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Effects of Dietary Carbohydrate and Fat Intake on Glucose and Lipoprotein Metabolism in Individuals With Diabetes Mellitus

The dietary treatment of individuals with diabetes remains a controversial issue. The major emphasis in recent years has been on the reduction of total fat and saturated fat and replacement with complex carbohydrate. The rationale for this approach is based on the premise that such diets will reduce the risk of coronary artery disease (CAD) by reducing total and lowdensity lipoprotein cholesterol concentrations. In this article, we review the available data and conclude that there is little evidence to support the notion that low-fat high-carbohydrate diets per se lead to any reduction in the risk for CAD in individuals with diabetes. The only data indicating that low-fat high-carbohydrate diets lead to beneficial effects on carbohydrate and lipoprotein metabolism are confounded either by the lack of suitable experimental control, by the fact that diets also differed in the type of dietary fat and amount of dietary cholesterol, or were enormously enriched in dietary fiber. When these factors are taken into consideration, there appears to be little evidence in support of the view that substituting carbohydrate for fat in the diets of individuals with diabetes results in any measurable beneficial effect. Indeed, it could be argued that the most characteristic defects in carbohydrate and lipoprotein metabolism are exacerbated in response to low-fat high-carbohydrate diets. Alternatively, the data presented herein strongly suggest that diets containing conventional quantities of fat, in which saturated fat is replaced by unsaturated fat and dietary cholesterol reduced, would result in the desired reductions to total and low-density lipoprotein cholesterol concentrations without the adverse effects of increased postprandial glucose and insulin

concentrations, increased fasting and postprandial total and very-low-density lipoprotein triglyceride concentrations, and decreased fasting high-density lipoprotein cholesterol concentrations. *Diabetes Care* 14:774–85, 1991

Ithough there is general agreement that diet should serve as the cornerstone in the treatment of individuals with diabetes, the exact nature of the diet remains controversial (1-4). Interest in dietary management has intensified in recent years, associated with heightened efforts to normalize carbohydrate and lipoprotein metabolism in individuals with diabetes. However, an understanding of the impact that differences in dietary composition have on the metabolic abnormalities present within this syndrome is far from clear. In this review, we attempt to clarify some of the dietary issues related to the treatment of carbohydrate intolerance and dyslipemia present in the diabetic syndrome. We will draw our comments from our experience (5-10) over the past several years, as well as the work of others (11-23). Furthermore, we limit our comments to studies that have assessed the effects of dietary changes under controlled well-defined dietary conditions.

Several studies have been conducted in outpatient settings where individuals are given dietary guidelines, asked to obtain specific foods, and follow the advice for periods up to 6 wk (24–26). Because the experimental variable in these studies (i.e., diet) is outside the control of the investigator, it is difficult to accept these data as persuasive scientific evidence of the effects that specific dietary changes might have on the regulation of carbohydrate and lipoprotein metabolism. Unfortunately,

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many of these latter studies play a prominent role in the rationale for the dietary advice being given (1,2).

Finally, before turning our attention to an analyses that specific dietary manipulation might have on carbohydrate and lipoprotein metabolism, it would seem useful to consider the differences in carbohydrate and lipoprotein metabolism that characterize individuals with diabetes and the relationship of these abnormalities to the risk of coronary artery disease (CAD).

ABNORMALITIES OF CARBOHYDRATE AND LIPOPROTEIN METABOLISM IN DIABETES

Abnormalities in carbohydrate metabolism are present in patients with both insulin-dependent diabetes mellitus (IDDM) and non-insulin-dependent diabetes mellitus (NIDDM) (27,28). However, the nature of these abnormalities vary considerably between the two syndromes. Individuals with IDDM are characterized by the total absence of insulin secretion as a result of pancreatic β cell destruction (27). Thus, the primary cause of hyperglycemia in IDDM is related to insulin deficiency. On the other hand, although individuals with NIDDM may have decreased insulin secretion in response to a glucose stimulus, most individuals maintain normal or greater than normal levels of circulating insulin in response to mixed meals (28-30). The primary cause of ambient hyperglycemia in these individuals appears to be reduced insulin sensitivity of peripheral tissue rather than reduced insulin secretion (28). Consequently, insulin resistance and compensatory hyperinsulinism represent the major metabolic abnormality in carbohydrate metabolism present in NIDDM.

