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Dietary carbohydrate quality and quantity in relation to the incidence of type 2 diabetes: A prospective cohort study of middle-aged and older Korean adults

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ABSTRACT

Objectives: This study aimed to investigate whether dietary glycemic load (GL), glycemic index (GI), and carbohydrate intake were prospectively associated with incident type 2 diabetes mellitus (T2DM) in a middle-aged and older Korean populations.
Methods: Data from the Korean Genome and Epidemiology Study were used. A total of 7294 Korean adults ages 40 y to 69 y and with no previous diagnosis of T2DM or cancer at baseline were followed for 10 y. Dietary GL, GI, and carbohydrate intake were estimated on the basis of participants' responses to a validated, semiquantitative, food-frequency questionnaire at baseline. T2DM was defined according to the World Health Organization and International Diabetes Federation criteria.
Results: During 7.7 y (56 377 person-years) of follow-up time, 1259 participants (17.3%) developed T2DM. Grain and its products (particularly refined and whole grains) were the greatest contributors to dietary GL. In the multivariable Cox models, dietary GL was differentially associated with T2DM risk by sex. Men in the highest quintile demonstrated a higher risk of T2DM incidence than did those with the lowest, energy-adjusted, dietary GL (hazard ratio for fifth vs. first quarter = 1.26; 95% confidence interval, 1.05–1.52; *P* for trend < 0.05) but no association between dietary GL and the risk of T2DM was observed in women. Similar to the findings from the main models, the effect of dietary GL on T2DM incidence according to body mass index, abdominal obesity, and physical activity levels differed substantially by sex.
Conclusions: High GL diets may increase the risk of the development of T2DM in middle-aged and older Korean men but not in women. Nutrition education and emphasis on self-monitoring of dietary carbohydrate quality and quantity of overall diets is necessary in the middle-aged and older Korean populations.

Introduction

Type 2 diabetes mellitus (T2DM), which is characterized by impaired insulin action and secretion [1], is a serious noncommunicable disease that affects 514 million patients globally [2]. Over the past 4 decades, the prevalence of T2DM has increased by 7% in Korea and surpasses the global average of 4% [3]. In Korea, diabetes was the sixth leading cause of death and the fourth leading cause of disability [4]. In 2015, T2DM affected 12.0% men and 9.4% women ages ≥30 y [5].

Because poorly controlled T2DM may increase the risk of cardiovascular disease and diabetes-related complications such as retinopathy, neuropathy, diabetic foot, and premature death [6], the prevention of diabetes is a critical public health issue. The International Diabetes Federation emphasizes a healthy diet that limits sugar and fat and regular exercise as key strategies for diabetes prevention [2]. In addition, many epidemiologic studies have documented the important roles of dietary factors, particularly dietary carbohydrates, in the development and management of T2DM [7].

As part of a continuing effort to capture the glycemic effects of specific carbohydrate sources, two indices were developed: Dietary glycemic index (GI), which measures the quality of dietary carbohydrates [8] and dietary glycemic load (GL), which measures both

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the quality and quantity of consumed carbohydrates [9]. Although the associations between dietary GL, GI, or carbohydrate intake and T2DM have been widely investigated, the findings on their associations are indeterminate. Moreover, since most previous prospective studies involved Western populations [10,11], the results may not be generalizable to Asian populations among whom the total energy intake from carbohydrates are much higher than that observed in Western populations. Asian adults obtain >60% to 65% of their total daily energy from carbohydrates [5,12] whereas American and European adults receive <50% of their total daily energy from carbohydrates [13,14]. The differences in the sources and amounts of dietary carbohydrates result in substantial differences in dietary GL and GI and their associations with T2DM among different populations of the world. However, little is known about the prospective effect of carbohydrates on T2DM incidence among Asian populations. Particularly, in the Korean population, only cross-sectional studies have been conducted and no associations of dietary GL and GI with T2DM were observed [15].

Therefore, this study aimed to investigate whether dietary GL, GI, or carbohydrate intake was associated with T2DM incidence and whether this association may be modified by various factors in middle-aged and older Korean populations.

Methods

Data source and study population

We used data from the Ansan-Ansung Cohort Study of the Korean Genome and Epidemiology Study (KoGES), which is an ongoing large-scale prospective study that is conducted by the Korea National Institute of Health [16]. In brief, the Ansan-Ansung community-based cohort study was initiated in 2001–2002 to explore dietary and lifestyle factors that affect chronic disease in the Korean population. A total of 10 030 adults ages 40 y to 69 y who resided in Ansan (urban) and Ansung (rural) were recruited. Participants of the cohort study were followed up every 2 y and we used the follow-up data until 2012 for the study.

