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ORIGINAL CONTRIBUTION

Dietary patterns and the risk of type 2 diabetes in overweight and obese individuals

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Abstract
Purpose Although overweight is an important determinant of diabetes risk, it remains unclear whether food choices can still influence the risk for type 2 diabetes in overweight persons. In this paper, we aim to clarify the role of dietary patterns in the development of type 2 diabetes in overweight and obese individuals.
Methods We studied 20,835 overweight and obese participants in the Dutch part of the European Investigation into Cancer and Nutrition (EPIC-NL) study. Dietary intake was measured using a validated food frequency questionnaire, and dietary patterns were generated using factor analysis. Incident type 2 diabetes was verified against medical records. Cox proportional hazards models were used to assess the association between the dietary patterns (factor scores categorized in quartiles) and incident type 2 diabetes.
Results Scoring on Pattern 1, characterized by fish, wine, chicken, raw vegetables and fruit juices, was not associated with type 2 diabetes risk after confounder adjustment. A high score on Pattern 2, characterized by soft drinks, fries and snacks, was associated with higher risk of type 2 diabetes (HR Q4 vs. Q1 (95 % CI): 1.70 (1.31; 2.20), $p_{\text{trend}} \leq 0.0001$), particularly among less active individuals [less active: HR Q4 vs. Q1 (95 % CI): 2.14 (1.48; 3.09), $p_{\text{trend}} = 0.00004$, more active: HR Q4 vs. Q1 (95 % CI): 1.35 (0.93; 1.97), $p_{\text{trend}} = 0.01$; $p_{\text{interaction}} = 0.02$].
Conclusions A high score on a pattern high in soft drinks, fries and snacks and low in fruit and vegetables was associated with higher risk of type 2 diabetes in overweight and obese subjects especially among physically less active individuals.

Keywords Dietary pattern · Type 2 diabetes · Obesity · Epidemiology

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Introduction

Overweight and obesity are the most important risk factors for type 2 diabetes and result from an imbalance in energy intake and expenditure [1]. This imbalance is often the result of an unhealthy lifestyle, combining low physical activity with unhealthy dietary intake [2].

Currently, the prevention of weight gain and obesity are the key features for type 2 diabetes prevention. Diet probably affects type 2 diabetes risk through the development of overweight or obesity. However, there is also some evidence that diet is an independent risk factor for type 2 diabetes. Several macronutrients and food groups have been identified as independent determinants of type 2 diabetes risk [2].

Dietary patterns represent the effects of the whole diet rather than the individual nutrients and may be more strongly associated with disease risk by better reflecting real-life dietary behavior [2]. Different dietary patterns across countries have been related to diabetes risk [3–5]. These patterns fit into two main pattern types, namely a so-called Prudent (healthy) pattern, which is associated with a moderately lower diabetes risk [4], and a Western (unhealthy) pattern, which is associated with higher diabetes risk [3–5]. These studies adjusted for body mass index (BMI) and showed that these patterns are independent risk factors for type 2 diabetes as well [3–5].

Although overweight increases the risk of chronic diseases, this risk seems to be lower in women who are fat, but also fit and active compared to fat, unfit women [6]. This suggests that even in overweight individuals, lifestyle still can have an important contribution in determining disease risk. Following this line of reasoning, it is conceivable that healthy dietary patterns are also associated with a lower risk for diabetes in overweight and obese individuals. However, dietary patterns in only overweight and obese subjects have not yet been defined and investigated.

Because of the high and increasing prevalence of overweight and obesity, from a public health perspective, it is important to study this group, to see whether in this group, food choices next to or combined with an active healthy lifestyle could be means to lower diabetes risk. Therefore, we investigated the relation between dietary patterns and type 2 diabetes risk in obese and overweight subjects.