Although diabetes is usually characterized as a disease of carbohydrate metabolism, abnormalities of lipoprotein metabolism are also present in individuals with this syndrome. The abnormalities are particularly important given the acceleration of CAD associated with diabetes and the public and scientific attention given to the possible relationship between diet and CAD. The dyslipemia present in diabetes also appears to vary considerably between the two syndromes. For example, hypertriglyceridemia is common in individuals with uncontrolled IDDM. This hypertriglyceridemia is almost certainly due to a defect in the removal of triglyceriderich lipoprotein chylomicrons and very-low-density lipoproteins (VLDLs) from plasma (31). Hypertriglyceridemia is also common in individuals with NIDDM; however, the elevated plasma triglyceride concentrations appear to result primarily from increased endogenous triglyceride synthesis (32–35). Moreover, although plasma triglyceride concentrations may fall in response to improved glycemic control in both syndromes, the reasons for the reduction and the degree to which normal plasma triglyceride concentrations are achieved differ in IDDM compared with NIDDM. The defect in triglyceride removal in IDDM seems to be related to the absence of circulating plasma insulin. Insulin-replacement therapy appears to correct the defect in the removal rate of chylomicrons and VLDL triglyceride in individuals with IDDM, and plasma triglyceride concentrations can be lowered to relatively normal levels, although they may remain hyperglycemic (34). In contrast, the reduction in plasma triglyceride concentrations in individuals with NIDDM is associated with improved glycemic control and is probably related to a reduction in VLDL triglyceride secretion, secondary to a fall in free fatty acid (FFA) concentrations, which occur with improvements in glycemic control (33,34). Furthermore, individuals with NIDDM continue to manifest an increase in VLDL triglyceride secretion rates and hypertriglyceridemia compared with individuals with IDDM matched for plasma glucose and FFA concentrations (34).

In addition to the differences in VLDL metabolism noted between individuals with IDDM and NIDDM, there also seems to be differences in high-density lipoprotein (HDL) metabolism. For example, HDL cholesterol concentrations are generally not reduced and may even be increased in individuals with IDDM (36). In contrast, low plasma HDL cholesterol concentrations occur frequently in individuals with NIDDM (37). Note that in both IDDM and NIDDM, plasma low-density lipoprotein (LDL) cholesterol concentrations do not differ substantially from individuals without diabetes (38). This observation is particularly interesting, because the major thrust of dietary advice for patients with diabetes is aimed at lowering plasma LDL cholesterol concentrations.

At this point in our discussion it would seem important to relate these abnormalities in carbohydrate and lipoprotein metabolism to the risk of developing CAD in the diabetic population. In this regard, hypertriglyceridemia has been associated with an increased incidence of CAD in both cross-sectional and prospective studies (39-42). In the World Health Organization multinational study (41), the single risk factor that correlated the strongest with the incidence of CAD in the nine diabetic populations studied was plasma triglyceride concentrations. Similar evidence of the importance of plasma triglyceride as a risk factor for the development of CAD in individuals with diabetes is provided by the Paris Prospective Study (42). In this study, although plasma triglyceride, cholesterol, and insulin all correlated with the incidence of CAD by univariate analysis, plasma triglyceride was the only factor that was significantly associated with CAD by multivariate regression analysis. The results of these two studies serve to underscore the importance of hypertriglyceridemia as a risk factor for CAD in individuals with diabetes. Unfortunately, these two studies assessed only total plasma triglyceride and cholesterol concentrations and did not evaluate various lipoprotein fractions (41,42). In addition to hypertriglyceridemia, low HDL cholesterol concentrations have been shown to be associated with an increased risk for CAD in individuals without diabetes (43,44), and there is evidence that the reduced HDL

cholesterol levels seen in individuals with NIDDM also contribute to enhanced atherosclerosis observed within this syndrome (45,46). There appears to be a close inverse relationship between VLDL triglyceride and HDL cholesterol (47,48). The decline in HDL cholesterol, which accompanies the increase in VLDL triglyceride, has been suggested to reflect the interchange of cholesterol esters and triglyceride between HDL and VLDL particles, representing a recycling of cholesterol esters from HDL back to VLDL (48).

Although increased concentrations of both total plasma and LDL cholesterol are strong risk factors for CAD in the general population, they have not been identified as particularly strong risk factors for CAD in individuals with diabetes. As mentioned previously, total and LDL cholesterol are perhaps the most normal aspect of lipoprotein metabolism in diabetes and do not appear to be elevated compared with a normal glucosetolerant population.

Finally, the idea that elevated plasma insulin concentrations may play a role in the development of CAD was proposed >20 yr ago (49). Since that time, evidence in support of that hypothesis has accumulated in various patient populations (50–52), and was extensively reviewed recently (53). Hyperinsulinemia is a common finding in individuals with NIDDM (30,40,42), and there is evidence that hyperinsulinemia may play an important role in the development of CAD in this syndrome as well (40,42,50).

Obviously, a major evaluation of the effects of dietary manipulation on carbohydrate and lipoprotein metabolism must take into consideration the relationship between any observed changes in metabolism and the risk for CAD in individuals with diabetes. In particular, attention must be directed to the impact that specific dietary changes have on the metabolic risk factors for CAD that are known to exist in individuals with diabetes. These dietary changes have been outlined above and are the focus of our discussion on the effects of diet on carbohydrate and lipoprotein metabolism in this review.

