Prev. Nutr. Food Sci. 2019;24(1):1-7
https://doi.org/10.3746/pnf.2019.24.1.1
pISSN 2287-1098 · eISSN 2287-8602

The Association between Dietary Fat Pattern and the Risk of Type 2 Diabetes

Zahra Gaeini[1], Zahra Bahadoran[2], Parvin Mirmiran[3], and Abolghasem Djazayery[1]

[1]Department of Clinical Nutrition and Dietetics, Science and Research Branch, Islamic Azad University, Tehran 19585-466, Iran
[2]Nutrition and Endocrine Research Center and [3]Obesity Research Center, Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran 19395-4763, Iran

ABSTRACT: Despite several studies examining single dietary fats on type 2 diabetes (T2D) incidence, little is known about the effects of multiple fatty acids on the risk of T2D. We aimed to address this question in the Tehran Lipid and Glucose Study (TLGS) population. Dietary intakes of participants without T2D (n=2,139) were assessed using the validated food frequency questionnaire. To assess the risk of T2D after 6 years of follow-up, we used multivariate Cox proportional hazard regression models. Three major dietary fat patterns were: (1) high amounts of dietary cholesterol, saturated fats, oleic acid, linoleic acid, linolenic acid, and trans fats; (2) high amounts of long-chain polyunsaturated fats; and (3) high amounts of dietary cholesterol and saturated fats. Dietary total fat intake hazard ratio [HR=1.31, 95% confidence interval (CI)=0.77～2.23 and HR=0.69, 95% CI=0.27～1.76, in the second and third tertile, respectively] was not related to the development of T2D. Animal- and plant-based dietary fat intakes were additionally not related to the risk of T2D. After adjustment for confounding variables, there was no significant association between dietary fat pattern score and T2D incidence. Whereas, the third pattern had a borderline negative association with diabetes development (HR=0.56, 95% CI=0.29～1.07). These novel data suggest that dietary fat composition may modify the risk of T2D incidence.

Keywords: fatty acids, dietary fat, diabetes, dysglycemia

INTRODUCTION

Type 2 diabetes (T2D) is an important public health problem with an increasing prevalence at the global level (1). There are several metabolic, genetic, and lifestyle risk factors that contribute to T2D development; among these, modifiable lifestyle factors, including dietary factors, are of particular importance for disease prevention and control (2). Some prospective cohort studies have examined associations of several individual fatty acids with T2D risk (3-9). Studies show conflicting results regarding the effect of fish consumption omega-3 polyunsaturated fatty acids (PUFAs) on T2D: some reported no effect (4,5), some an adverse effect (6,7), while others found a beneficial effect (8). Moreover, consumption of the monounsaturated fatty acids (MUFA) n-3 and n-6 PUFA were positively associated with incidence of T2D in a large cohort study (9). Almost all such studies have focused on individual fatty acids as separate exposures, and may therefore have missed synergistic or additive effects of intake of multiple fatty acids. Analyzing patterns of fats could dissolve these complexities through uncovering interrelations of dietary fatty acids.

The fatty acids pattern in plasma and erythrocytes in relation to insulin resistance and risk of T2D have been investigated in two previous studies. Imamura et al. (10) suggested that a plasma fatty acid pattern with high concentrations of linoleic acid, odd-chain fatty acids, and very long-chain fatty acids, may be associated with lower risk of T2D. Likewise, a longitudinal follow-up study undertaken by Bigornia et al. (11) showed that an erythrocyte fatty acid pattern with low concentrations of n-6 PUFAs and *de novo* lipogenesis fatty acids was associated with impaired insulin sensitivity.

Fats are physiologically crucial in development of T2D, however there is a lack of data on the association between dietary fat pattern and diabetes. The aim of this study was therefore to investigate possible associations of dietary fat patterns with the risk of diabetes mellitus.