Methods

Study population

The European Prospective Investigation into Cancer and Nutrition (EPIC) was established to investigate the relation between nutrition, various lifestyles and environmental factors and the incidence of cancer and other chronic diseases. EPIC-NL consists of the two Dutch contributions to the EPIC study, that is Prospect-EPIC and MORGEN-EPIC. The individual cohorts of EPIC-NL were set up simultaneously in 1993–1997 within the context of EPIC and were merged in 2007 according to standardized processes into one large Dutch EPIC cohort. Its design and baseline characteristics have been described elsewhere [7].

In brief, the Prospect-EPIC study includes a total of 17,357 women aged 49–70 years at baseline, participating in the national breast cancer screening program, and living in the city of Utrecht and its surroundings [8]. The MORGEN-EPIC cohort consists of 22,654 men and women aged 21–64 years selected from yearly random samples of the Dutch population in three towns in the Netherlands (Amsterdam, Doetinchem, and Maastricht) [9].

In the present analysis, only participants with BMI $\geq$ 25 kg/m^2 were included ($n = 21{,}607$). After exclusion of prevalent diabetes cases at baseline ($n = 514$), individuals with missing nutritional data ($n = 111$) or, abnormal energy intake (kcal <600 or >5,000; $n = 46$), and individuals lost-to-follow-up ($n = 551$), 20,385 participants were included for analysis.

Assessment of type 2 diabetes

The occurrence of diabetes during follow-up was self-reported in two follow-up questionnaires with 3–5-year intervals. Participants were asked whether diabetes was diagnosed, in what year, by whom, and what treatment they received. Diagnoses of diabetes were also obtained from the Dutch Centre for Health Care Information, which holds a standardized computerized register of hospital discharge diagnoses. In this register, admission files have been filed continuously from all general and university hospitals in the Netherlands from 1990 onwards. All diagnoses were coded according to the International Classification of Diseases, Clinical Modification, 9th revision. Follow-up was complete until January 1st 2006. In Prospect-EPIC, additional incident diabetes cases were detected via a urinary glucose strip test, sent out with the first follow-up questionnaire, for detection of glucosuria. Prevalent and incident potential diabetes cases ($n = 2{,}289$) identified by any of these methods were verified with the participants' general practitioner or with pharmacist information through mailed questionnaires. Diabetes was defined present when either one of them confirmed the diagnosis. After verification of ascertained diabetes cases, 67 % were defined as having diabetes. In total, 924 verified incident type 2 diabetes cases were identified [10].

Dietary assessment

To assess dietary intake, a validated food frequency questionnaire (FFQ) was administered once at baseline, which contains questions on the usual frequency of consumption of 79 main food groups during the year preceding enrollment. Overall, the questionnaire allows the estimation of the average daily consumption of 178 foods, by asking about sub-items for several food items, like fruit and vegetables, in additional questions [11]. Energy-adjusted nutrient intake and intake of food groups was calculated using the nutrient-density method [12]. The FFQ has been validated for food groups with 12 monthly 24-h recalls [11]. For men, Spearman correlation coefficients between estimates of food group intake based on the questionnaire and those based on 24-h recalls ranged from 0.21 for cooked vegetables to 0.78 for sugar and sweet products. For women, the correlation coefficients ranged from 0.31 for vegetables to 0.87 for alcoholic beverages.

To identify dietary patterns, we grouped the food items of the FFQ into 33 food groups based on 23 main standard Dutch food groups defined according to the Dutch food composition table [13], the studies of Waijers et al. [14] and van Dam et al. [5]. As a result, some of the main groups were broken down, for example: 'vegetables' was divided into 'boiled vegetables' and 'raw vegetables'. We log transformed some food groups as they were not normally distributed, for example, shellfish and chicken.

To estimate underreporting of energy intake, we used Goldberg's equation, which compares dietary energy intake with energy expenditure. The reported energy intake for each individual was divided by the estimated basal metabolic rate (EI/BMR), where BMR was measured using the Schofield equations [15]. Participants with an EI/BMR < 1.14 were defined as energy under-reporters, whereas those with an EI/BMR ≥ 1.14 were classified as normal and high energy reporters and EI/BMR > 2.4 as high energy reporters [15].