ISOCALORIC SUBSTITUTION OF CARBOHYDRATE FOR FAT

Normal glucose-tolerant individuals. Several years ago, we demonstrated that the isocaloric substitution of carbohydrate for fat in the diets of individuals with normal carbohydrate and lipoprotein metabolism resulted in a significant increase in fasting total plasma triglyceride (+49%, P < 0.001) and a significant reduction in HDL cholesterol (-18%, P < 0.01) (5). Of particular interest is the observation that deleterious effects to lipoprotein metabolism occurred in the absence of the anticipated improvement in total plasma or LDL cholesterol concentrations. In addition, postprandial triglyceride and insulin concentrations were significantly elevated after the low-fat diet. In the same year we reported a significant increase in fasting triglyceride concentrations (238 vs. 348 mg/dl, P < 0.001) in a group

of nondiabetic individuals with endogenous hypertriglyceridemia when carbohydrate was substituted for fat in the diet (6). The increase in triglyceride could be explained primarily by a significant increase in VLDL triglyceride concentration (147 vs. 241 mg/dl, P < 0.001). Again, the expected changes in total plasma and LDL cholesterol were not observed on the low-fat diet. In addition, as was observed in the nondiabetic individuals cited above (5), postprandial insulin concentrations were significantly increased when carbohydrate was substituted for fat in the diet. Grundy (11) and Grundy et al. (12) reported similar findings when saturated fat was replaced by either complex carbohydrate or monounsaturated fat in the diets of individuals with normal carbohydrate and lipoprotein metabolism. In their first study, these investigators demonstrated a significant increase in total plasma cholesterol (208 vs. 222 mg/dl, P < 0.05) and triglyceride concentrations (178 vs. 235 mg/dl, P < 0.05) after the high-carbohydrate low-fat diet (11). In addition, HDL cholesterol was significantly decreased (39 vs. 32 mg/dl, P < 0.01). Because no significant change in LDL cholesterol concentration was observed, the ratio of LDL to HDL cholesterol was significantly increased (3.5 vs. 4.7, P <0.01) after the low-fat diet. Their second study also showed significant decrease in HDL cholesterol concentrations (50 vs. 46 mg/dl, P < 0.02) without any significant change in total plasma or LDL cholesterol concentrations after the high-carbohydrate diet (12).

Thus, there now appears to be substantial evidence in individuals without diabetes, which suggests that lowfat diets per se do not provide any significant advantage in lowering total plasma or LDL cholesterol concentrations than diets in which saturated fats are replaced with unsaturated fats (either monounsaturated or polyunsaturated). More importantly, diets increased in carbohydrates have a tendency to result in significantly higher fasting and postprandial triglyceride concentrations, increased postprandial insulin concentrations, and lower HDL cholesterol concentrations, all of which have been associated with an increased risk of CAD. The significant fall in HDL cholesterol in the absence of any change in total or LDL cholesterol concentrations appears to be of substantial clinical importance. With the data on nondiabetic individuals as a background, we would like to turn our attention to individuals with diabetes.

Individuals with diabetes mellitus. The effects of isocaloric substitution of carbohydrate for fat in the diets of individuals with diabetes appear to be similar to individuals with normal glucose tolerance. Studies conducted by our group (7,8) and others (13–15) have consistently indicated that the substitution of carbohydrate for fat in the diet of individuals with diabetes results in an increase in plasma glucose, insulin, total plasma and VLDL triglyceride concentrations, and a reduction in HDL cholesterol concentrations without appreciably affecting total plasma or LDL cholesterol concentrations. For example, two studies by our group showed that the isocaloric substitution of carbohydrate for fat resulted in significant increases in fasting and postprandial total plasma triglyceride concentrations (7,8; Fig. 1). The increase in fasting total triglyceride concentrations could be explained almost completely by a significant increase in VLDL triglyceride concentrations (Fig. 2). In both studies, there was also a significant increase in VLDL cholesterol and a significant decrease in HDL cholesterol concentrations after the low-fat diet (Fig. 3). The only difference in lipoprotein response between the two studies was that although in one study (7) no significant improvement in LDL cholesterol concentration was observed, there was a small but significant fall in LDL cholesterol after the low-fat diet in the other (8). In addition to the changes in lipoprotein metabolism in these studies (7,8), there were also alterations in carbohydrate metabolism observed. Specifically, postprandial plasma glucose and insulin concentrations were significantly elevated after the highcarbohydrate diets on both studies (Fig. 4). Further evidence of deterioration in glycemic control is apparent from the significant increase in 24-h urinary glucose excretion after the high-carbohydrate diet. Similar results have been reported by Sestoft et al. (13). These investigators demonstrated that increasing dietary carbohydrate as polysaccharide from 40 to 50% of total calories in individuals with NIDDM resulted in a significant increase in total plasma and VLDL triglyceride concentrations and a significant decrease in HDL cholesterol concentrations. In addition, there was a significant in-



FIG. 1. An example of fasting and postprandial plasma triglyceride concentrations in individuals with non-insulindependent diabetes after diets containing either 40% (\bullet) or 60% (\odot) of total calories as carbohydrate (CHO). From Coulston et al. (7). © by the American Journal of Medicine.