Received 5 October 2018; Accepted 12 February 2019; Published online 31 March 2019

Correspondence to Abolghasem Djazayery, Tel: +98-21-8895-5975, E-mail: djazayery@yahoo.com
Author information: Zahra Gaeini (Researcher), Zahra Bahadoran (Researcher), Parvin Mirmiran (Professor), Abolghasem Djazayery (Professor)

MATERIALS AND METHODS

Study population

Population-based analysis was conducted within the framework of the Tehran Lipid and Glucose Study (TLGS). TLGS is a prospective cohort study, aimed at preventing non-communicable disease risk factors, which included a sample of residents under the coverage of 3 medical health centers in District No.13 of Tehran, Iran (12). Up until now, the prospective ongoing phase of TLGS has consisted of 5 examination phases, with 3-year interval follow-up assessments. During the 3rd phase of the TLGS (2006～2008), 3,687 participants who had completed food frequency questionnaire (FFQ) were selected from a total of 20,188. From those aged 20 to 70 years (n=2,924), participants with diabetes mellitus at baseline (n=321) and who reported daily energy intakes outside the range of 800～4,200 kcal/d (n=284) were excluded. In addition participants with missing anthropometrics, physical activity, or 2 h post challenge plasma glucose (2 h-PCPG) data (n=63), and participants who did not have any follow-up data (n=117) were excluded. After 6 years of follow-up, data for 2,139 subjects was available for the final analysis.

Ethical consideration

The study protocol was approved by the ethics committee of the Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran. Informed written consent was obtained from all participants. The ethical number of the study is IR.SBMU.ENDOCRINE.REC.1396.460.

Dietary assessment

The normal dietary intake of participants was assessed using a 168-item semi-quantitative FFQ. The validity and reliability of the FFQ have been previously described in detail (13). During face-to-face interviews, trained dieticians collected data on participant's consumption frequency for a given serving of each food item during the previous year on a daily, weekly, and monthly basis. Prior to analysis, the reported frequency for each food item was converted to daily intake, and portion sizes of consumed food were converted to grams. Since the Iranian Food Composition Table (FCT) is incomplete, the US Department of Agriculture's (USDA) Food Composition Table was used to obtain the amount of energy per grams of each type of food, and the fatty acids compositions. For traditional Iranian foods not included in the USDA FCT, including 'kashk' (a traditional yogurt drink), the content of fatty acids was determined using the Iranian FCT. Total fat intakes, and intakes of plant-derived and animal-derived fats were estimated. Plant-derived fats included fats from plant-based foods including nuts, seeds, vegetable oils, olive and olive oil, and grains. Animal-derived fats were included fats from animal-based foods including meats, processed meats, poultry, egg, fast foods, dairy, cream, butter, and ice cream.

To assess the validity and reliability of the FFQ, a random subsample of 132 participants (61 male and 71 female) aged 20 years and over completed a 168-item FFQ twice with a 14-month interval, and 12 dietary recalls (once per month). Data from each FFQ and the 12 dietary recalls were compared to show correlation coefficients between the FFQ and multiple 24 h recalls of 0.53 and 0.39, and between the two FFQs of 0.59 and 0.60 in males and females, respectively (13).

Biochemical assessment

Blood samples were taken from all study participants whilst in sitting positions between 7:00 and 9:00 am, following fasting overnight for 12 to 14 h. All blood analyses was carried out at the research laboratory of TLGS on the day of blood collection using a Selectra 2 autoanalyzer (Vital Scientific, Spankeren, the Netherlands). Fasting plasma glucose (FPG), 2 h-PCPG, and serum triglyceride (TG) levels were assayed using an enzymatic colorimetric method, with glucose oxidase and glycerol phosphate oxidase, respectively. High-density lipoprotein cholesterol (HDL-C) was measured after precipitation of apolipoprotein B-containing lipoproteins with phosphotungstic acid. Both inter- and intra-assay coefficients of variation were less than 5% at baseline and at follow-up phases.