Baseline characteristics

At baseline, participants completed a general questionnaire containing questions on demographics, the presence of chronic diseases, and risk factors for chronic diseases.

Education was categorized into low (primary education, lower vocational education, advanced elementary education and intermediate vocational education), middle (higher general secondary 3rd year with success and higher general secondary completed) and high (higher vocational education, university to bachelor examination and university completed), and smoking was categorized into current, past and never smoker. Physical activity was assessed using a questionnaire validated in an elderly population [16] and categorized (less active: inactive, moderately inactive; more active: moderately active, active) after calculating the Cambridge Physical Activity Score [17]. Because we could not calculate a total physical activity score for 14 % of the participants, we imputed missing scores using single linear regression modeling (SPSS MVA procedure, SPSS version 15.0). Body weight, height, waist and hip circumference were measured according to standard operating procedures, and BMI was calculated.

Data analysis

Dietary patterns were generated using factor analysis, a principal component analysis [18]. Principal components were extracted by using the correlation matrix to adjust for unequal variances of the original variables with varimax rotation. To identify the number of principal components to be retained, we used eigenvalues exceeding 1, a scree plot (plot of the eigenvalues from each component), and the interpretability of each component. Food groups with absolute scoring coefficients (factor loadings) >0.25 were considered important contributors to a component. We identified patterns based on the combinations of food groups that contributed most strongly to the respective component. Each person received a score for each identified pattern by summing the standardized values of the food groups weighted by their factor loadings.

Cox proportional hazard models were used to calculate adjusted hazard ratios (HR) and 95 % confidence intervals (CI) for the association between the dietary patterns [categorized in quartiles of the factor scores per individual (Q)] and incident type 2 diabetes. We estimated p-for trend by including the dietary patterns in quartiles as a continuous variable in the Cox regression models. All models were adjusted for age at recruitment, sex and total energy intake. In a second model, we additionally adjusted for education, physical activity, smoking and family history of diabetes. In the third model, we added BMI to see whether BMI in our subgroup of individuals with a BMI ≥ 25 still had an influence on diabetes risk. We added BMI as a dichotomous variable into the third model, because BMI was not linear distributed.

We examined interactions with BMI ($\geq$25–29.99 vs. $\geq$30 kg/m^2), physical activity [more active (moderately active and active) vs. less active (moderately inactive and inactive)] and education (3 categories), which could modify the effect of the relation between dietary patterns and diabetes risk, by additionally including interaction terms. The overall p-for interaction was statistically significant when $p < 0.05$.

Data were analyzed using SPSS (version 15.0) for Windows.

Results

We derived two main patterns in overweight and obese individuals: Pattern 1 and Pattern 2. The factor loadings of these two patterns are shown in Table 1. The main food groups contributing to Pattern 1 consisted of shellfish,

Table 1 Factor loadings of the 2 major principal components in men and women of the Dutch European Prospective Investigation into Cancer and Nutrition (EPIC-NL) with a BMI ≥ 25

Food groups	Pattern 1	Pattern 2
Shellfish (ln en%)	0.83	
High-fat fish (ln en%)	0.80	
Low-fat fish (ln en%)	0.76	
Wine (ln en%)	0.44	
Raw vegetables (en%)	0.44	−0.28
Cereals with high amount of fiber (ln en%)	0.37	−0.34
Cereals with low amount of fiber (ln en%)	0.30	
Chicken (ln en%)	0.28	
Fruit juices (ln en%)	0.28	
Soft drinks sugar free (ln en%)	0.25	0.63
Soft drinks with sugar (ln en%)		0.76
Other non-alcoholic drinks (ln en%)	0.26	0.72
French fries (ln en%)		0.62
Snacks (en%)[a]		0.51
Bread with low amount of fiber (en%)	−0.28	0.34
Fruit (en%)		−0.47
Low-fat dairy products (en%)		−0.36
Boiled vegetables and legumes (en%)		−0.33
Cakes and cookies (en%)		−0.28
Fat and butter (en%)	−0.27	
Potatoes (en%)	−0.35	
High-fat dairy products (en%)		
Cheese (en%)		
Processed meat (en%)		
Red meat (en%)		
Sugar and sweets (en%)		
All kinds of oil and diet margarine (en%)		
Coffee and tea (en%)		
Eggs (ln en%)		
Nuts and seeds, soy products and peanut butter (en%)		
Soups (ln en%)		
Other alcoholic beverages (ln en%)		