FIG. 2. Elevation in total plasma triglyceride (TG) concentrations frequently observed in individuals with non-insulin-dependent diabetes after high-carbohydrate (CHO) low-fat diets can be explained by significant increase in very-low-density lipoprotein (VLDL) TG. From Coulston et al. (7). © by the American Journal of Medicine.

crease in both postprandial glucose and insulin concentrations after the high-carbohydrate low-fat diet.

Finally, Garg et al. (14) demonstrated that replacing saturated fats with monounsaturated fats resulted in significant metabolic advantages over replacing saturated fat with complex carbohydrate. Specifically, there were no significant changes in either fasting total plasma or LDL cholesterol concentrations as a result of reducing total fat from 50 to 25% of the total calories. However, fasting total plasma triglyceride (163 vs. 218 mg/dl, P <0.01) and VLDL cholesterol concentrations (28 vs. 43 mg/dl, P < 0.005) and total-HDL cholesterol ratio (6 vs. 7.2, P < 0.05) were significantly increased and HDL cholesterol concentrations (34 vs. 30 mg/dl, P < 0.005) significantly decreased after the high-carbohydrate lowfat diet. In addition, postprandial plasma glucose (+12%, P < 0.01), insulin (+24%, P < 0.01), and triglyceride (+26%, P < 0.005) concentrations were all significantly elevated after the high-carbohydrate lowfat diet. This increase in daylong glucose concentrations occurred, despite the fact that insulin dose was significantly increased (+16%, P < 0.05) after the increase in dietary carbohydrate to maintain fasting plasma glucose concentrations.

The results of these studies in individuals with diabetes are remarkably similar and consistent with the overall findings in nondiabetic individuals. They indi-



FIG. 3. Example of changes in fasting plasma lipoprotein cholesterol concentrations that have been observed in individuals with non-insulin-dependent diabetes after diets containing either 40 or 60% of total calories as carbohydrate (CHO). VLDL, very-low-density lipoprotein; LDL, low-density lipoprotein; HDL, high-density lipoprotein. From Coulston et al. (7). © by the American Journal of Medicine.

cate that when carbohydrate is substituted for saturated fat in the diet a constellation of deleterious metabolic effects to both carbohydrate and lipoprotein metabolism emerge, including increased fasting and postprandial triglyceride concentrations, increased postprandial glucose and insulin concentrations, and a decrease in HDL cholesterol concentrations (Table 1). Moreover, improvements in fasting total plasma and LDL cholesterol are not consistently demonstrated. When a reduction in LDL cholesterol has been observed, it has been accompanied by a significnt increase in VLDL cholesterol and VLDL triglyceride (8,13). Given the observed relationship between VLDL and LDL cholesterol and VLDL triglyceride and HDL cholesterol, one must be cautious in interpreting the clinical significance of small reductions in LDL cholesterol under these conditions.

HIGH-CARBOHYDRATE MODIFIED-FAT CHOLESTEROL-RESTRICTED DIETS

From the discussion of the literature thus far, it appears that the putative beneficial effects on plasma lipoprotein cholesterol concentrations, for which low-fat diets have been recommended, have not been observed. However, not all high-carbohydrate low-fat diets have lead to the same conclusions. In fact, there are several controlled metabolic studies that report significant improvements in both carbohydrate and lipoprotein metabolism



FIG. 4. Fasting and postprandial plasma glucose (A) and insulin (B) concentrations observed in individuals with noninsulin-dependent diabetes after diets containing either 40% (\bullet) or 60% (\bigcirc) of total calories as carbohydrate (CHO). From Coulston et al. (8). © by the American Diabetes Association.

	Refs.				
	Sestoft et al. (13)	Coulston et al. (7)	Coulston et al. (8)	Garg et al. (14)	Rivellese et al. (15)
Fasting plasma					
Total cholesterol	NS	NS	NS	NS	NS
VLDL cholesterol	NS	1	1	1	↑
LDL cholesterol	\downarrow	NS	Ļ	NS	NS
HDL cholesterol	Ļ	\downarrow	\downarrow	Ļ	NS
Total triglyceride	↑	1	1	↑	ſ
VLDL triglyceride	ŕ	<u>^</u>	ŕ	*	ŕ
Postprandial plasma					
Glucose	î	↑	Ŷ	↑	NS
Insulin	*	↑	Ŷ	Ŷ	NS
Triglyceride	î	1	Î	1	*

TABLE 1 Metabolic effects of isocaloric substitution of carbohydrate for fat in diets of individuals with non-insulin-dependent diabetes

NS, no significant change; VLDL, very-low-density lipoprotein; LDL, low-density lipoprotein; HDL, high-density lipoprotein. \uparrow , Increase; \downarrow , decrease.

