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Low-, medium- and high-glycaemic index carbohydrates and risk of type 2 diabetes in men

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Abstract

Findings on dietary glycaemic index (GI) and glycaemic load (GL) as risk factors for type 2 diabetes have been controversial. We examined the associations of dietary GI and GL and the associations of substitution of lower-GI carbohydrates for higher-GI carbohydrates with diabetes risk in a cohort of Finnish men. The cohort consisted of 25 943 male smokers aged 50–69 years. Diet was assessed, at baseline, using a validated diet history questionnaire. During a 12-year follow-up, 1098 incident diabetes cases were identified from a national register. Cox proportional hazard modelling was used to estimate the risk of diabetes, and multivariate nutrient density models were used to examine the effects of substitution of different carbohydrates. Dietary GI and GL were not associated with diabetes risk; multivariate relative risk (RR) for highest *v.* lowest quintile for GI was 0·87 (95 % CI 0·71, 1·07) and for GL 0·88 (95 % CI 0·65, 1·17). Substitution of medium-GI carbohydrates for high-GI carbohydrates was inversely associated with diabetes risk (multivariate RR for highest *v.* lowest quintile 0·75, 95 % CI 0·59, 0·96), but substitution of low-GI carbohydrates for medium- or high-GI carbohydrates was not associated with the risk. In conclusion, dietary GI and GL were not associated with diabetes risk, and substitutions of lower-GI carbohydrates for higher-GI carbohydrates were not consistently associated with a lower diabetes risk. The associations of dietary GI and GL with diabetes risk should be interpreted by considering nutritional correlates, as foods may have different properties that affect risk.

Key words: Glycaemic index: Glycaemic load: Carbohydrates: Type 2 diabetes: Alpha-Tocopherol, Beta-Carotene Cancer Prevention Study

The increasing prevalence of type 2 diabetes worldwide emphasises the importance of understanding its different risk factors. Obesity and physical inactivity are known to be associated with increased risk of type 2 diabetes, and lifestyle trials have demonstrated that the risk of type 2 diabetes among high-risk individuals can be halved[1].

Attention is currently being directed to dietary carbohydrates, a major source of dietary energy, as a risk factor for type 2 diabetes. The quality of carbohydrates has been suggested to be crucial; carbohydrates that induce a rapid elevation in blood glucose have detrimental metabolic effects compared with carbohydrates that elevate blood glucose more slowly and steadily[2]. A measure that ranks foods on the basis of the blood glucose response that they produce upon ingestion (compared with the response of a reference glucose solution or white wheat bread) is the glycaemic index (GI)[3]. Glycaemic load (GL) takes into account the amount of carbohydrates consumed in addition to GI[4].

Findings regarding the role of dietary GI and GL in type 2 diabetes risk have been inconsistent. Some cohort studies have reported a positive association between GI and diabetes risk[4–8], whereas others have not observed such association[9–15], and some cohort studies have reported a positive association between GL and diabetes risk[6,8,16], whereas most have not[4,5,7,10–15]. A meta-analysis of studies published up to March 2007 found a significant positive association between the dietary GI and risk of type 2 diabetes, fully adjusted relative risk 1·20 (95 % CI 1·04, 1·38) between the highest and lowest quintiles[17]. Since nearly all studies that have observed a positive association between the dietary GI and diabetes risk have been comprised solely of women and studies including men have mostly found no association, we examined the associations of dietary GI and GL with diabetes risk in a cohort of Finnish men. In addition, we investigated the associations of substituting lower-GI carbohydrates for higher-GI carbohydrates with diabetes

Abbreviations: ATBC, Alpha-Tocopherol, Beta-Carotene Cancer Prevention; E%, percentage of energy; GI, glycaemic index; GL, glycaemic load.

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risk, not analysed in previous studies, to better model the original aim of the GI concept to choose lower-GI carbohydrates instead of higher-GI carbohydrates.