Loadings of an absolute value >0.25 are shown

$n = 20{,}385$

en% energy percentage

[a] Contains spring rolls, crisps, Russian salad, pizza and Dutch fried meat snacks

high-fat fish, low-fat fish, wine, raw vegetables, chicken and fruit juice, while the main components for Pattern 2 were soft drinks, other non-alcoholic beverages, French fries, snacks and low-fiber cereal bread.

Baseline characteristics for the 20,385 overweight and obese subjects across quartiles of the two dietary patterns are shown in Table 2. Subjects with higher scores on Pattern 1 had an overall healthier lifestyle. They were more often female, had a higher education, were more physically active and had a higher alcohol intake, while their BMI and waist circumference were lower and they were less likely to smoke. For Pattern 2, exactly the opposite was seen; subjects who scored high on Pattern 2 were more likely to be male and current smokers, were younger and less physically active, and had higher weight and waist circumference than subjects who scored low on Pattern 2.

During a mean (±SD) of 10.1 (±1.9) years of follow-up, we documented 831 incident type 2 diabetes cases with BMI ≥ 25 kg/m^2. Scoring high on Pattern 1 was not associated with diabetes risk in the multivariate model [Table 3: Model 2, HR Q4 vs. Q1 (95 % CI): 0.97 (0.79; 1.20); $p_{\text{trend}} = 0.57$]. A high score on Pattern 2 was associated with a higher risk of diabetes [Table 3: Model 2, HR Q4 vs. Q1 (95 % CI): 1.70 (1.31; 2.20), $p_{\text{trend}} \leq 0.0001$]. Adding BMI as a dichotomous variable into the models did not alter the results (Table 3: Model 3), and adding BMI as a continuous variable did also not alter the results (data not shown). Also exclusion of potential under and over reporters (based on EI/BMR) did not alter the results [excluding low energy reporters, Model 2 HR Q4 vs. Q1 (95 % CI): 1.76 (1.24; 2.50); excluding high energy reporters, Model 2 HR Q4 vs. Q1 (95 % CI): 1.69 (1.30; 2.19)].

We observed a significant interaction of Pattern 2 with physical activity (overall p-for interaction 0.02). Stratified analysis for more active and less active individuals showed that although a high score on Pattern 2 was associated with a higher diabetes risk both in more active and less active individuals, the relation was much stronger in the less active subjects [less active: HR Q4 vs. Q1 (95 % CI): 2.14 (1.48; 3.09), $p_{\text{trend}} = 0.00004$, more active: HR Q4 vs. Q1 (95 % CI): 1.35 (0.93; 1.97), $p_{\text{trend}} = 0.01$].

Adding alcohol intake into the equation did not change the estimates (data not shown).

The interaction of Pattern 1 and physical activity was not statistically significant ($p = 0.20$). Interactions of the dietary patterns with BMI and education were not statistically significant ($p > 0.05$).

Discussion

This large prospective study shows that in obese or overweight individuals, a dietary pattern characterized by soft drinks, other non-alcoholic beverages, French fries, snacks and low-fiber cereal bread was positively associated with the risk for type 2 diabetes in both more active and less active subjects, where inactivity seems to strengthen the effect. A pattern characterized by fish, wine, chicken, raw vegetables and fruit juices was not statistically significantly associated with the risk of type 2 diabetes in these subjects.