During each examination, information on sociodemographic and lifestyle characteristics, medical history, reproductive health (for women), anthropometric measures, and blood and urine tests was collected by trained staff and interviewers using standard methods and protocols. The final analytical sample of the present study consisted of 7294 people (3502 men and 3792 women) after excluding patients with T2DM (n = 1237) and cancer (n = 201) at baseline, those who did not attend at least 1 follow-up visit until 2012 (n = 814), those with no dietary data (n = 282), those who reported energy intake of <500 kcal/d or >5,000 kcal/d (n = 75), and those with missing information on the covariates (n = 127).

Dietary assessment, dietary glycemic load, glycemic index, and carbohydrate intake

During the baseline examination, the dietary data of the study participants were collected by well-trained interviewers using a 103-item semiquantitative food-frequency questionnaire (FFQ). This validated FFQ was developed to assess the usual dietary intake of Korean adults who participated in the KoGES [17]. All study participants were asked how often they consumed each unit of a particular food item during the last year. Nine responses for consumption frequency ranging from never or seldom to ≥3 times per day were possible [17]. The usual intake of foods and nutrients including carbohydrates were calculated by multiplying the consumption frequency of each unit of food item by the nutrient content of each unit of food item using a nutrient database (CAN-Pro 2.0) developed by the Korean Nutrition Society [18].

Furthermore, we calculated the daily dietary GI and GL with individual food and nutrient intake data obtained from the FFQs. The GI values of each food item were determined on the basis of previous literature on estimated GI for commonly consumed foods by Koreans with glucose as a reference (GI value for glucose: 100) [19,20]. Where multiple GI values for a single food were available, the mean value was used in this study.

To calculate the mean daily dietary GI for each participant, we first multiplied the consumption frequency and carbohydrate content of each food item by its GI value and summed the products. Second, we divided the value by the total amount of daily carbohydrate intake [21]. The mean daily dietary GL was calculated in a similar manner but divided by 100 instead of the total amount of daily carbohydrate intake [9]. Some FFQ items such as meat, poultry, fish, shellfish, eggs, and cheese have little or no carbohydrates and barely raise blood glucose levels even when large amounts are consumed [19]; therefore, no value was assigned to these food items. Dietary variables including dietary GL, GI, and carbohydrate intake were adjusted for total energy intake using the residual method [22].

To explore food group contributions to daily dietary GL, 103 food items of the FFQ were aggregated into 15 main food groups (grain and its products; starchy vegetables; sugar and sweets; legumes and legume products; nuts and seeds; vegetables; mushrooms; fruits; meat and poultry; eggs; fish; seaweed; milk and dairy products; fats and oils; and beverages) on the basis of the food group classification system that was used in previous literature [23]. The grains and its products group, which is a major source of carbohydrates, were further subgrouped into refined grains; whole grains; noodles, dumplings, and instant ramen; breads; rice cakes; cakes, and snack cookies; cereals; and pizza and hamburger.

Definition of type 2 diabetes mellitus

During the biennial follow-up examination, fasting blood glucose levels were measured after at least 8 h of fasting and a 2-hour 75-g oral glucose tolerance test was conducted. In accordance with the definition of the World Health Organization [24] and American Diabetes Association [25], incident T2DM was diagnosed if the participant had fasting blood glucose levels ≥126 mg/dL or postprandial 2-h glucose levels ≥200 mg/dL at the time of the follow-up examinations. Additionally, we also categorized participants who reported that they were newly diagnosed with T2DM or under treatment with insulin/oral antidiabetic drugs at or between the follow-up examinations as incident cases.

Statistical analyses

Study participants were divided into quintiles by dietary GL, GI, and carbohydrate intake. The baseline characteristics of the study participants across the quintile of dietary GL were described using the Mantel-Haenszel χ^2 test for categorical variables and a generalized linear regression for continuous variables. Using multivariable Cox proportional hazards models, hazard ratios (HRs) and 95% confidence intervals (CIs) for incident T2DM were estimated across the quintiles of dietary GL, GI, and carbohydrate intake. The potential covariates that were entered into the model were age (y), area of residence (Ansan, Ansung), education level (elementary school or lower [<7 y of school completed], middle/high school [7–12 y], college or higher [>12 y]), smoking status (never, former smoker, current smoker), alcohol consumption (g/d), physical activity (metabolic equivalent task[MET]-h/wk), body mass index (BMI; kg/m^2), family history of diabetes (determined on the basis of self-reports: yes, no), menopausal status (women only: yes, no), total daily energy intake (kcal/d), and energy-adjusted intake of fat, protein, and fiber (all, g/d).