*No data available.

in individuals with diabetes after high-carbohydrate low-fat diets (10,16,19,21,22). For example, Hollenbeck et al. (10) reported significant improvements in fasting total plasma (201 vs. 156 mg/dl, P < 0.05) and LDL cholesterol (126 vs. 90 mg/dl, P < 0.05) concentrations in young individuals with IDDM after 6 wk of high-carbohydrate low-fat cholesterol-restricted diets. On the other hand, the low-fat diet resulted in higher fasting plasma (115 vs. 96 mg/dl, P < 0.01) and VLDL triglyceride (76 vs. 59 mg/dl, P < 0.001) concentrations and a significant decrease in HDL cholesterol concentrations (50 vs. 39 mg/dl, P < 0.05). There were no changes in either plasma glucose concentrations or insulin dose between the two diet periods. Although this study demonstrated improvement in lipoprotein metabolism associated with the high-carbohydrate low-fat diet, the improvements were limited to a fall in total plasma and LDL cholesterol and are difficult to interpret in the light of the concomitant increase in total plasma and VLDL triglyceride and significant fall in HDL cholesterol concentrations. It is also important to understand that the diets used by these investigators did not represent the isocaloric substitution of carbohydrate for fat. The polyunsaturated-saturated ratio (0.14 vs. 1.40) was significantly higher and dietary cholesterol significantly lower (580 vs. 62 mg/day) on the high-carbohydrate low-fat diet. One must consider the nature of the metabolic changes observed in this study in relation to the dietary changes. For example, based on current evidence one could argue that the improvements in total plasma and LDL cholesterol observed in this study resulted primarily from the changes in the polyunsaturated-saturated ratio and decrease in dietary cholesterol, whereas the deleterious effects to total plasma and VLDL triglyceride and HDL cholesterol resulted from increased carbohydrate. This will be discussed in more detail below.

Abbott et al. (19) compared baseline diets containing 45% carbohydrate, 43% fat with a polyunsaturated-saturated ratio of 0.3, and 9 g fiber/1000 kcal with highcarbohydrate low-fat diets containing 65% carbohydrate, 21% fat with a polyunsaturated-saturated ratio of 1.2, and 18 g fiber/1000 kcal in seven Pima Indians with NIDDM. The results demonstrated no significant changes in total plasma or HDL cholesterol, total plasma triglyceride, fasting plasma glucose, or insulin concentrations. On the other hand, there was a significant lowering in LDL cholesterol concentrations (107 vs. 84 mg/dl, P < 0.01). At first glance, these data also appear to be in contrast to several previous studies comparing the metabolic effects of high-carbohydrate diets (7,8,13–15). Again, if one considers the results in the light of their experimental dietary protocols, these differences become more apparent than real. For example, a fall in LDL cholesterol concentration almost always follows the reduction of saturated fat, regardless of whether it is replaced by carbohydrate (10–12,16,20) or unsaturated fats (11,12,18,20). The observation that the reduction of total fat in the diet did not lead to any significant fall in total plasma cholesterol is also an almost uniform finding (5-8,10,12-17,19,20). Finally, the fact that increased dietary carbohydrate did not lead to the expected deleterious effects on plasma triglyceride, glucose, and insulin concentration may be explained primarily by the judicious choice of dietary carbohydrate and fiber. Specifically, these investigators chose to increase carbohydrate by including sources of legumes (pinto, kidney, and lima beans, lentils, and split peas). As a result, the concomitant increase in dietary fiber was primarily associated with an increase in leguminous fiber. There is evidence that legumes in general (16,54,55), and perhaps leguminous fiber more specifically (16,55,56), can attenuate the deleterious metabolic effects of high-carbohydrate diets.