Demographic and anthropometric measures

The anthropometric and demographic measures were assessed at baseline (2006～2008). Weight measurements were carried out using digital scales (Seca, Hamburg, Germany) while subjects were minimally dressed and without shoes, and was recorded to the nearest 0.1 kg. Subject height was measured while without shoes and with shoulders in a normal position. Height was recorded to the nearest of 0.5 cm. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Waist circumference, determined as midway between the lower border of the ribs and the widest part of the iliac crest, was measured using a soft measuring tape without applying any pressure to the body, and was recorded to the nearest 0.1 cm. For measurements of both systolic (SBP) and diastolic blood pressure, two measurements of blood pressure were taken on the right arm using a standardized mercury sphygmomanometer, after a 15-min rest in the sitting position. The mean of the two measurements was considered to be the participant's blood pressure.

Levels of physical activity were expressed as metabolic equivalent task hours per week (METs h/week), calcu-

lated using the modifiable activity questionnaire. Light levels of physical activity were classed as MET <3 h/week, moderate levels classed as MET 3 to <6 h/week, and heavy levels classed as MET ≥6 h/week (14). Additional covariate information including age, medical history, smoking habit, and demographic data was obtained at the beginning of the study using an orally pretested questionnaire.

Definition of terms

Diabetic patients were defined as participant who met at least one of the following criteria: FPG ≥126 mg/dL, 2 h-PCPG ≥200 mg/dL, or taking anti-diabetic medication (15). A participant who had at least one parent or sibling with T2D were considered to have a positive family history of diabetes. The diabetes risk score (DRS) was calculated as SBP (mm Hg): <120 (0 point), 120~140 (3 point), ≥140 (7 point); family history of diabetes (5 point); waist to height ratio (WHtR): <0.54 (0 point), 0.54~0.59 (6 point), ≥0.59 (11 point); TG/HDL-C: <3.5 (0 point), ≥3.5 (3 point); FPG (mmol/L): <5.0 (0 point), 5.0~5.5 (12 point), 5.6~6.9 (33 point) (16).

Statistical analysis

Baseline characteristics of participants are shown as mean ±standard deviation (SD) or frequency (%). Significant differences in general characteristics and total dietary intake of energy and fats between healthy and diabetic subjects were evaluated using one-way analysis of variance, and was reported as mean±SD. For qualitative variables reported as frequency (%), the Chi-square test was used to detect any significant differences.

The principle component analysis (PCA) was used to determine patterns of fat intakes based on 8 fat groups [dietary cholesterol, saturated fatty acids (SFA), oleic acid, linoleic acid, linolenic acid, eicosapentaenoic acid, docosahexaenoic acid, and trans fatty acids]. Due to a high correlation between fats, the promax rotation was used. To determine the number of factors to retain, we considered eigenvalues >0.3, the scree plot, and the interpretability of the patterns. All 8 fat groups contributed to the pattern score calculation, however fats with an absolute component loading score of ≥0.50 were selected to describe the pattern. The Kaiser-Meyer-Olkin statistic, a measure of sampling adequacy, was 0.59, and the *P* value for Bartlett's test of sphericity was <0.001.

The factor score for each pattern was calculated using the sum of fat intake weighted by respective factor loadings on each fat pattern. The fat pattern scores were assessed as tertiles.

To assess the hazard ratios (HRs) of total dietary fat, in relation to the diabetes mellitus incidence, we used cox proportional hazard regression models, with person-year as the underlying time metric. The confounder variables were adjusted in two models: Model 1 was adjusted for DRS, whereas Model 2 was additionally adjustment for total energy intakes (kcal/d), dietary intakes of carbohydrate (g/d) and total fiber intake (g/d), based on univariate analysis. DRS, which comprises of FPG, WHtR, and TG to HDL-C ratio, and SBP is a simple pragmatic risk score, which has been validated among the Iranian population as a main predictor of T2D (16). This approach is thought to be superior to relying on common individual risk factors for identifying individuals at high risk of developing T2D in a large Middle Eastern adult population (16). An important advantage of using this score is to account for major T2D confounders without adding variables that may lead to instability of our models.

Variables with P_E (*P* entry) values of less than 0.2 in the univariate analyses were selected as confounders.

