, and increased flatus. There were no dietary complaints from patients on the control diet.

In the quantitative assessment of diabetic control in the 11 women who received the HCF diet and the 9 who followed the control diet, it was apparent that marked improvement occurred on both regimens. Lower mean 24-h plasma glucose values and less urinary glucose loss were noted at term in women who followed the HCF diet, but MAGE values did not differ between groups. Our most important observation was the decreased insulin requirement in women who followed the HCF diet.

The physiologic explanation for lower insulin requirements in women receiving an HCF diet is not apparent from this study. It has been suggested that dietary fiber improves glucose tolerance by slowing intestinal absorption of simple carbohydrates,[21–23] decreasing plasma glucagon levels, and increasing tissue sensitivity to insulin.[24] There may also be effects of fiber ingestion on gastrointestinal hormones such as gastric inhibitory peptide (GIP), vasoactive intestinal peptide (VIP), and intestinal glucagon.[25] Decreased release of these hormones with fiber ingestion may contribute to lower insulin responses. Anderson[26] noted that insulin requirements of IDDM patients were 25% lower on the HCF diet and suggested that high dietary fiber enhances sensitivity to exogenous insulin. He has also reported that in humans, HCF diets are associated with significantly higher binding of insulin to monocytes than are control diets.[27]

In this study, the failure to find a statistically significant difference in diabetic control as assessed by HbA_{1c} determinations, mean 24-h plasma glucose values, MAGE, or mean 24-h urinary loss of glucose indicates that similar diabetic control was achieved in both dietary groups. Of primary importance, however, is the finding that significantly lower amounts of insulin were required to achieve such control in subjects who received the HCF diet in contrast to those who followed the control diet.

ACKNOWLEDGMENTS: We wish to thank Paula Payne for her help with preparation of the manuscript, Diane Hulbert, Nurse-Physician Assistant, for coordinating patient care and the Clinical Research Center nurses, and laboratory and dietary technicians for their invaluable assistance implementing the research protocol. We are grateful to Dr. Allen Lein for his editorial assistance and review of the manuscript.

This project was supported in part by the UCSD General Clinical Research Center NIH/Division of Research Resources Grant RR-0827, and NIH Grant RO1 HD-13469.

From the UCSD General Clinical Research Center (D.N.) and the Department of Reproductive Medicine T002 (D.R.H., L.C.), University of California, San Diego, La Jolla, California 92093.

Address reprint requests to Dorothy R. Hollingsworth at the above address.

REFERENCES

[1] Freinkel, N., and Metzger, B. E.: Pregnancy as a tissue culture experience: the critical implications of maternal metabolism for fetal development. *In* Pregnancy Metabolism, Diabetes and the Fetus, CIBA Foundation Symposium 63 (New Series). Amsterdam, Excerpta Medica, 1978, pp. 3–28.

[2] Ney, D., and Hollingsworth, D. R.: Nutritional management of pregnancy complicated by diabetes: historical perspective. Diabetes Care 4: 647–55, 1981.

[3] Kiehm, T. G., Anderson, J. W., and Ward, K.: Beneficial effects of a high-carbohydrate, high-fiber diet on hyperglycemic diabetic men. Am. J. Clin. Nutr. 29: 895–99, 1976.

[4] Jenkins, D. J. A., Goff, D. V., Leeds, A. R., Alberti, K. G. M. M., Wolever, T. M. S., Gassull, M. A., and Hockaday, T. D. R.: Unabsorbable carbohydrates and diabetes: decreased postprandial hyperglycemia. Lancet 2: 172–74, 1976.

[5] Jenkins, D. J. A., Leeds, A. R., Gassull, M. A., Cochet, B., and Alberti, K. G. M. M.: Decrease in postprandial insulin and glucose concentrations by guar and pectin. Ann. Intern. Med. 86: 20–23, 1977.

[6] Miranda, P. M., and Horwitz, D. L.: High-fiber diets in the treatment of diabetes mellitus. Ann. Intern. Med. 88: 482–86, 1978.

[7] Anderson, J. W., and Ward, K.: High-carbohydrate, high-fiber diets for insulin-treated men with diabetes mellitus. Am. J. Clin. Nutr. 32: 2312–21, 1979.

[8] Albrink, M. J., Newman, T., and Davidson, P. C.: Effect of high and low fiber diets on plasma lipids and insulin. Am. J. Clin. Nutr. 32: 1486–91, 1979.