Methods

Study population

The Alpha-Tocopherol, Beta-Carotene Cancer Prevention (ATBC) Study was a randomised, double-blind, placebo-controlled primary prevention trial testing whether supplementation with α-tocopherol, β-carotene or both would reduce the incidence of lung cancer and other cancers[18]. A total of 29 133 Finnish male smokers were recruited between 1985 and 1988 from the total male population aged between 50 and 69 years in southwestern Finland (*n* 290 406). The study design and methods have been described in detail elsewhere[18]. The ATBC Study was approved by the institutional review boards of the National Public Health Institute of Finland (Helsinki, Finland) and the United States National Cancer Institute (Bethesda, MD, USA). Each participant provided written informed consent at baseline.

At baseline, participants completed a demographic, general medical, physical activity and smoking history questionnaire. Height and weight were measured.

Dietary assessment

Diet was assessed at baseline using a self-administered, modified diet history questionnaire[19]. The questionnaire included 276 food items and mixed dishes. In addition, the participants could add foods that were not listed in the questionnaire after each subgroup. Frequencies of consumption of foods were reported as number of times per day, week or month within the previous 12 months. The questionnaire was used with a picture booklet of 122 photographs of foods, each with three to five different portion sizes, to estimate the usual portion size of foods. During the first baseline visit, each participant received the questionnaire to be completed at home. At the second visit 2 weeks later, they returned the questionnaires, which were reviewed and completed with the help of a trained nurse. The questionnaires of 27 111 participants (93 %) were satisfactorily completed.

The dietary method was validated before the ATBC Study among men aged 55–69 years[19]. The energy-adjusted correlations between the dietary questionnaire and food records were 0·55 for total carbohydrates, 0·73 for starch, 0·50 for sucrose and 0·72 for dietary fibre.

Calculation of nutrient intakes and dietary glycaemic index and glycaemic load

Nutrient intakes and dietary GI and GL were calculated using the food composition database and in-house nutrient intake calculation software at the National Institute for Health and Welfare, Helsinki, Finland. The compilation of the GI database (glucose solution as the reference) has been described earlier[20]. Dietary GL was calculated by summing the products of the carbohydrate amount of each food consumed multiplied by its GI divided by 100. Dietary GI was calculated by dividing the dietary GL by the total carbohydrate amount and then multiplied by 100. The intake of carbohydrates as a percentage of energy (E%) was calculated for total intake and separately for intakes from low (GI 55 or less)-, medium (GI between 56 and 69)- and high-GI foods (GI 70 or more).

Definition of diabetes

Incident diabetes cases were identified from the registry of reimbursement for costs of diabetes medication. In Finland, patients needing medical treatment for diabetes are entitled to reimbursement of their medication expenses according to sickness insurance legislation. This necessitates a detailed medical certificate from the attending physician. The certificate is verified to fulfil the diagnostic criteria for diabetes at the Social Insurance Institution (Helsinki, Finland), which maintains a central register of all persons receiving drug reimbursement. The ATBC Study participants were linked to the register through the unique personal identity number assigned to each Finnish citizen.

At study entry, of the 27 111 participants, 1168 had a history of physician-diagnosed diabetes. After their exclusion, the final cohort comprised 25 943 men, among whom 1098 incident diabetes cases were identified from the drug reimbursement register during the 12-year follow-up.

Statistical analysis

Baseline characteristics and dietary intakes were calculated in quintiles of dietary GI, GL and intake of low-, medium- and high-GI carbohydrates. The trends were tested with Cuzick's trend test. The linear regression model including age, intervention group and thirty-three food ingredient groups was fit to detect the food ingredient groups that explained most of the inter-individual variation in dietary GI. The ingredient groups were rye, wheat, other cereals, potatoes, legumes, roots, other vegetables, fruits, berries, fruit juices, sugar-sweetened berry juices, soft drinks, sugars, sweets, milk, cream, yogurt, ice cream, cheese, butter, soft margarines, harder margarines, vegetable oils, low-fat fats, other fats, meat, egg, coffee, tea, water, beer, other alcohol and others (e.g. sauces). The associations between the ingredient groups explaining more than 1 % of variation and the diabetes risk were assessed in a Cox regression model adjusted for age and intervention group.