All statistical analyses were conducted using the SPSS version 20 (IBM Corp., Armonk, NY, USA) and STATA version 12 SE (Stata Corp LP, College Station, TX, USA). Two-tailed *P* values of <0.05 were considered significant.

Table 1. Baseline characteristics and dietary intakes of the participants

Baseline characteristics	$T2D^+$ (n=143)	$T2D^-$ (n=1,996)	*P*-value
Age (y)	47.3±12.4	38.9±12.4	<0.001
Men (%)	47.6	45.2	0.592
Family history of T2D (%)	24.5	18.5	0.077
Current smoker (%)	13.3	12.2	0.930
Low physical activity (%)	39.7	39.3	0.926
Body mass index (kg/m^2)	30.9±4.6	26.7±4.6	<0.001
Total energy intake (kcal/d)	2,176.7±689.5	2,273.6±714.9	0.117
Total fiber intake (g/d)	38.2±19.7	37.5±20.6	0.682
Total fat intake (%energy)	13.5±3.4	13.9±3.1	0.099
SFA (g/d)	23.5±9.8	26.5±11.6	0.003
MUFA (g/d)	25.3±11.2	27.4±11.2	0.040
Oleic acid (g/d)	22.9±10.5	24.8±10.6	0.037
PUFA (g/d)	15.5±8.1	16.5±7.8	0.160
Linoleic acid (g/d)	13.3±7.3	14.3±7.1	0.144
α-Linolenic acid (g/d)	1.07±0.6	1.2±0.6	0.083
EPA (g/d)	0.02±0.03	0.03±0.09	0.510
DHA (g/d)	0.08±0.09	0.1±0.3	0.480
Total trans fatty acids (g/d)	5.6±5.2	6.0±4.6	0.350
Cholesterol (mg/d)	193.2±88.4	226.9±141.1	0.005

Data are mean±SD.
T2D, type 2 diabetes; SFA, saturated fatty acid; MUFA, mono-unsaturated fatty acid; PUFA, poly-unsaturated fatty acid; EPA, echosapanthaenoic acid; DHA, docosahexaenoic acid.

Table 2. The hazard ratio (95% confidence interval) of diabetes mellitus across tertile categories of dietary fats

Dietary fat	T1	T2	T3	*P* for trend
Total dietary fat				
Crude	1.00	0.92 (0.63~1.35)	0.65 (0.43~0.98)	0.037
Model 1	1.00	1.23 (0.81~1.87)	0.58 (0.36~0.95)	0.026
Model 2	1.00	1.31 (0.77~2.23)	0.69 (0.27~1.76)	0.458
Animal fats				
Crude	1.00	0.73 (0.50~1.08)	0.62 (0.41~0.93)	0.022
Model 1	1.00	0.75 (0.48~1.16)	0.55 (0.35~0.87)	0.011
Model 2	1.00	0.80 (0.50~1.28)	0.65 (0.36~1.17)	0.152
Plant-based fats				
Crude	1.00	0.77 (0.52~1.14)	0.69 (0.46~1.03)	0.075
Model 1	1.00	1.02 (0.66~1.57)	0.70 (0.44~1.10)	0.117
Model 2	1.00	1.28 (0.75~2.20)	1.19 (0.52~2.73)	0.705

Model 1, adjusted for diabetes risk score; Model 2, additional adjustment for total energy intakes (kcal/d), dietary intakes of carbohydrate (g/d), and total fiber intake (g/d).

RESULTS

A total of 2,139 adult participants aged 20 years and over were included in this study. 55.1% of study participants were female, with an overall mean age of 38.3±12.7 years. After an average follow-up of 5.1 years, 143 participants had diabetes (6.6%). The total fat intake for the study population was 78.7±31.0 g/d (data not shown).