[9] Kanter, Y., Eitan, N., Brook, G., and Barzilaid, D.: Improved glucose tolerance and insulin response in obese and diabetic patients on a fiber-enriched diet. Isr. J. Med. Sci. 16: 1–6, 1980.

[10] Kay, R. M., Grobin, W., and Track, N. S.: Diets rich in natural fibre improve carbohydrate tolerance in maturity-onset non-insulin-dependent diabetics. Diabetologia 20: 18–21, 1981.

[11] Crapo, P. A., Kolterman, O. G., Waldeck, N., Reaven, G. M., and Olefsky, J. M.: Postprandial hormonal responses to different types of complex carbohydrate in individuals with impaired glucose tolerance. Am. J. Clin. Nutr. 33: 1723–28, 1980.

[12] Coulston, A., Greenfield, M., Kraemer, F., Tobey, T., and Reaven, G.: Effect of source of dietary carbohydrate on plasma glucose and insulin responses to test meals in normal subjects. Am. J. Clin. Nutr. 33: 1279–82, 1980.

[13] Service, F. J., Molnar, G. D., Rosevear, J. W., Ackerman, E., Gatewood, L. C., and Taylor, W. F.: Mean amplitude of glycemic excursions, a measure of diabetic instability. Diabetes 19: 644–55, 1970.

[14] Anderson, J. W., and Sieling, B.: HCF Diets. A Professional Guide to High-Carbohydrate, High-Fiber Diets. Lexington, The University of Kentucky Diabetes Fund, 1979.

[15] Anderson, J. W., Lin, W. -J., and Ward, K.: Composition of foods commonly used in diets for persons with diabetes. Diabetes Care 1: 293–302, 1978.

[16] Paul, A. A., and Southgate, D. A. T.: McCance and Widdowson's The Composition of Foods, 4th edit. London, H. M. Stationery Office, 1978.

[17] Southgate, D. A. T., Bailey, B., Collinson, E., and Walker, A.: A guide to calculating intakes of dietary fibre. J. Hum. Nutr. 30: 303–13, 1976.

[18] Ney, D., Stubblefield, N., and Fischer, C.: Evaluation of a new system for the assessment of compliance with a diabetic diet. Submitted to J. Am. Dietet. Assoc.

[19] Mintz, D. H., Skyler, J. S., and Chez, R. A.: Diabetes mellitus and pregnancy. Diabetes Care 1: 49–63, 1978.

[20] Schulman, P. K., Gyves, M. T., and Merkatz, I. R.: Role of nutrition in the management of the pregnant diabetic patient. Semin. Perinatol. 2: 353–60, 1978.

[21] Simpson, H. C. R., Lousley, S., Geekie, M., Simpson, R. W., Carter, R. D., Hockaday, T. D. R., and Mann, J. I.: A high-carbohydrate leguminous fibre diet improves all aspects of diabetic control. Lancet 1: 1–5, 1981.

[22] Monnier, L. H., Blotman, M. J., Colette, C., Monnier, M. P., and Mirouze, J.: Effects of dietary fibre supplementation in stable and labile insulin-dependent diabetics. Diabetologia 20: 12–17, 1981.

[23] Jenkins, D. J. A., Wolever, T. M. S., Leeds, A. R., Gassull, M. A., Haisman, P., Dilawari, J., Goff, D. V., Metz, G. L., and Alberti, K. G. M. M.: Dietary fibers, fibre analogues and glucose tolerance: importance of viscosity. Br. Med. J. 1: 1392–94, 1978.

[24] Goulder, T. J., Morgan, L. M., Marks, V., Smythe, T., and Hinks, L.: Effects of guar on metabolic and hormonal responses to meals in normal and diabetic subjects. Diabetologia 14: 235, 1978.

[25] Miller, L. J., Malegelada, J. R., and Go, V. L. W.: Intestinal nutrient influence on the enteroinsular axis. J. Clin. Endocrinol. Metab. 47: 1009–1014, 1978.

[26] Anderson, J. W.: Dietary fiber and diabetes. *In* Medical Aspects of Dietary Fiber. Spiller, G. A., and Kay, R. McP., Eds. New York, Plenum Press, 1980, pp. 193–221.

[27] Anderson, J. W.: High carbohydrate, high fiber diets for patients with diabetes. *In* Treatment of Early Diabetes. Camerini-Davalos, R. A., and Hanover, B. A., Eds. New York, Plenum Press, 1979, pp. 263–73.