Table 2 Baseline characteristics of 20,385 overweight and obese subjects (BMI ≥ 25) in the EPIC-NL study by quartiles of Pattern 1 and Pattern 2

	Quartiles			
	1 (lowest)	2	3	4 (highest)
N	5,096	5,096	5,097	5,096
Pattern 1				
Female sex (%)	68	68	73	84
Mean age (SD)	52 (11)	51 (11)	51 (11)	52 (9.4)
Education				
Low (%)	67	55	42	27
Middle (%)	27	34	41	45
High (%)	6	11	16	27
Smoking				
Never (%)	40	41	39	36
Past (%)	28	32	34	41
Current (%)	32	27	27	23
Physical activity				
Inactive (%)	14	11	10	8
Moderately inactive (%)	31	31	28	28
Moderately active (%)	25	26	27	28
Active (%)	30	32	35	36
Hypertension (%)	49	47	48	46
Hypercholesterolemia (%)	11	12	10	9
Mean height (SD)	167.4 (9.1)	168.0 (9.2)	167.8 (8.8)	166.6 (8.1)
Mean weight (SD)	80.3 (12.0)	80.6 (12.2)	79.9 (11.9)	78.3 (10.9)
Mean BMI (SD)	28.6 (3.4)	28.5 (3.4)	28.4 (3.3)	28.1 (3.06)
Mean waist (SD)	93.0 (10.2)	92.7 (10.3)	91.5 (10.1)	89.6 (9.6)
Mean WHR (SD)	0.86 (0.09)	0.86 (0.09)	0.85 (0.08)	0.82 (0.08)
Mean total energy intake kcal (SD)	2069.2 (654.5)	2105.7 (640.2)	2041.7 (580.8)	1840.7 (501.3)
Mean alcohol en% (SD)	2.4 (4.3)	3.1 (4.6)	3.8 (4.9)	5.0 (5.4)
N	5,096	5,096	5,097	5,096
Pattern 2				
Female sex (%)	93	89	70	41
Mean age (SD)	58 (7)	56 (8)	51 (9)	43 (11)
Education				
Low (%)	53	49	47	43
Middle (%)	33	36	36	42
High (%)	13	15	16	15
Smoking				
Never (%)	44	42	36	33
Past (%)	34	36	34	30
Current (%)	21	22	29	36
Physical activity				
Inactive (%)	9	9	11	14
Moderately inactive (%)	28	28	30	33
Moderately active (%)	26	26	28	27
Active (%)	38	38	32	26
Hypertension (%)	51	51	48	40
Hypercholesterolemia (%)	9	9	13	12
Mean height (SD)	164.3 (7.0)	165.3 (7.5)	168.1 (8.9)	172.3 (9.6)
Mean weight (SD)	76.4 (10.3)	77.5 (10.7)	80.6 (11.7)	84.7 (12.5)
Mean BMI (SD)	28.3 (3.3)	28.4 (3.3)	28.5 (3.3)	28.5 (3.3)

Table 2 continued

	Quartiles			
	1 (lowest)	2	3	4 (highest)
Mean waist (SD)	89.3 (9.3)	90.0 (9.6)	92.6 (10.0)	94.8 (10.7)
Mean WHR (SD)	0.82 (0.07)	0.83 (0.07)	0.86 (0.08)	0.89 (0.09)
Mean total energy intake kcal (SD)	1734.9 (453.3)	1853.9 (473.8)	2074.1 (573.0)	2394.4 (677.5)
Mean alcohol en% (SD)	3.2 (4.9)	3.3 (4.7)	3.8 (4.9)	4.0 (5.1)

Table 3 Hazard ratios (and 95 % CI) for Pattern 1 and Pattern 2, and type 2 diabetes in overweight and obese individuals from the EPIC-NL study