Baseline characteristics and dietary intakes of the participants after 6 years of follow-up by T2D incidence are shown in Table 1. Compared to subjects diagnosed with T2D, those without T2D were significantly younger, with lower BMIs. However, there were no statistically significant differences by gender, family history of T2D, physical activity levels, and smoking status. Subjects with T2D consumed less SFA, MUFA, oleic acid, and cholesterol verses healthy participants. There was no significant differences in other dietary intakes between the groups.

Total, animal-, and plant-based fat intakes in relation to T2D risk were assessed and are presented in Table 2. Total dietary and animal-based fats were related to a lower risk of T2D in both the crude and the first adjusted model (*P* for trend <0.05). After adjustment for overall confounding variables, neither total fat, nor animal- or plant-based fats were associated with T2D development.

PCA identified three major fatty acid patterns (Table 3). Pattern 1 was characterized by higher loads of dietary cholesterol, SFA, oleic acid, linoleic acid, linolenic acid, and trans fatty acids; pattern 2 by higher loads of dietary long chain PUFAs, echosapanthaenoic acid (EPA), and docosahexaenoic acid (DHA); and pattern 3 by higher loads of dietary cholesterol and SFA. These patterns fat pattern 1 was significantly correlated with dietary intake of oils, egg, dairy products, seeds, and nuts (Pearson correlation was 0.668, 0.215, 0.285, and 0.271, respectively), whereas the fat pattern 2 (cholesterol and SFA pattern) was highly correlated with dairy products, red meats and poultry, egg, and processed meats (Pearson correlation was 0.456, 0.388, 0.590, and 0.218, respectively). Fat pattern 2 (long chain PUFAs pattern) showed a significant negative correlation with intake of oils (Pearson correlation: −0.071), and was positively correlated with fish intake (Pearson correlation: 0.344, data not shown).

Table 3. Component loadings for dietary fatty acid patterns

Fatty acids	Patterns		
	1	2	3
Cholesterol	0.565		0.732
SFA	0.815		0.360
Oleic acid (MUFA)	0.952		
Linoleic acid (PUFA)	0.876		
Linolenic acid (PUFA)	0.862		
EPA		0.962	
DHA		0.964	
Trans fatty acids	0.697		

SFA, saturated fatty acid; MUFA, mono-unsaturated fatty acid; PUFA, poly-unsaturated fatty acid; EPA, echosapanthaenoic acid; DHA, docosahexaenoic acid.

HRs (95% CI) of T2D in relation to major fat patterns scores are shown in Table 4. After adjustment for confounding variables, there were no significant relationship between dietary fat patterns 1 or 2 with incidence of diabetes, whereas pattern 3 showed a borderline negative association with diabetes development (HR=0.56, 95% CI=0.29~1.07, in the third compared to the first tertile of the fatty acid pattern score). The dietary fat pattern with a higher load of dietary cholesterol, SFA, oleic acid, linoleic acid, linolenic acid, and trans fatty acids was related to decreased risk of diabetes in both the crude (HR =0.65, 95% CI=0.43~0.98; *P* for trend=0.042) and first model adjusted for DRS (HR=0.52, 95% CI=0.32~0.86; *P* for trend=0.013). The third pattern was also characterized by a higher load of dietary cholesterol and SFA, and was related to a lower risk of T2D in both the crude (HR

Table 4. The hazard ratio (95% confidence interval) of diabetes across tertile categories of fatty acid patterns scores

Fatty acid pattern	T1	T2	T3	*P* for trend
Pattern 1				
Crude	1.00	0.87 (0.59～1.27)	0.65 (0.43～0.98)	0.042
Model 1	1.00	0.98 (0.65～1.48)	0.52 (0.32～0.86)	0.013
Model 2	1.00	1.00 (0.62～1.61)	0.56 (0.27～1.14)	0.167
Pattern 2				
Crude	1.00	0.94 (0.63～1.42)	1.05 (0.71～1.57)	0.793
Model 1	1.00	0.98 (0.63～1.52)	0.10 (0.63～1.57)	0.958
Model 2	1.00	1.07 (0.68～1.68)	1.10 (0.70～1.75)	0.674
Pattern 3				
Crude	1.00	0.96 (0.66～1.38)	0.53 (0.34～0.82)	0.005
Model 1	1.00	1.21 (0.81～1.83)	0.48 (0.29～0.81)	0.012
Model 2	1.00	1.29 (0.82～2.01)	0.56 (0.29～1.07)	0.174

Model 1, adjusted for diabetes risk score; Model 2, additional adjustment for total energy intakes (kcal/d), dietary intakes of carbohydrate (g/d), and total fiber intake (g/d).