We computed person-time of follow-up from the randomisation date to the date of diabetes occurrence or death

or end of follow-up (December 1997), whichever came first. Cox modelling was used to estimate the relative risk and 95 % CI for the diabetes incidence in each quintile of the dietary variable compared with the lowest quintile. The proportional hazard assumption was tested using Schoenfeld residuals.

Potential confounders and main determinants of diabetes were included as covariates in the Cox regression models. The basic model (model 1) estimating the associations of dietary GI, GL and risk of diabetes was adjusted for age and intervention group (supplementation during the original trial). The multivariate models were further adjusted for BMI, smoking (years of smoking and number of cigarettes smoked daily), physical activity and intakes of total energy and alcohol (model 2), and still further for energy-adjusted intakes of fat and fibre and for consumption of coffee (model 3).

Multivariate nutrient density models[21] were used to assess the effect of isoenergetic substitution of low-GI carbohydrates for medium-GI carbohydrates (A), low-GI carbohydrates for high-GI carbohydrates (B) and medium-GI carbohydrates for high-GI carbohydrates (C). The basic model (model 1) was adjusted for age, intervention group, intake of total energy, and intakes of fat, protein and alcohol, as E%. Furthermore, the basic model for A was adjusted for intake of high-GI carbohydrates, for B for medium-GI carbohydrates and for C for low-GI carbohydrates, as E% each. The second model (model 2) was further adjusted for BMI, smoking, physical activity, energy-adjusted intake of fibre and consumption of coffee. The main foods contributing to the intake of low-, medium- and high-GI carbohydrates (foods contributing >0·5 % of mean intake of each carbohydrate category) were evaluated.

Dietary GL and intake of fat (in dietary GI and GL models) and fibre were energy adjusted using the residual method[22]. Tests for linearity of trend were performed using the Wald test by treating the median values of each quintile as continuous variables. All *P* values were two-sided. Analyses were carried out with Stata software (version 9; StataCorp, College Station, TX, USA).

Results

Median dietary GI was 67·3 and GL 175. On average, participants with higher GI were younger, and participants with higher GL had lower BMI and were more physically active during leisure time (Table 1). With increasing GI and GL, the intake of fat and protein decreased and the intake of fibre increased. Alcohol intake was positively associated with GI but inversely associated with GL.

Food ingredient groups that contributed most to inter-individual variation in dietary GI were beer and milk, together explaining 65 % of the variation (Table 2). Other groups clearly contributed less; rye contributed 5 % and potatoes, sugars, yogurt, fruits and juices contributed 1–2 % each. Of the groups explaining more than 1 % of the variation, milk and fruits were directly associated with the risk of diabetes ($P<0·001$ and 0·002, respectively), whereas sugars and beer were inversely associated with the risk ($P<0·001$ and 0·08, respectively). The other major food ingredient groups were not associated with the risk of diabetes.

Dietary GI and GL were inversely associated with diabetes when adjusted for age and intervention group, but the relative risk of the highest quintile compared with the lowest quintile and the linear trend became non-significant in the multivariate models (Table 3).

The median intake of low-GI carbohydrates was 8·0 E%, medium-GI carbohydrates was 9·7 E% and high-GI carbohydrates was 21·7 E%. On average, participants with a higher intake of low-, medium- or high-GI carbohydrates were more physically active and had lower fat and alcohol intake (Table 4). Intake of protein rose with increasing low-GI carbohydrate intake and diminished with increasing medium-GI carbohydrate intake. Intake

Table 1. Baseline characteristics and dietary intakes (medians) by the lowest, middle and highest quintiles (Q) of dietary glycaemic index and glycaemic load (*n* 25 943)