	Quartiles				*p*-for trend
	1 (lowest)	2	3	4 (highest)	
Pattern 1					
No. of cases	236	225	189	181	
Person-years	1,310	1,215	1,010	945	
Age adjusted[a]	1	1.01 (0.84; 1.22)	0.87 (0.72; 1.05)	0.84 (0.69; 1.03)	0.04
Multivariate[b]	1	1.06 (0.88; 1.28)	0.95 (0.78; 1.15)	0.97 (0.79; 1.20)	0.57
Multivariate[c]	1	1.08 (0.90; 1.30)	0.96 (0.79; 1.17)	1.00 (0.81; 1.23)	0.73
Pattern 2					
No. of cases	214	225	233	159	
Person-years	1,110	1,143	1,301	928	
Age adjusted[a]	1	1.23 (1.01; 1.48)	1.67 (1.35; 2.02)	1.87 (1.45; 2.43)	<0.0001
Multivariate[b]	1	1.21 (1.00; 1.46)	1.56 (1.28; 1.90)	1.70 (1.31; 2.20)	<0.0001
Multivariate[c]	1	1.19 (0.99; 1.44)	1.50 (1.20; 1.83)	1.56 (1.20; 2.02)	0.0001
More active Pattern 1					
No. of cases	127	127	92	104	
Person-years	700	713	521	542	
Age adjusted[a]	1	1.01 (0.79; 1.29)	0.70 (0.79; 0.91)	0.79 (0.60; 1.02)	0.01
Multivariate[b]	1	1.02 (0.80; 1.31)	0.72 (0.55; 0.94)	0.84 (0.64; 1.11)	0.05
Multivariate[c]	1	1.04 (0.81; 1.33)	0.72 (0.54; 0.94)	0.87 (0.66; 1.15)	0.07
Less active Pattern 1					
No. of cases	109	98	97	77	
Person-years	610	503	489	403	
Age adjusted[a]	1	1.03 (0.78; 1.36)	1.15 (0.88; 1.52)	0.94 (0.70; 1.27)	0.99
Multivariate[b]	1	1.11 (0.84; 1.46)	1.29 (0.97; 1.70)	1.16 (0.85; 1.59)	0.18
Multivariate[c]	1	1.13 (0.85; 1.48)	1.34 (1.01; 1.77)	1.17 (0.86; 1.60)	0.14
More active Pattern 2					
No. of cases	130	123	130	67	
Person-years	700	713	521	542	
Age adjusted[a]	1	1.08 (0.84; 1.38)	1.58 (1.19; 2.03)	1.43 (0.99; 2.08)	0.005
Multivariate[b]	1	1.06 (0.83; 1.36)	1.48 (1.14; 1.94)	1.35 (0.93; 1.97)	0.01
Multivariate[c]	1	1.06 (0.83; 1.37)	1.46 (1.12; 1.90)	1.27 (0.87; 1.85)	0.05
Less active Pattern 2					
No. of cases	84	102	103	92	
Person-years	436	482	558	528	
Age adjusted[a]	1	1.45 (1.09; 1.94)	1.75 (1.28; 2.37)	2.31 (1.60; 3.34)	0.00001
Multivariate[b]	1	1.44 (1.07; 1.92)	1.66 (1.22; 2.25)	2.14 (1.48; 3.09)	0.00004
Multivariate[c]	1	1.40 (1.05; 1.88)	1.56 (1.15; 2.12)	1.92 (1.33; 2.77)	0.0002

BMI = body mass index (kg/m^2)

[a] Models were adjusted for age, sex, total energy intake (kcal)

[b] Models were adjusted for age, sex, total energy intake (kcal), education, physical activity, smoking, family history

[c] Models were adjusted for age, sex, total energy intake (kcal), education, physical activity, smoking, family history, BMI in 2 categories (BMI ≥ 25–29.99/ BMI ≥ 30)