At this juncture, it would seem important to stress that the differences in the literature attributed to amount of fat and carbohydrate may well result from differences in experimental approach rather than any inherent inconsistency in results per se. For example, our group (5-8)as well as other investigators (11–15) have tried to assess the role of lowering dietary fat on various aspects of carbohydrate and lipoprotein metabolism. In these studies, total fat was replaced by either carbohydrate or other unsaturated fats in such a manner that the polyunsaturated-saturated ratio, dietary cholesterol, dietary fiber, and other factors known to affect carbohydrate and lipid metabolism remained constant between the two experimental diets. This is critical in understanding the apparent differences reported in the literature in regard to the effects of low-fat diets on various aspects of carbohydrate and lipoprotein metabolism. It appears that virtually all controlled metabolic studies that report improvements in lipoprotein metabolism after high-carbohydrate low-fat diets (19,21-23) have not isolated changes in the relative amount of fat from those due to variations in either the kind of fat (saturated/monounsaturated/polyunsaturated) or amount of dietary cholesterol. Because dramatic changes in the relative proportions of saturated to polyunsaturated fat and decreases in the amount of dietary cholesterol alone could explain the observed improvements in plasma lipid concentrations, it is not clear that the lower plasma cholesterol concentrations could be attributed solely to a reduction in dietary fat (57–59). Moreover, the relative reduction of saturated fat has also been shown to have a profound effect on plasma lipoprotein metabolism, independent of dietary cholesterol content (57,58). Insight into the importance of modifying the composition of dietary fat and the restriction of dietary cholesterol in controlling plasma cholesterol concentrations is provided by two earlier studies in individuals with diabetes (17,18). In one study, Weinsier et al. (17) evaluated the effects of replacing total fat with carbohydrate with diets in which the polyunsaturated-saturated ratio and dietary cholesterol remained constant. These investigators failed to demonstrate any significant differences in total plasma cholesterol in 18 individuals with NIDDM after 20 wk of diets containing 60% of the calories as carbohydrate compared with conventional 40%-carbohydrate diets. With an entirely different approach, Kaufmann et al. (18) studied 270 individuals with IDDM on diets with similar carbohydrate (40%) and fat (40%) content, but differing in the polyunsaturated-saturated ratio (0.1 vs. 1.0) and amount of dietary cholesterol (700-1500 vs. 300 mg/day). Their results showed a substantial lowering in total plasma cholesterol over the 11- to 17-day periods that the modified-fat cholesterol-restricted diets were fed. Thus, it appears likely that the improvements in plasma cholesterol concentrations, which were reported by several investigators (10,16, 19,21-23) to occur in individuals after the use of lowfat diets, can be attributed to the concomitant changes in the composition of dietary fat and amount of dietary

cholesterol rather than to any specific effect of decreased fat.

Finally, it is now clear that specific groups of carbohydrate-containing foods (most prominently legumes) may delay digestion and absorption, and thus result in lower postprandial glucose and insulin response (16,54–56). The relatively unique ability of leguminous carbohydrate to attenuate the hyperglycemia, hyperinsulinemia, and hypertriglyceridemia observed after increased dietary carbohydrate is almost certainly due to the unique structure and/or physical form of the carbohydrate present (60-62). The attenuation in hyperglycemia, hyperinsulinemia, and hypertriglyceridemia that have been observed in studies utilizing leguminous carbohydrate should not be attributed to the fact that they are a complex carbohydrate. There is no evidence that we are aware of which would support the notion that complex carbohydrate provides any advantage over natural-occurring simple carbohydrate in controlling abnormalities of either carbohydrate or lipoprotein metabolism. Finally, the relatively unique effects of leguminous carbohydrate-containing foods should not be generalized to other food sources rich in complex carbohydrate. In other words, it is important that the results obtained with large amounts of legumes as the source of carbohydrate not be generalized to nonleguminous sources of carbohydrate.

UNSATURATED FATS: MONOUNSATURATED VERSUS POLYUNSATURATED

Although, it seems to have become fashionable to emphasize the replacement of saturated fat with monounsaturated fats in recent studies, it is important to understand that the experimental approach is not novel. It is essentially similar to the approach used by our group (5-8) and others (13,16,18,19,21-23,63) which have replaced saturated fat with either polyunsaturated fat or mixtures of unsaturated fats. The notion that monounsaturated fat may provide metabolic advantage over other unsaturated fats in this experimental paradigm is guestionable. For example, it has been argued that monounsaturated fat lowers HDL cholesterol levels to a lesser extent than polyunsaturated fat and therefore may provide greater advantage when replacing saturated fat in the diet (64,65). Whether diets containing predominantly polyunsaturated fat result in lower HDL cholesterol compared with diets containing primarily monounsaturated fat is unclear (63–71). Several studies report a decline in HDL cholesterol with the use of polyunsaturated fat (64-66), whereas others have not (63,67–77). Note that studies that report a decline in HDL with the use of polyunsaturated fat have relied on diets in which the polyunsaturated-saturated ratio was high (2-6.5) (64-66), whereas those that demonstrate comparable effects of polyunsaturated and monounsaturated fats have used somewhat more realistic polyunsaturated-saturated ratios (0.6–1.2) (63,67–71). In addition, it appears that both polyunsaturated and monounsaturated fats are equally effective in lowering total and LDL cholesterol concentrations. Therefore, it seems reasonable to conclude that replacing saturated fat with unsaturated fat, whether it is primarily polyunsaturated, monounsaturated, or mixtures of both, would result in essentially similar metabolic outcomes in terms of lipoprotein metabolism.