	Glycaemic index				Glycaemic load*			
	Q1	Q3	Q5	*P* for trend	Q1	Q3	Q5	*P* for trend
Median	62·6	67·3	73·1		144	175	208	
Characteristics								
Age (years)	57·7	57·2	56·3	<0·001	56·8	56·9	57·4	<0·001
BMI (kg/m^2)	26·0	25·9	25·9	0·001	26·2	25·9	25·7	<0·001
Moderate leisure-time physical activity (% of subjects)†	58·3	60·5	53·7	<0·001	51·9	59·3	62·8	<0·001
Dietary intakes*								
Energy (MJ/d)	10·8	11·0	10·5	0·024	10·8	11·0	10·7	0·014
Carbohydrates (g/d)	259	264	248	<0·001	218	261	303	<0·001
Protein (g/d)	95	92	87	<0·001	95	92	88	<0·001
Fat (g/d)	121	120	114	<0·001	133	120	105	<0·001
Fibre (g/d)	21	26	26	<0·001	20	25	31	<0·001
Alcohol (g/d)	7	10	26	<0·001	21	11	5	<0·001

* Energy adjusted (except for energy and alcohol) using the residual method.
† Leisure-time physical activity classified as light or moderate.

Table 2. Food ingredient groups contributing at least 1 % to inter-individual variation in dietary glycaemic index (GI) (β and partial R^2 values, *n* 25 943)*

Food group	β†	Partial R^2
Beer	0·87	0·41
Milk‡	−0·62	0·24
Rye	2·39	0·05
Fruits	−0·68	0·02
Potatoes	1·04	0·02
Sugars	−2·26	0·02
Yogurt	−1·26	0·02
Sugar-sweetened berry juices	−0·44	0·02
Fruit juices	−0·86	0·01

* Adjusted for age and intervention group, model R^2 0·81.
† Change in dietary GI per increase of 100 g of food/d.
‡ Liquid, non-sugared milk products.

of fibre diminished with increasing medium-GI carbohydrate intake and rose strongly with increasing high-GI carbohydrate intake.

The main foods that contributed to high-GI carbohydrate intake were wheat bread and bakery items (32 % of mean intake of high-GI carbohydrates), rye bread (29 %), potatoes (17 %) and beer (5 %). Foods contributing to medium-GI carbohydrate intake were sugar added to coffee or tea (27 %), other added sugar and foods rich in sugar (e.g. soft drinks and sweets, 30 %) and wheat bakery items (15 %). The main foods contributing to low-GI carbohydrate intake were milk (49 %) and fruits, vegetables and legumes (20 %).

Substitution of medium-GI carbohydrates for an isoenergetic amount of high-GI carbohydrates was inversely associated with diabetes risk (Table 5). The largest decrease in diabetes risk was observed when the intake of medium-GI carbohydrates substituting for high-GI carbohydrates increased from the lowest quintile to the second lowest quintile (increase 2–3 E%).

Substitution of low-GI carbohydrates for high-GI carbohydrates was not associated with diabetes risk. Substitution of low-GI carbohydrates for medium-GI carbohydrates was associated with an increased risk of diabetes in a model adjusted for age, intervention group, energy, fat, protein, alcohol and high-GI carbohydrates, but the relative risk of the highest quintile compared with the lowest quintile and the linear trend became non-significant when further adjusted for BMI, smoking, physical activity, intake of fibre and consumption of coffee.

Discussion

In the present study, dietary GI was not associated with diabetes risk. Some cohort studies have reported a positive association between GI and diabetes risk[4–8], while others have observed no such association[9–15]. The present finding of no association is in line with several studies that have included male subjects[9,10,12–15]. Thus, studies with men have suggested that there is no association between dietary GI and diabetes risk. This contradicts findings from studies that have included only women and have suggested a direct association[5–8]. We do not have any obvious explanation for this sex difference. One hypothesis is, however, residual confounding; women may consume more such low-GI foods (e.g. fruits) that also may have other properties that lower the risk of diabetes.