=0.53, 95% CI=0.34～0.82; *P* for trend=0.005) and first adjusted model (HR=0.48, 95% CI=0.29～0.81; *P* for trend=0.012).

DISCUSSION

In our large, prospective cohort study of 2,139 participants, we observed no significant associations between dietary total, plant-, and animal-based fat and incidence of T2D. We identified three dietary fat patterns; the first pattern was associated with a high load of dietary cholesterol, SFA, oleic acid, linoleic acid, linolenic acid, and trans fatty acids, the second pattern with a high load of dietary long chain PUFAs (EPA and DHA), and the third pattern with a high load of dietary cholesterol and SFA. The results from our data analysis did not show any significant associations between fat patterns and incidence of T2D. However, the cholesterol and SFA pattern (third pattern) had a borderline negative association with the T2D development.

Although there are few studies that have examined the effect of dietary fat on T2D incidence, these have produced inconsistent results (17-22). In a recent population-based study, a higher intake of total dietary fat was associated with a higher fasting glucose concentration (odd ratio=1.46, 95% CI=1.07～2.00) (17), whereas a large-scale cohort study found that higher intakes of fat had no effect on T2D risk (18); however, we did not find evidence to support the relationship between total fat intake and T2D. Clinical recommendations emphasize the importance of low-fat diets, without drawing attention to the quality of fats (19). This current study examined the amount, as well as the type of dietary fat on T2D risk. Two systematic literature reviews, which summarize the associations between the amounts and types of dietary fats and T2D incidence, suggested that replacing SFA and trans fatty acids with PUFAs and/or MUFAs may reduce T2D risk. Limited evidence suggests that PUFAs n-6 (linoleic acid), but not n-3, is inversely associated with risk of diabetes and insulin resistance (20,21). The conclusions of these systematic reviews in the context n-3 fatty acids are in line with our findings; pattern 2 in the present study showed a higher load of n-3 PUFAs had no significant association with T2D. Studies investigating the association of dietary cholesterol with diabetes risk also have conflicting results (22,23). A recent meta-analysis of five longitudinal studies suggested that a higher intake of cholesterol may be positively associated with T2D risk (22). However, a 5-year follow-up study did not find any significant associations between intake of cholesterol or eggs and risk of T2D in Japanese populations (23). In this study a negative association between T2D risk and higher dietary cholesterol intake was observed in postmenopausal women (23). Our findings in respect to the high-cholesterol pattern do not support those of previous studies, which report that high exposure to cholesterol may increase the risk of T2D (22). However, the reasons underlying these conflicting results remain unclear.

Although the amount and type of dietary fat is highlighted in a few previous studies, the fat patterns of an individual's diet may elucidate the synergistic relation between fats and T2D. The present study is to our knowledge the first to report results separately for animal- and plant-based dietary fats, as well as the dietary fat patterns. As noted above, in this study we observed a weak non-significant association between high cholesterol and SFA, and a null association between total fat, animal-, and plant-based fat and risk of T2D. Further studies in other populations should try and replicate these findings.

The strengths of the present study include a prospective design, a relatively large sample size, a long-term follow-up period, and detailed data on potential confounders, laboratory assessments for diabetes diagnosis, and

dietary assessment using a validated FFQ. The PCA used in this study to determine fat patterns generates a broad overview of dietary fat composition, and can dissolve complexities and take interrelations of dietary fats into account. Our study also had some limitations. First, we used a self-reported FFQ, therefore measurement error was not excluded. Second, we used the USDA food composition table to obtain energy of foods and fatty acids compositions. Although we adjusted for a wide range of potential confounders, we were unable to assess the role of environmental and genetic factors.