EFFECTS OF INCREASED DIETARY CARBOHYDRATE

As mentioned earlier, an increase in total plasma and VLDL triglyceride concentrations are a common finding in individuals with diabetes. This is particularly true of individuals with NIDDM (31-34). Concern for the presence of hypertriglyceridemia in individuals with diabetes is amplified by the strong relationship between hypertriglyceridemia and the occurrence of CAD in this population (41,42). Because there is extensive evidence that low-fat high-carbohydrate diets lead to an increase in plasma triglyceride concentrations (5–11,13–16,72– 74), this is an obvious drawback to the use of such diets in individuals with diabetes. It has been argued that the carbohydrate-induced hypertriglyceridemic effect of low-fat high-carbohydrate diets can be attenuated if such diets are greatly enriched with dietary fiber (16, 19,21,22). Although this may be true, the amount of dietary fiber needed to accomplish this goal has generally been five to seven times the quantity of dietary fiber that is consumed in the United States or Great Britain and appears to be an amount that most individuals do not find acceptable (75,25). Moreover, it is now apparent that only specific types of dietary fiber may be successful in attenuating carbohydrate-induced hypertriglyceridemia (9,76,77). Therefore, the ability to prevent the deleterious effects of high-carbohydrate diets would depend to a large extent on the ability to institute the necessary modification in the type and amount of dietary fiber. Because the studies that have attempted these modifications have been largely unsuccessful (75,25), it would seem reasonable to assume that adopting a high-carbohydrate low-fat diet would lead to increased triglyceride concentrations in most individuals with diabetes. Indeed, when Anderson et al. (21) reduced the fiber content of his low-fat high-carbohydrate high-fiber (34 g/1000 kcal) diets toward a more conventional level (12 g/1000 kcal), he noted the development of hypertriglyceridemia (+28%, P < 0.01) in his group of individuals with NIDDM who had previously not shown this phenomenon of the high-fiber diet. It must be emphasized that the fiber content of the lowfat high-carbohydrate diet that led to an increase in plasma triglyceride concentrations was not low, but was essentially identical to current dietary recommendations (1). A study by our group was unable to demonstrate any beneficial effect on either carbohydrate or lipoprotein metabolism when dietary fiber was increased from 11 to 27 g/1000 kcal in individuals with NIDDM consuming high-carbohydrate low-fat diets (9). In this study, there was a significant increase in fasting plasma triglyceride concentrations that occurred after the highcarbohydrate diet, which was unchanged by increasing dietary fiber. Thus, it appears that hypertriglyceridemia might be viewed as the likely consequence if individuals with diabetes, particularly NIDDM, complied with the current dietary advice to increase dietary carbohydrate.

It has also been argued that carbohydrate-induced hypertriglyceridemia is a transient phenomenon. However, some studies that have reevaluated the hypertriglyceridemia associated with increased dietary carbohydrate do not support this conclusion (68,78). More importantly, there appears to be a conspicuous absence of any data in individuals with diabetes, which would support an evanescent nature of carbohydrate-induced hypertriglyceridemia. The available data from several controlled metabolic studies have reported the persistence of carbohydrate-induced hypertriglyceridemia for at least 6 wk (8,10,14). This is perhaps best illustrated in a study by our group (8). Fasting plasma triglyceride concentrations were significantly elevated by the end of the 1st wk of the high-carbohydrate low-fat diet and remained unchanged for the remainder of the 6-wk period (Fig. 5). The only long-term study of the effects of low-fat high-carbohydrate diets on plasma triglyceride concentrations is, unfortunately, difficult to interpret. Stone and Connor (79) reported no significant increase in plasma triglyceride in individuals with IDDM after 1 yr of a cholesterol-restricted low-fat high-carbohydrate diet. These results have been interpreted as supporting the view that carbohydrate-induced hypertriglyceridemia is a transitory phenomenon. However, fasting triglyceride concentrations were measured only at the beginning and end of the 1-yr study, and the concentrations of triglyceride was unchanged. Therefore, there was no evidence presented to indicate that the dietary changes resulted in an increase in triglyceride concentrations. The individuals studied by Stone and Connor (79) had IDDM and their glycemia was well controlled. Plasma triglyceride concentrations are rarely elevated in such individuals (34,38). Consequently, these data could also be interpreted as demonstrating that low-fat high-carbohydrate diets do not necessarily lead to an increase in plasma triglyceride concentrations in wellcontrolled individuals with IDDM.

Another potential deleterious effect, which has been described in individuals with diabetes after high-carbohydrate low-fat diets, is a significant reduction in HDL cholesterol concentrations. The observation that high-carbohydrate diets lead to significant reductions in HDL cholesterol appears to be a common phenomenon and has been shown to occur in nondiabetic individuals (5,6,11,12) and in individuals with diabetes mellitus (7,8,13–15). Because HDL cholesterol concentration has been shown to be inversely associated with the development of CAD, it is difficult to easily dismiss the



FIG. 5. Weekly fasting plasma triglyceride concentrations in individuals with non-insulin-dependent diabetes after diets containing either 40% (\bullet) or 60% (\odot) of total calories as carbohydrate (CHO). Data indicate persistent nature of CHO-induced hypertriglyceridemia observed after high-CHO low-fat diets. From Coulston et al. (8). © by the American Diabetes Association.

significance of the decrease in HDL cholesterol associated with high-carbohydrate diets (43–46).