We further conducted Cox proportional hazards models stratified by BMI status, abdominal obesity, and physical activity levels to evaluate the effect modification of these variables. In addition, we performed a sensitivity analysis after excluding individuals with impaired glucose tolerance (determined by fasting glucose levels <126 mg/dL and glucose levels of either ≥140 or <200 mg/dL 2 h after a 75 g oral glucose challenge test [26]).

All statistical analyses were conducted with SAS software version 9.4 (SAS Institute, Cary, NC). A *P*-value of < 0.05 was considered statistically significant on the basis of a two-sided probability.

Results

The baseline characteristics of the study participants by quintile of dietary GL among men and women are presented in Tables 1 and 2, respectively. Both men and women in the highest quintile of dietary GL were more likely to be older and spend more time performing physical activity and less likely to live in urban areas, be highly educated, and drink alcohol. In addition, they demonstrated high GI and carbohydrate intake and low intake of protein, fat, and fiber. In men and women, grain and its products accounted for approximately 82% of the total dietary GL (Suppl. Table 1). However, there was a minor difference in major food sources, which contributed to dietary GL differences between men and women. In men, refined grains (47.0%), whole grains (25.6%), noodles or dumplings (6.0%), fruits (4.6%), and beverages (3.3%) comprised the majority dietary GL whereas the major contributors to dietary GL in women were whole grains (36.2%), refined grains (35.8%), fruits (6.6%), noodles or dumplings (4.2%), and vegetables (3.6%).

During an average follow-up period of 7.7 y (56 377 person-years), 1259 participants (676 men and 583 women) developed T2DM. In Model 2, which was adjusted for age and T2DM risk factors, dietary GL was not associated with an increased risk of incident T2DM among both men and women. After additional adjustment for dietary variables such as total energy intake and energy-adjusted intake of fat, protein, and dietary fiber (Model 3), the associations between dietary GL and T2DM incidence differed by sex (Table 3). Compared with men in the lowest quintile of energy-adjusted dietary GL, men in the highest quintile demonstrated a significantly higher incidence of T2DM (adjusted HR: 1.26; 95% CI, 1.05–1.52; P for trend = 0.04) but this association remained non-significant in women. In sensitivity analyses that excluded individuals with impaired glucose tolerance at baseline, the results were unchanged with HRs of 1.23 (95% CI, 1.01–1.49; P for trend = 0.03) in men and 0.99 (95% CI, 0.82–1.19; P for trend = 0.22) in women for dietary GL in the highest versus lowest quintile (Suppl. Table 2).

To clarify the relationship of carbohydrate quantity or quality to T2DM risk, we also examined the relationship of dietary carbohydrate intake and GI with risk of T2DM incidence (Table 4). When total carbohydrate intake, which indicates the quantity of dietary carbohydrates, was entered into a multivariable model, a significant increasing trend of T2DM risk across the quintile was observed in men (P for trend = 0.04) but not in women. However, dietary carbohydrate quality that was measured by dietary GI was not associated with a high risk of T2DM in both men and women. HRs for those at the highest quintile compared with those in the lowest quintile of energy-adjusted dietary GI were 1.08 (95% CIs, 0.93–1.26) for men and 1.04 (95% CIs, 0.89–1.22) for women.

We further investigated whether BMI status, abdominal obesity, and physical activity level modified the association between dietary GL and T2DM risk (Table 5). Positive associations of energy-adjusted GL with T2DM incidence were observed only among men with overweight/obesity, abdominal obesity, or a low level of physical activity. Stratification by BMI status at baseline indicated a positive association between dietary GL and risk of T2DM incidence among men of overweight/obesity but no association was observed among men with a normal weight. The adjusted HR for men with overweight/obesity in the highest compared with those in the lowest quintile of energy-adjusted dietary GL was 1.43 (95% CI, 1.14–1.79; P for trend = 0.03). Men with abdominal obesity in the highest quintile had a 1.87-fold risk of T2DM incidence (95% CI, 1.21–2.89) than those in the lowest quintile of dietary GL (P for trend = 0.01).

Among men with a low level of physical activity (lower two quintiles of metabolic equivalent task-hours/d), the adjusted HR across the extreme quintiles of dietary GL was 1.28 (95% CI, 1.02–1.62; P for trend = 0.02) in men. However, there were no effect modifications by BMI status, abdominal obesity, and physical activity levels on the relationship between energy-adjusted dietary GL and T2DM among women, which is consistent with our findings on the main effect of dietary GL on the incidence of T2DM (Table 5).