In conclusion, this study revealed that there is no significant association between dietary fat patterns and risk of T2D. There was no relationship between total dietary fat intake, or animal- or plant-based fat intake and the incidence of T2D. These results are suggestive that dietary fat composition may play a more important role than the total amount of fat intake for increasing the risk of T2D.

ACKNOWLEDGEMENTS

The authors appreciate to the participants in the Tehran Lipid and Glucose Study and the staff of the Research Institute for Endocrine Science, Tehran Lipid and Glucose Study Unit.

AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

REFERENCES

1. Olokoba AB, Obateru OA, Olokoba LB. 2012. Type 2 diabetes mellitus: a review of current trends. *Oman Med J* 27: 269-273.
2. Murakami K, Okubo H, Sasaki S. 2005. Effect of dietary factors on incidence of type 2 diabetes: a systematic review of cohort studies. *J Nutr Sci Vitaminol* 51: 292-310.
3. Salmerón J, Hu FB, Manson JE, Stampfer MJ, Colditz GA, Rimm EB, Willett WC. 2001. Dietary fat intake and risk of type 2 diabetes in women. *Am J Clin Nutr* 73: 1019-1026.
4. Patel PS, Forouhi NG, Kuijsten A, Schulze MB, van Woudenbergh GJ, Ardanaz E, Amiano P, Arriola L, Balkau B, Barricarte A, Beulens JW, Boeing H, Buijsse B, Crowe FL, de Lauzon-Guillan B, Fagherazzi G, Franks PW, Gonzalez C, Grioni S, Halkjaer J, Huerta JM, Key TJ, Kühn T, Masala G, Nilsson P, Overvad K, Panico S, Quirós JR, Rolandsson O, Sacerdote C, Sánchez MJ, Schmidt EB, Slimani N, Spijkerman AM, Teucher B, Tjonneland A, Tormo MJ, Tumino R, van der A DL, van der Schouw YT, Sharp SJ, Langenberg C, Feskens EJ, Riboli E, Wareham NJ; InterAct Consortium. 2012. The prospective association between total and type of fish intake and type 2 diabetes in 8 European countries: EPIC-InterAct Study. *Am J Clin Nutr* 95: 1445-1453.
5. Wallin A, Di Giuseppe D, Orsini N, Åkesson A, Forouhi NG, Wolk A. 2015. Fish consumption and frying of fish in relation to type 2 diabetes incidence: a prospective cohort study of Swedish men. *Eur J Nutr* 56: 843-852.
6. Djoussé L, Gaziano JM, Buring JE, Lee IM. 2011. Dietary omega-3 fatty acids and fish consumption and risk of type 2 diabetes. *Am J Clin Nutr* 93: 143-150.
7. Kaushik M, Mozaffarian D, Spiegelman D, Manson JE, Willett WC, Hu FB. 2009. Long-chain omega-3 fatty acids, fish intake, and the risk of type 2 diabetes mellitus. *Am J Clin Nutr* 90: 613-620.
8. Villegas R, Xiang YB, Elasy T, Li HL, Yang G, Cai H, Ye F, Gao YT, Shyr Y, Zheng W, Shu XO. 2011. Fish, shellfish, and long-chain n-3 fatty acid consumption and risk of incident type 2 diabetes in middle-aged Chinese men and women. *Am J Clin Nutr* 94: 543-551.
9. Alhazmi A, Stojanovski E, McEvoy M, Garg ML. 2014. Macronutrient intake and type 2 diabetes risk in middle-aged Australian women. Results from the Australian Longitudinal Study on Women's Health. *Public Health Nutr* 17: 1587-1594.