Finally, there is the observation that increasing dietary carbohydrate in individuals with diabetes leads to a significant deterioration in carbohydrate metabolism (7,8,13–15). Specifically, high-carbohydrate diets have resulted in increased daylong glucose and insulin concentrations and increased urinary glucose excretion. This appears to be a common finding in individuals with diabetes, unless the major source of dietary carbohydrate contains relatively large amounts of legumes and leguminous fiber (16,19,21,22).

Although high-carbohydrate diets are generally believed to increase insulin sensitivity (80–83), the experimental evidence in support of this notion is not as convincing as generally perceived. First, most of the studies cited in this regard do not actually measure insulin sensitivity directly and thus do not provide compelling evidence that the use of high-carbohydrate diets enhance insulin action (80–82). There are relatively few studies that have measured insulin action directly, and the results of these appear to be mixed. In nondiabetic glucose-tolerant individuals, Kolterman et al. (83) reported an increase in insulin-stimulated glucose disposal rate after diets that contained 75% of total calories as carbohydrate, whereas Borkman et al. (84) failed to demonstrate any significant improvement in insulinstimulated glucose uptake after diets containing 55% of calories as carbohydrate. It is possible that improvements in insulin action are observed only at the higher carbohydrate intakes used by Kolterman et al. (83). More importantly, however, the small improvements in insulin action demonstrated by Kolterman et al. should not divert attention from the fact that ambient plasma glucose and insulin concentrations were significantly elevated after the high-carbohydrate diet. Thus, the small improvements observed in insulin-stimulated glucose disposal were apparently insufficient to compensate for the hyperglycemic and hyperinsulinemic effects of the increased carbohydrate in individuals with normal glucose tolerance. In the only study to measure insulin action in individuals with diabetes, Garg et al. (85) reported no significant improvement in insulin action after diets containing 60% of calories as carbohydrate. In addition, studies assessing the effects of high-fiber diets on insulin action have been negative (86,87), despite speculation that high-fiber diets lead to improvements in insulin action (88). There is now substantial evidence that suggests that the improvement in postprandial glucose on high-fiber diets results from gastrointestinal effects delaying digestion and absorption (88).

CONCLUSIONS

The major focus of dietary advice for individuals with diabetes over the past several years has been the emphasis on high-carbohydrate low-fat diets. The rationale for this approach appears to be based on the premise that such diets result in a decrease in LDL cholesterol concentrations and ultimately reduce the risk and incidence of CAD in individuals with diabetes. However, replacing dietary fat, or more specifically saturated fat, with dietary carbohydrate may not be the most appropriate means of reducing cardiovascular risk factors in this population. As reviewed herein, there are conflicting reports of the metabolic impact of high-carbohydrate low-fat diets. Much of the confusion seems to be related to the differences in dietary protocols. After careful review, it seems essential to separate the changes due to differences in the relative amount of fat and carbohydrate from those due to variations in the kind of fat and carbohydrate and amount of dietary cholesterol. There is now substantial evidence that suggests that diets containing conventional quantities of fat (~40% of total calories), in which the composition of fat has been modified to reduce saturated fatty acids and dietary cholesterol, appear to offer the best overall control of carbohydrate and lipoprotein metabolism in individuals with diabetes. Data indicating that high-carbohydrate low-fat diets lead to beneficial effects on carbohydrate

or lipoprotein metabolism are confounded either by the lack of suitable experimental control, or by the fact that diets also differed in the type of dietary fat and amount of dietary cholesterol, or were enormously enriched in dietary fiber. When these factors are taken into consideration, there appears to be little evidence in support of the view that substituting carbohydrate for fat in the diets of individuals with diabetes results in any measurable beneficial effect on either carbohdyrate or lipoprotein metabolism. Indeed, it could be argued that the available evidence supports the conclusion that the most characteristic defects in carbohydrate and lipoprotein metabolism in individuals with diabetes have a marked tendency to deteriorate in response to increased dietary carbohydrate. Consequently, we believe that the available evidence does not support the view that individuals with diabetes should be encouraged to follow high-carbohydrate low-fat diets. This statement should not be interpreted to indicate that dietary fat is unimportant. On the contrary, in this review, we have attempted to stress that the available data support the importance of type of dietary fat and amount of dietary cholesterol in the regulation of lipoprotein metabolism in individuals with diabetes. The replacement of saturated fat with unsaturated fat and reduction of dietary cholesterol in the context of conventional diets results in the desired fall in total and LDL cholesterol without the deleterious effects of hyperglycemia, hyperinsulinemia, hypertriglyceridemia, and reduced HDL cholesterol concentrations.

ACKNOWLEDGMENTS

This work was supported in part by Human Health Services Grant M01-RR-00070, General Clinical Research Centers, Division of Research Resources, National Institutes of Health.

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