Discussion

In this prospective population-based cohort study, we observed a significant association between dietary GL and increasing T2DM incidence in middle-aged and older Korean men but not women. During an average follow-up period of 7.7 y, those in the highest quintile had approximately a 26% higher rate of incident T2DM than did those in the lowest quintile of energy-adjusted dietary GL in men. Furthermore, we observed an effect modification for the association between dietary GL, indicators of quality and quantity of carbohydrates, and T2DM in Korean men by BMI status, abdominal obesity, and physical activity levels.

Our findings of the positive relationship between dietary GL and T2DM incidence among Korean men is in accordance with the results from previous epidemiologic studies. A pooled analysis of three prospective cohort studies reported that people who consumed high-GL diets demonstrated a 10% higher relative risk (RR; 95% CI, 2%–18%) of T2DM [27]. In a recent meta-analysis of 21 cohort studies, the RR for T2DM significantly increased with dietary GL (RR: 1.03; 95% CI, 1.00–1.05 per 20 units) [28]. Furthermore, findings from another Asian study were similar. A prospective study of 64 227 middle-aged Chinese women reported that dietary GL notably increased the risk of developing T2DM (RR: 1.34; 95% CI, 1.13–1.58) [29].

Although the exact mechanisms between dietary GL and T2DM are unclear, two plausible pathways have been proposed. First, insulin resistance-induced pancreatic β-cell dysfunction may be an indirect mechanism of action. High GL/GI diets increase levels of blood glucose and free fatty acids [30]. Chronic exposure to elevated levels of blood glucose and free fatty acids can induce β-cell failure. Together, these processes may disrupt the function of pancreatic β-cells and ultimately lead to T2DM [31]. The other mechanism may be that high GL/GI diets directly contribute to insulin resistance, which can potentially result in glucose intolerance and T2DM [32].

Previous studies of Western populations documented inconsistent findings on relationships between dietary GL and T2DM incidence. Unlike the findings of this study, the Nurses' Health Study II [10], the European Prospective Investigation into Cancer and Nutrition cohort [11], and one Japanese study [33] reported no association between dietary GL and T2DM. A likely explanation for the inconsistency with previous findings could be the differences in carbohydrate sources and amounts among different study populations. The participants in our study mainly consumed rice as a source of carbohydrate. In addition, they consumed >70% of their total daily energy from carbohydrates, which is considerably higher than that of Western populations [13,34] as well as that of other Asian populations [12]. Furthermore, in the present study, the mean GL values were 225 in men and 213 in women, which are higher than those reported in existing studies of American (range, 117–150) [27, 35] and European (range, 100–120) [11, 36] populations.

In this study, dietary GL was positively associated with the incidence of T2DM in men but not in women. The reasons for the difference in this association by sex are unclear. One explanation could be that women are more sensitive to insulin and show better glucose homeostasis than men because of higher estrogen levels and body fat mass [37,38]. Differences in estrogen levels and body-fat distribution may have caused the difference in the association between dietary GL and T2DM incidence by sex. Moreover, many epidemiologic studies have reported that a high intake of whole grains, fruits, and vegetables is favorably associated with a reduced risk of T2DM [39–41].

In the current study, the contribution of refined grains (47%) to dietary GL was dominant in men but in women, whole grains (36%) and refined grains (36%) contributed to dietary GL at similar rates. Additionally, consuming more fruits and vegetables contributed more to dietary GL in women than in men. Therefore, in accordance with previous findings, differences in the contribution of foods to dietary GL between men and women (especially the high contribution of whole grains, fruits, and vegetables to dietary GL in women) may differentially influence the development of T2DM by sex.

Our findings on the effect modification by various factors are consistent with those of previous studies [10,29]. In this study, the association between dietary GL and T2DM risk was more pronounced among men with a higher BMI and abdominal obesity. Particularly, in obese individuals, increased fat-mass elevates free fatty acid levels in the body and thereby decrease the secretion of

Table 1
Characteristics of study participants at baseline by quintile of dietary glycemic load among 3502 men from the Korean Genome and Epidemiology Study (Ansan-Ansung)