This highlights the fact that dietary GI as an average measure of carbohydrate quality (calculated as a weighted mean of GI of all foods consumed) may conceal many different dimensions of diet because the same dietary GI can be a result of several different combinations of carbohydrate-containing foods with different health effects. The inconsistent findings between dietary GI and diabetes risk may partly be due to variability in essential

Table 3. Risk of diabetes by quintiles of glycaemic index and glycaemic load (Relative risks (RR) and 95 % confidence intervals, *n* 25 943)

	Quintiles									
	1	2		3		4		5		
	RR	RR	95 % CI	RR	95 % CI	RR	95 % CI	RR	95 % CI	*P* for trend
Glycaemic index										
Median	62·6	65·4		67·3		69·3		73·1		
Cases (*n*)	266	201		205		210		216		
Model 1*	1·00	0·73	0·61, 0·88	0·75	0·62, 0·90	0·76	0·64, 0·91	0·79	0·66, 0·94	0·03
Model 2†	1·00	0·82	0·68, 0·98	0·81	0·67, 0·97	0·88	0·73, 1·05	0·88	0·73, 1·06	0·29
Model 3‡	1·00	0·82	0·68, 0·98	0·81	0·67, 0·98	0·89	0·73, 1·07	0·87	0·71, 1·07	0·33
Glycaemic load§										
Median	144	162		175		188		208		
Cases (*n*)	280	241		203		195		179		
Model 1*	1·00	0·84	0·71, 1·00	0·71	0·59, 0·85	0·67	0·56, 0·81	0·63	0·52, 0·76	<0·001
Model 2†	1·00	0·92	0·77, 1·09	0·83	0·69, 1·00	0·82	0·68, 0·99	0·78	0·65, 0·95	0·006
Model 3‡	1·00	0·95	0·79, 1·14	0·88	0·71, 1·09	0·88	0·69, 1·11	0·88	0·65, 1·17	0·30

* Model 1: adjusted for age and intervention group.
† Model 2: model 1 further adjusted for BMI, smoking (years, number of cigarettes per day), physical activity and intakes of total energy and alcohol.
‡ Model 3: model 2 further adjusted for energy-adjusted intakes of fat and fibre and for consumption of coffee.
§ Energy adjusted using the residual method.

Table 4. Baseline characteristics and dietary intakes (medians) by the lowest, middle and highest quintiles (Q) of intake of low-, moderate- and high-glycaemic index (GI) carbohydrates (CHO) (*n* 25 943)

	Low-GI CHO			Medium-GI CHO			High-GI CHO		
	Q1	Q3	Q5	Q1	Q3	Q5	Q1	Q3	Q5
Median (% of energy intake)	4·6	8·0	12·0	4·7	9·7	16·7	15·3	21·7	28·8
Characteristics									
Age (years)	56·5	57·1	57·3	56·6	56·9	57·4	57·2	56·7	57·3
BMI (kg/m^2)	25·7	25·9	26·1	26·7	25·8	25·4	25·9	25·9	26·0
Moderate leisure-time physical activity (% of subjects)*	54·2	60·1	60·7	54·4	59·5	60·3	55·1	59·6	61·9
Dietary intakes									
Energy (MJ/d)	10·9	11·1	10·4	10·3	11·0	11·0	10·9	11·0	10·5
Carbohydrates (% of energy)	39·1	40·5	41·7	36·6	40·1	44·5	36·9	39·9	44·6
Protein (% of energy)	13·3	14·3	15·3	15·0	14·5	13·6	14·4	14·4	14·3
Fat (% of energy)	40·6	40·9	39·5	41·5	41·0	38·5	42·6	41·0	37·6
Alcohol (% of energy)	4·7	2·9	2·0	5·0	2·8	1·8	4·3	3·1	1·8
Fibre (g/d)†	24·1	24·7	25·0	25·3	24·9	23·5	19·4	24·7	31·7

* Leisure-time physical activity classified as light or moderate.
† Energy adjusted using the residual method.

carbohydrate sources in study populations. In the present study, the main contributors of the inter-individual variation in dietary GI, beer and milk, are examples of this, since their consumption is associated with diabetes risk contrary to expectations based on their glycaemic responses. Beer has a high GI value[23], and consumption of beer was marginally inversely associated with the risk of diabetes. The inverse association is in accordance with former findings[24] and may be due to lower insulin secretion influenced by alcohol consumption[25]. Low-GI food, milk, instead, was positively associated with diabetes risk. Although milk produces a low glycaemic response, its insulin response is high[26]. Protein of milk has found to be insulinotropic[27], and hyperinsulinaemia has been demonstrated to lead to the development of insulin resistance[28].