This study specifically addresses the question whether dietary patterns defined in only overweight and obese subjects still influence type 2 diabetes risk independently of BMI. Furthermore, this study has a large sample size, and a prospective design. All diabetes cases were validated against information from the general practitioners or the pharmacist and extensive information about lifestyle and diet of the participants was available. However, the study also has some limitations that need to be addressed. First, we relied on self-reported dietary intake data based on a FFQ administered once at baseline and therefore misclassification may have occurred. Although the FFQ has been validated for food groups, the relative validity for vegetables and fish was somewhat low [11]. As these two items are important components in Pattern 1, misclassification might have occurred there. Assuming this is random error, the effect of this pattern on diabetes risk may be underestimated. Furthermore, although we used energy-adjusted nutrient intake and intake of food groups and adjusted for total energy intake in our analysis, misclassification could be due to under- or over-reporting of energy intake. However, excluding low- and high-energy reporters did not influence our results (data not shown).

Second, factor analysis with its principal component method requires several arbitrary decisions on the selection of included variables, the number of retained factors, the method of rotation and the labels of the factors [19]. Although the general character of the derived patterns is comparable across studies, the content of dietary patterns differs in specific food groups for different countries [20].

We hypothesized the possibility that healthy food choices could be associated with a lower diabetes risk in overweight and obese subjects, following the line of reasoning that chronic disease risk seems to be lower in individuals who are fat, but also fit and active compared to fat, unfit subjects [6]. Our results indeed support this hypothesis. Moreover, the increased risk was most pronounced in persons who were overweight or obese, with a high score on Pattern 2, and who were additionally physically less active. Other studies also showed that reduced physical activity enhances the adverse effects of diet on type 2 diabetes. For instance, Van Dam et al. show that the highest risk for type 2 diabetes was found in those subjects with a high score on a Western dietary pattern in combination with low physical activity [5]. Also, in Shanghai women, a statistically significant interaction between physical activity and dietary intake was found. Less active women with a higher energy intake had a higher risk than active women with lower energy intake (p-interaction = 0.02) [21]. A possible mechanism could be through the enhancement of weight gain during follow-up. It has been shown that physical activity and diet also interact on the propensity of weight gain [22–26]. It can be hypothesized that subjects that scored high on Pattern 2 and who were physically less active had an enhanced weight gain during follow-up, which subsequently increased their diabetes risk. Previous studies showed that the effect of diet on diabetes risk was independent of BMI; however, most of these studies measured BMI at baseline and weight changes during follow-up were not taken into account [3–5]. Only van Dam et al. adjusted for updated BMI and it seems that the association is independent of weight change [5]. In our study, data were available for a small group on annual weight change. However, additional adjustment for annual weight change did not alter our results [HR for inactive subjects consuming the highest score on Pattern 2 1.95 (1.27; 2.98)]. However, weight during follow-up was mainly self-reported, whereas it was measured at baseline, which may have limited the detection of possible mediating effects of weight change and adjusting for weight change may not adequately address reverse causation in the absence of repeated measure of diet.

The interaction between diet and physical activity on diabetes risk could also have its effect through insulin sensitivity. An individual's insulin sensitivity is determined by the degree of adiposity, physical activity and dietary intake. A Western dietary pattern that was characterized with high-fat intake, especially saturated and *trans* fats, was correlated with higher fasting insulin [27]. Physical activity improves insulin sensitivity among both non-diabetic and diabetic populations in observational and clinical trial data [28]. We studied already overweight and obese subjects probably with an average to extreme insulin resistance. Being more obese, less active and scoring high on Pattern 2 is likely to increase insulin resistance that leads to an increased diabetes risk. Further studies are needed to investigate whether the interaction between diet and physical activity on diabetes risk has its effect through changes in weight or is, in part, independent of these weight changes and/or has its effect through insulin sensitivity.

In conclusion, a dietary pattern characterized by soft drinks, French fries and snacks increases the risk of type 2 diabetes in overweight and obese subjects, especially in physically less active subjects. Our findings support the view that diabetes prevention in obese subjects benefits from targeting dietary behavior in combination with an exercise program [29].

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Conflict of interest None of the authors had a conflict of interest.

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