	Quintile of energy-adjusted dietary glycemic load score				
	1 (lowest)	2	3	4	5 (highest)
Quintile mean score	200	209	217	223	276
Age (y)	49.4 ± 0.3*	50.0 ± 0.3	50.7 ± 0.3	51.4 ± 0.3	54.8 ± 0.3
Urban area (Ansan) residents (%)	62.3	71.8	62.6	50.8	23.4
Higher education (%)	27.3	27.3	22.9	19.0	13.6
Current smoker (%)	50.9	45.5	48.9	46.9	51.3
Family history of diabetes (%)	11.0	9.7	10.7	9.3	7.6
Physical activity (MET-h/wk)	168.2 ± 3.9	153.6 ± 3.9	164.7 ± 3.9	181.5 ± 3.9	203.4 ± 4.0
Alcohol consumption (g/d)	19.9 ± 1.2	17.2 ± 1.3	16.1 ± 1.2	14.1 ± 1.2	13.2 ± 1.3
Body mass index (kg/m^2)	24.4 ± 0.1	24.5 ± 0.1	24.2 ± 0.1	24.0 ± 0.1	23.8 ± 0.1
Daily dietary intake†					
Total energy intake (kcal)	2214 ± 26	2017 ± 27	1947 ± 26	1848 ± 26	2137 ± 27
Glycemic index	60.8 ± 0.1	63.4 ± 0.1	64.9 ± 0.1	66.3 ± 0.1	68.6 ± 0.1
Carbohydrate (g)	311.4 ± 1.1	343.0 ± 1.2	351.9 ± 1.1	362.7 ± 1.1	386.5 ± 1.2
Protein (g)	80.8 ± 0.4	72.1 ± 0.4	68.7 ± 0.4	64.6 ± 0.4	57.9 ± 0.4
Fat (g)	48.8 ± 0.4	37.9 ± 0.4	35.1 ± 0.4	31.8 ± 0.4	22.9 ± 0.4
Dietary fiber (g)	7.2 ± 0.1	7.3 ± 0.1	7.1 ± 0.1	6.7 ± 0.1	6.3 ± 0.1
Food groups					
Grain and its products (g)	653.1 ± 5.3	764.6 ± 5.4	806.5 ± 5.3	857.3 ± 5.3	962.6 ± 5.4
Refined grains (g)	155.7 ± 11.3	255.6 ± 11.3	404.7 ± 11.1	595.7 ± 11.2	700.6 ± 11.4
Whole grains (g)	354.1 ± 12.8	385.2 ± 12.9	283.4 ± 12.7	141.4 ± 12.7	170.3 ± 13.0
Noodles/dumpling (g)	111.7 ± 3.5	94.5 ± 3.6	88.0 ± 3.5	89.7 ± 3.5	65.4 ± 3.6
Bread (g)	11.9 ± 1.0	12.0 ± 1.0	12.4 ± 1.0	12.5 ± 1.0	10.1 ± 1.0
Fruits (g)	269.6 ± 11.4	266.8 ± 11.4	259.6 ± 11.3	264.1 ± 11.3	213.4 ± 11.5
Vegetables (g)	317.6 ± 7.9	317.9 ± 7.9	315.8 ± 7.8	314.6 ± 7.8	291.5 ± 8.0
Beverages (g)	96.9 ± 4.5	89.9 ± 4.5	87.6 ± 4.4	90.6 ± 4.4	92.7 ± 4.5
Sugar and sweets (g)	7.0 ± 0.3	7.1 ± 0.3	6.7 ± 0.3	7.3 ± 0.3	6.0 ± 0.3
Milk and dairy products (g)	139.4 ± 5.5	113.0 ± 5.5	101.8 ± 5.4	90.4 ± 5.4	58.9 ± 5.5
Potatoes, starchy vegetables (g)	16.5 ± 0.9	17.5 ± 0.9	16.2 ± 0.9	15.4 ± 0.9	15.2 ± 0.9

MET, metabolic equivalent task
* Mean ± standard error (all such values)
† All dietary intake variables were energy-adjusted.

Table 2
Characteristics of study participants at baseline by quintile of dietary glycemic load among 3792 women from the Korean Genome and Epidemiology Study (Ansan-Ansung)