Moreover, because subjects normally eat a wide variety of foods with different GI, the average dietary GI often falls within a fairly narrow range. In the present study, the GI quintile medians ranged from 62·6 to 73·1. These do not differ much from the GI level and range of the studies that have found a significant association between dietary GI and risk of diabetes, e.g. the difference between the highest and lowest GI quintile medians has varied from eleven to sixteen[4–7]. Thus, the present finding of no association is hardly due to the range of dietary GI.

Table 5. Risk of diabetes by quintiles (% of total energy intake (E%)) and per 1 E% of low-glycaemic index (GI) carbohydrates (CHO) substituted for an isoenergetic amount of high- or medium-GI carbohydrates, and medium-GI carbohydrates substituted for high-GI carbohydrates
(Relative risks (RR) and 95 % confidence intervals, *n* 25 943)

	Quintiles											
	1	2		3		4		5			Per 1 E%	
	RR	RR	95 % CI	RR	95 % CI	RR	95 % CI	RR	95 % CI	*P* for trend	RR	95 % CI
Low-GI CHO												
Median (E%)	4·6	6·6		8·0		9·5		12·0				
Cases (*n*)	206	201		220		228		243				
Low for high												
Model 1*	1·00	0·92	0·76, 1·12	0·99	0·82, 1·21	0·99	0·81, 1·20	1·00	0·82, 1·23	0·74	1·01	0·99, 1·03
Model 2†	1·00	0·92	0·75, 1·12	0·98	0·81, 1·20	0·87	0·71, 1·06	0·92	0·75, 1·13	0·39	0·99	0·97, 1·01
Low for medium												
Model 1‡	1·00	0·99	0·81, 1·21	1·11	0·91, 1·36	1·16	0·94, 1·43	1·29	1·03, 1·63	0·01	1·04	1·02, 1·07
Model 2†	1·00	0·95	0·78, 1·16	1·04	0·85, 1·28	0·94	0·76, 1·16	1·05	0·83, 1·33	0·69	1·01	0·98, 1·03
Medium-GI CHO												
Median (E%)	4·7	7·5		9·7		12·2		16·7				
Cases (*n*)	336	223		195		184		160				
Medium for high												
Model 1§	1·00	0·69	0·58, 0·82	0·62	0·51, 0·74	0·60	0·50, 0·73	0·59	0·48, 0·74	<0·001	0·97	0·95, 0·98
Model 2†	1·00	0·83	0·69, 0·98	0·78	0·65, 0·95	0·79	0·64, 0·96	0·75	0·59, 0·96	0·02	0·98	0·97, 1·00

* Model 1: adjusted for age, intervention group, total energy, and E% from fat, protein, alcohol and medium-GI carbohydrates.
† Model 2: model 1 further adjusted for BMI, smoking (years, number of cigarettes/d), physical activity, consumption of coffee and energy-adjusted intake of fibre.
‡ Model 1: adjusted for age, intervention group, total energy, and E% from fat, protein, alcohol and high-GI carbohydrates.
§ Model 1: adjusted for age, intervention group, total energy, and E% from fat, protein, alcohol and low-GI carbohydrates.