10. Imamura F, Sharp SJ, Koulman A, Schulze MB, Kröger J, Griffin JL, Huerta JM, Guevara M, Sluijs I, Agudo A, Ardanaz E, Balkau B, Boeing H, Chajes V, Dahm CC, Dow C, Fagherazzi G, Feskens EJM, Franks PW, Gavrila D, Gunter M, Kaaks R, Key TJ, Khaw KT, Kühn T, Melander O, Molina-Portillo E, Nilsson PM, Olsen A, Overvad K, Palli D, Panico S, Rolandsson O, Sieri S, Sacerdote C, Slimani N, Spijkerman AMW, Tjønneland A, Tumino R, van der Schouw YT, Langenberg C, Riboli E, Forouhi NG, Wareham NJ. 2017. A combination of plasma phospholipid fatty acids and its association with incidence of type 2 diabetes: The EPIC-InterAct case-cohort study. *PLoS Med* 14: e1002409.
11. Bigornia SJ, Lichtenstein AH, Harris WS, Tucker KL. 2016. Associations of erythrocyte fatty acid patterns with insulin resistance. *Am J Clin Nutr* 103: 902-909.
12. Azizi F, Ghanbarian A, Momenan AA, Hadaegh F, Mirmiran P, Hedayati M, Mehrabi Y, Zahedi-Asl S; Tehran Lipid and Glucose Study Group. 2009. Prevention of non-communicable disease in a population in nutrition transition: Tehran Lipid and Glucose Study phase II. *Trials* 10: 5.
13. Mirmiran P, Esfahani FH, Mehrabi Y, Hedayati M, Azizi F. 2010. Reliability and relative validity of an FFQ for nutrients in the Tehran lipid and glucose study. *Public Health Nutr* 13: 654-662.
14. Ainsworth BE, Haskell WL, Leon AS, Jacobs DR Jr, Montoye HJ, Sallis JF, Paffenbarger RS Jr. 1993. Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc* 25: 71-80.
15. American Diabetes Association. 2014. Standards of medical care in diabetes. *Diabetes Care* 37: S14-S80.
16. Bozorgmanesh M, Hadaegh F, Ghaffari S, Harati H, Azizi F. 2011. A simple risk score effectively predicted type 2 diabetes in Iranian adult population: population-based cohort study. *Eur J Public Health* 21: 554-559.
17. Narasimhan S, Nagarajan L, Vaidya R, Gunasekaran G, Rajagopal G, Parthasarathy V, Unnikrishnan R, Anjana RM, Mohan V, Sudha V. 2016. Dietary fat intake and its association with risk of selected components of the metabolic syndrome among rural South Indians. *Indian J Endocrinol Metab* 20: 47-54.
18. van Dam RM, Willett WC, Rimm EB, Stampfer MJ, Hu FB. 2002. Dietary fat and meat intake in relation to risk of type 2 diabetes in men. *Diabetes Care* 25: 417-424.
19. Mozaffarian D. 2016. Dietary and policy priorities for cardiovascular disease, diabetes, and obesity: a comprehensive review. *Circulation* 133: 187-225.
20. Risérus U, Willett WC, Hu FB. 2009. Dietary fats and prevention of type 2 diabetes. *Prog Lipid Res* 48: 44-51.
21. Schwab U, Lauritzen L, Tholstrup T, Haldorssoni T, Riserus

U, Uusitupa M, Becker W. 2014. Effect of the amount and type of dietary fat on cardiometabolic risk factors and risk of developing type 2 diabetes, cardiovascular diseases, and cancer: a systematic review. *Food Nutr Res* 58: 10.3402/fnr.v58.25145.

22. Tajima R, Kodama S, Hirata M, Horikawa C, Fujihara K, Yachi Y, Yoshizawa S, Iida KT, Sone H. 2014. High cholesterol intake is associated with elevated risk of type 2 diabetes mellitus—a meta-analysis. *Clin Nutr* 33: 946-950.
23. Kurotani K, Nanri A, Goto A, Mizoue T, Noda M, Oba S, Sawada N, Tsugane S; Japan Public Health Center-based Prospective Study Group. 2014. Cholesterol and egg intakes and the risk of type 2 diabetes: the Japan Public Health Center-based Prospective Study. *Br J Nutr* 112: 1636-1643.