	Quintile of energy-adjusted dietary glycemic load score				
	1 (lowest)	2	3	4	5 (highest)
Quintile mean score	188	192	199	217	269
Age (y)	48.2 ± 0.3*	50.5 ± 0.3	52.6 ± 0.3	53.1 ± 0.3	56.4 ± 0.3
Urban area (Ansan) residents (%)	60.0	63.6	48.8	46.3	16.2
Higher education (%)	10.8	10.1	4.6	4.2	2.2
Current smoker (%)	5.3	3.0	4.2	2.1	3.7
Family history of diabetes (%)	14.6	12.9	11.1	10.4	7.0
Physical activity (MET-h/wk)	148.4 ± 3.7	151.7 ± 3.6	158.2 ± 3.6	164.0 ± 3.6	194.6 ± 3.7
Alcohol consumption (g/d)	19.9 ± 1.2	17.2 ± 1.3	16.1 ± 1.2	14.1 ± 1.2	13.2 ± 1.3
Body mass index (kg/m^2)	24.5 ± 0.1	24.7 ± 0.1	25.1 ± 0.1	24.7 ± 0.1	24.9 ± 0.1
Daily dietary intake†					
Total energy intake (kcal)	2132 ± 210	1909 ± 211	1844 ± 211	1855 ± 211	2083 ± 210
Glycemic index	56.8 ± 0.9	60.0 ± 0.9	61.8 ± 0.9	63.5 ± 0.9	66.3 ± 0.9
Carbohydrate (g)	301.8 ± 8.5	333.9 ± 8.5	346.1 ± 8.5	353.9 ± 8.5	375.4 ± 8.5
Protein (g)	74.6 ± 3.0	65.2 ± 3.0	61.8 ± 3.0	58.2 ± 3.0	51.4 ± 3.0
Fat (g)	42.7 ± 2.8	31.6 ± 2.8	27.1 ± 2.8	24.8 ± 2.8	16.7 ± 2.8
Dietary fiber (g)	8.7 ± 0.8	8.8 ± 0.8	8.7 ± 0.8	8.1 ± 0.8	7.3 ± 0.8
Food groups					
Grain and its products (g)	559.3 ± 8.7	687.0 ± 8.8	747.6 ± 8.9	794.9 ± 9.0	919.0 ± 9.1
Refined grains (g)	100.4 ± 16.2	145.7 ± 16.5	216.9 ± 16.5	478.8 ± 16.7	643.7 ± 17.1
Whole grains (g)	334.5 ± 19.2	439.1 ± 19.5	433.6 ± 19.6	219.8 ± 19.8	197.7 ± 20.2
Noodle/dumpling (g)	80.4 ± 4.8	66.8 ± 4.9	65.8 ± 4.9	65.4 ± 5.0	52.9 ± 5.1
Bread (g)	18.9 ± 1.4	15.2 ± 1.4	13.0 ± 1.4	12.4 ± 1.4	9.6 ± 1.5
Fruits (g)	552.8 ± 112.8	519.6 ± 112.9	498.3 ± 112.9	499.3 ± 112.9	401.8 ± 112.6
Vegetables (g)	317.4 ± 56.4	303.9 ± 56.4	308.3 ± 56.4	305.8 ± 56.4	287.7 ± 56.3
Beverages (g)	80.1 ± 33.8	69.0 ± 33.8	62.2 ± 33.8	69.5 ± 33.8	67.9 ± 33.7
Sugar and sweets (g)	8.0 ± 2.2	7.9 ± 2.2	7.5 ± 2.2	7.6 ± 2.2	7.2 ± 2.2
Milk and dairy products (g)	242.1 ± 43.2	186.4 ± 43.2	154.1 ± 43.2	142.5 ± 43.3	100.8 ± 43.1
Potatoes, starchy vegetables (g)	42.2 ± 10.3	42.2 ± 10.3	43.8 ± 10.3	43.2 ± 10.3	41.5 ± 10.3

MET, metabolic equivalent task
* Mean ± standard error (all such values)
† All dietary intake variables were energy-adjusted.

Table 3
Adjusted HRs (with 95% CIs) for T2DM by quintile of dietary glycemic load in the Korean Genome and Epidemiology Study (Ansan-Ansung)*

	Quintile of energy-adjusted dietary glycemic load score					
	1 (lowest)	2	3	4	5 (highest)	*P* for trend†
Men (n = 3502)						
Cases of T2DM	147	150	135	121	123	
Person-years	5199	5254	5289	5443	5241	
HR (95% CI)						
Model 1‡: Adjusted for age	1.00	1.00 (0.89–1.13)	1.05 (0.94–1.19)	0.99 (0.88–1.11)	1.03 (0.91–1.16)	0.69
Model 2‡: Adjusted for model 1 + T2DM risk factors	1.00	0.99 (0.88–1.12)	1.06 (0.95–1.20)	1.01 (0.90–1.14)	1.09 (0.96–1.23)	0.18
Model 3‡: Adjusted for model 2 + dietary variables	1.00	1.05 (0.92–1.20)	1.16 (1.01–1.34)	1.14 (0.98–1.32)	1.26 (1.05–1.52)	0.04†
Women (n = 3792)						
Cases of T2DM	103	118	132	107	123	
Person-years	5960	6041	6078	5919	5953	
HR (95% CI)						
Model 1‡: Adjusted for age	1.00	0.88 (0.79–0.98)	0.90 (0.80–1.00)	1.01 (0.90–1.12)	0.96 (0.85–1.07)	0.50
Model 2‡: Adjusted for model 1 + T2DM risk factors	1.00	0.88 (0.79–0.98)	0.91 (0.81–1.02)	1.02 (0.91–1.14)	0.99 (0.88–1.12)	0.18
Model 3‡: Adjusted for model 2 + dietary variables	1.00	0.89 (0.78–1.00)	0.91 (0.80–1.05)	1.04 (0.90–1.20)	1.00 (0.83–1.19)	0.20