In the present study, dietary GL was not associated with diabetes risk. Many earlier cohort studies have not found an association between GL and type 2 diabetes[4,5,7,10–15], but a few have reported a positive association[6,8,16]. GL, the product of GI and weight (g) of carbohydrates consumed, describes the amount of carbohydrates in addition to carbohydrate quality. Thus, GL can be altered either by changing GI or by changing the amount of carbohydrate consumed, or both. In using dietary GL to analyse disease risk, it is not possible to separate changes in carbohydrate quality and changes in carbohydrate quantity. In order for dietary GL to be a valid measure, reducing dietary GI should have the same metabolic effects as reducing the amount of carbohydrates in the diet. However, the effects do not seem to be the same[29]. Changes in the amount of dietary carbohydrates are often associated with changes in the intake of other energy-yielding nutrients, protein and fat, and the effect on diabetes risk may be related to changes in the intake of these nutrients[30].

We applied the multivariate nutrient density model to examine the associations of substitution of lower-GI carbohydrates for higher-GI carbohydrates with diabetes risk. This was done to better model the original aim of the GI concept to choose lower-GI carbohydrates instead of higher-GI carbohydrates when total carbohydrate intake is kept constant. Also, the effect of other macronutrients can be kept constant because the change in carbohydrates with different GI is studied under isoenergetic conditions adjusting for the other macronutrients.

The substitution of medium-GI carbohydrates for high-GI carbohydrates was inversely associated with diabetes risk. This finding is in line with the hypothesis that carbohydrates that induce a smaller elevation in blood glucose may have beneficial effects on diabetes risk compared with carbohydrates that induce higher blood glucose response. The inverse association between substitution of medium-GI carbohydrates for high-GI carbohydrates and diabetes risk was, however, not proportional; the largest decrease was found when the substitution increased from the lowest quintile to the second lowest quintile.

Contrary to the GI hypothesis, we found no decreased risk of diabetes when substituting low-GI carbohydrates for medium- or high-GI carbohydrates. One explanation could be the major role of milk (49 %) as a source of low-GI carbohydrates. Recent prospective studies have suggested that consumption of low-fat dairy products is inversely associated with the risk of type 2 diabetes, but their data are consistent with the possibility that milk seems to influence glucose tolerance more through its insulinotropic effect than through its relatively lower GL[31,32]. We, however, found a positive association between consumption of milk and risk of diabetes. This may be due to high consumption of high-fat milk since its saturated fat may have mitigated the potential benefits of other milk components. Although beer was the strongest food ingredient group to explain inter-individual variation, it did not dominate the substitution results to the same extent, since it contributed only 5 % to the mean intake of high-GI carbohydrates.

One of the strengths of the present study was the prospective cohort design, which minimised recall and selection biases. In addition, the detailed background and dietary data allowed adjustment for potential confounders. We retrieved the incident diabetes cases from a nationwide drug reimbursement register, which provides no information on the type of diabetes. However, in a Finnish survey, 96 % of all diabetic participants diagnosed after the age of 55 years had type 2 diabetes[33]. Since the participants of the ATBC Study were aged 50–69 years at study entry, the incident diabetes cases can be assumed to be primarily type 2 diabetes. We were able to identify only patients receiving medication for the treatment of diabetes, but not individuals treating their disease with dietary changes.

We had only a single assessment of diet at baseline focusing on the frequencies of consumption and portion sizes of foods within the previous 12 months. This involves potential for measurement error in dietary intakes contributing to a misclassification of exposure. In addition, we had data on dietary and non-dietary covariates only from baseline, and thus possible changes in these during the 12-year follow-up may have confounded the association between GI and risk of diabetes. These may have attenuated the associations towards unity. On the other hand, although we were able to adjust for many dietary and non-dietary risk factors of type 2 diabetes, we cannot rule out the possibility of residual or unmeasured confounding.

We conclude that high dietary GI and GL were not associated with increased diabetes risk. The associations of dietary GI and GL with diabetes risk should be interpreted by considering nutritional correlates, as foods may have different properties that affect diabetes risk. Substitution of lower-GI carbohydrates for higher-GI carbohydrates was not consistently associated with a lower diabetes risk. We suggest that application of multivariate nutrient density models to epidemiological studies on GI and diabetes would bring new insights into this contradictory topic.

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