CI, confidence interval; HR, hazard ratio; T2DM, type 2 diabetes mellitus

* *P*-value for trend obtained from the analyses of dietary glycemic load as continuous variables

† $P < 0.05$

‡ Model 1 was adjusted for age (y); Model 2 was adjusted as that in Model 1 plus area of residence (Ansan or Ansung), education level (≤elementary school, middle/high school, or ≥college), smoking status (never, past, or current), alcohol consumption (g/d), physical activity (MET-h/wk), body mass index (kg/m^2), family history of diabetes (yes or no), and menopausal status (yes or no; women only); Model 3 was adjusted as that in Model 2 plus total energy intake (kcal/d), and energy-adjusted intake of fat, protein, and fiber (all, g/d).

adiponectin (insulin sensitizer) by stimulating fatty acid oxidation, which triggers insulin resistance and T2DM [42,43]. In addition, we observed that men with low levels of physical activity were more susceptible to T2DM as similarly reported in previous literature [44]. Both physical activity and insulin activate glucose transporters, which stimulate glucose uptake in skeletal muscles, via different signaling pathways [45].

Our study had several limitations. First, study participants were recruited from specific parts of Korea (Ansan and Ansung) among those between 40 y and 69 y of age; therefore, the study results may not be applicable to the general Korean population. An additional investigation of a representative population of Koreans that covers a broader age group is warranted. Second, we evaluated dietary GL/GI on the basis of dietary information that was obtained from FFQ, which was not originally developed for GL/GI calculations. FFQ includes a restricted number of food items and if many carbohydrate-rich foods were excluded from the FFQ, GL or GI may have been underestimated or vice versa. However, the FFQ used in this study have been sufficiently validated to estimate carbohydrate intake [17].

Despite these limitations, to the best of our knowledge, this is the first prospective study to investigate the association between dietary GL and the incidence of T2DM by sex as well as the effect modification by various factors among Koreans in consideration of dietary variables that are related to carbohydrate intake. Our study provides additional insights into the importance of dietary GL in incident T2DM among Korean men on the basis of a population with a substantially high carbohydrate intake diet and expands on previous findings with regard to Western populations with a low carbohydrate intake.

Conclusions

Our findings demonstrated that both the quality and quantity of carbohydrate intake increased the development of T2DM in Korean men, which indicates a difference by sex in the prospective relationship between dietary GL and T2DM risk. The sex disparities that are presented in this study may be attributed to differences in pathophysiological mechanisms of T2DM and food sources that contribute to dietary GL between men and women. Based on our findings from the large, prospective, cohort study of Koreans, sex-specific strategies for T2DM prevention should be designed in the context of an individual's dietary pattern.

Furthermore, the associations between dietary GL and T2DM differed by BMI status (normal vs. overweight or obese) and abdominal obesity among men. These associations were also

Table 4
Adjusted HRs (with 95% CIs) for T2DM by quintile of total carbohydrate and dietary glycemic index in the Korean Genome and Epidemiology Study (Ansan-Ansung)*

	Quintiles of energy-adjusted score					
	1 (lowest)	2	3	4	5 (highest)	*P* for trend†
Men (n = 3502)						
Total carbohydrate†	1.00	0.98 (0.85–1.14)	1.03 (0.87–1.22)	1.03 (0.85–1.25)	1.17 (0.91–1.50)	0.04‡
Glycemic index	1.00	1.06 (0.94–1.20)	1.08 (0.95–1.22)	0.99 (0.87–1.14)	1.08 (0.93–1.26)	0.55
Women (n = 3792)						
Total carbohydrate	1.00	1.02 (0.89–1.16)	1.07 (0.92–1.25)	1.08 (0.90–1.28)	1.19 (0.96–1.49)	0.11
Glycemic index	1.00	0.97 (0.86–1.09)	0.99 (0.88–1.12)	1.00 (0.88–1.14)	1.04 (0.89–1.22)	0.59

CI, confidence interval; HR, hazard ratio; T2DM, type 2 diabetes mellitus

* All models were adjusted for age (y); area of residence (Ansan or Ansung); education level (≤elementary school, middle/high school, or ≥college); smoking status (never, past, or current); alcohol consumption (g/d); physical activity (MET-h/wk); body mass index (kg/m^2); family history of diabetes (yes or no); menopausal status (yes or no; women only); total energy intake (kcal/d); and energy-adjusted intake of fat, protein, and fiber (all, g/d).

† *P* for trend obtained from the analyses of dietary glycemic load, carbohydrate intake, and glycemic index as continuous variables

‡ $P < 0.05$.

Table 5
Adjusted HRs (with 95% CIs) for T2DM by quintile of dietary glycemic load by baseline BMI, abdominal obesity, and physical activity in the Korean Genome and Epidemiology Study (Ansan-Ansung)*

	Quintile of energy-adjusted dietary glycemic load score					
	1 (lowest)	2	3	4	5 (highest)	*P* for trend†
Men (n = 3502)						
Weight status‡						
BMI <23 kg/m² (n = 1197)	1.00	0.92 (0.72–1.17)	0.99 (0.78–1.27)	0.93 (0.71–1.22)	0.97 (0.71–1.34)	0.71
BMI ≥23 kg/m² (n = 2305)	1.00	1.11 (0.94–1.30)	1.25 (1.05–1.48)	1.23 (1.02–1.49)	1.43 (1.14–1.79)	0.03§
Abdominal obesity						
No (n = 2801)	1.00	0.97 (0.83–1.12)	1.11 (0.95–1.30)	1.01 (0.85–1.20)	1.15 (0.94–1.41)	0.13
Yes (n = 701)	1.00	1.48 (1.09–2.01)	1.33 (0.94–1.87)	1.83 (1.29–2.59)	1.87 (1.21–2.89)	0.01§
Physical activity‖						
Low (n = 1396)	1.00	1.04 (0.87–1.25)	1.11 (0.93–1.33)	1.06 (0.87–1.29)	1.28 (1.02–1.62)	0.02§
High (n = 2106)	1.00	1.04 (0.85–1.27)	1.23 (0.98–1.55)	1.26 (0.98–1.61)	1.19 (0.88–1.61)	0.95
Women (n = 3792)						
Weight status‡						
BMI <23 kg/m² (n = 1140)	1.00	0.83 (0.68–1.03)	0.84 (0.66–1.06)	0.94 (0.73–1.22)	0.95 (0.70–1.30)	0.32
BMI ≥23 kg/m² (n = 2652)	1.00	0.91 (0.78–1.06)	0.96 (0.81–1.13)	1.09 (0.92–1.30)	1.01 (0.81–1.25)	0.51
Abdominal obesity						
No (n = 2478)	1.00	0.88 (0.77–1.02)	0.94 (0.80–1.10)	1.06 (0.89–1.26)	1.05 (0.85–1.31)	0.14
Yes (n = 1314)	1.00	0.90 (0.70–1.17)	0.87 (0.67–1.14)	1.04 (0.79–1.37)	0.93 (0.68–1.27)	0.74
Physical activity‖						
Low (n = 1508)	1.00	0.87 (0.72–1.05)	0.91 (0.73–1.13)	1.03 (0.82–1.29)	1.05 (0.79–1.39)	0.18
High (n = 2284)	1.00	0.90 (0.76–1.06)	0.92 (0.77–1.10)	1.05 (0.87–1.27)	0.98 (0.78–1.23)	0.42

BMI, body mass index; CI, confidence interval; HR, hazard ratio; T2DM, type 2 diabetes mellitus
* All models were adjusted for age (y); area of residence (Ansan or Ansung); education level (≤elementary school, middle/high school, or ≥college); smoking status (never, past, or current); alcohol consumption (g/d); physical activity (MET-h/wk); body mass index (kg/m²); family history of diabetes (yes or no); menopausal status (yes or no; women only); total energy intake (kcal/d); and energy-adjusted intake of fat, protein, and fiber (all, g/d).
† *P* for trend obtained from the analyses of dietary glycemic load, carbohydrate intake, and glycemic index as continuous variables
‡ The model was not adjusted for BMI
§ $P < 0.05$
‖ Physical activity levels were categorized into two groups (low vs. high) on the basis of the quintile of activity level. Participants in the lower two quintiles of physical activity level were classified in the low physical activity group and those in the upper three quintiles in the high physical activity group. The model was not adjusted for physical activity.

strengthened by lifestyle characteristics such as a low physical activity level. Therefore, to prevent or postpone the development of T2DM, education should emphasize regular exercise and the continuous monitoring of GL within the overall diet. To better understand the effect of dietary GL in the etiology of T2DM, further intervention studies are warranted.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nut.2018.04.011.

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