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ORIGINAL CONTRIBUTION

trans Fatty acid consumption, lifestyle and type 2 diabetes prevalence in a Spanish population

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Abstract
Aim of the study To analyse the association of *trans* fatty acid (TFA) consumption with the risk of type 2 diabetes and lifestyle in a South European population.
Methods Data were obtained from two population-based cross-sectional surveys conducted in Gerona (Spain) in 2000 and 2005. The present analysis included 7,774 free-living Spanish men and women aged 35–74 years. Diet was assessed by a validated food frequency questionnaire. Fasting blood sugar was measured and history of diabetes recorded.
Results *trans* Fatty acid intake was relatively low in our study population (1.5 g d^{-1} for women and 1.8 g d^{-1} for men). Multiple logistic regression analysis revealed a null association between TFA intake and risk of type 2 diabetes in men and women. Total energy intake, alcohol consumption and the prevalence of smoking increased across quartiles of TFA intake. An inverse association was found between TFA intake and the consumption of vegetables, fruit, fish, legumes, white bread and olive oil in both genders ($p < 0.001$) after adjusting for energy intake. In contrast, intakes of meat, sausages and pastry products increased across quartiles of TFA intake in both genders ($p < 0.001$).
Conclusions *trans* Fatty acid intake was not associated with a higher risk of type 2 diabetes. Higher TFA intake was associated with less healthy lifestyle and dietary habits in both sexes.

Keywords *trans* Fatty acids · Type 2 diabetes · Lifestyle · Diet · Spanish population

Introduction

Type 2 diabetes accounts for 90–95% of diabetes cases worldwide [1]. The prevalence of this disease, estimated at 171 million cases worldwide in 2000 [2, 3], is expected to reach 300 million by 2025 [4]. For this reason, diabetes is considered to be an increasingly important global public health problem that threatens to reach pandemic levels.

Insulin resistance, defined as an impaired tissue response to insulin, is central to the pathogenesis of type 2 diabetes and is the underlying abnormality in most people that develop the disease [1, 5]. Evidence suggests that insulin resistance is affected by dietary fatty acids [5]. Replacing saturated fatty acids with unsaturated fatty acids improves insulin sensitivity [6]. However, data on the effect of *trans* fatty acids (TFA), i.e. unsaturated fatty acids with at least one double bond in the *trans* configuration, on insulin resistance have been inconsistent [5]. Although their effects on cardiovascular disease are well known [7–9], their role in the development of diabetes has not been widely studied. Furthermore, there is limited information on TFA consumption in European populations.

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Recent evidence indicates that there is an important variation in total TFA intake as well as food sources of TFA between countries worldwide. Average estimates show lower mean TFA intake among European countries (2.2 g d^{-1}) [10] than in North America (3–4 g d^{-1}) [11].

The present study had three objectives: to analyse TFA consumption in a representative Spanish population, describe the association of TFA intake with lifestyle variables and evaluate the relationship between TFA consumption and prevalence of type 2 diabetes.

Materials and methods

Subjects

Data were obtained from two population-based cross-sectional surveys conducted in Gerona (Spain) in 2000 and 2005. Response rates for the two surveys were 71.0 and 71.5%, respectively. The first survey included 3,054 randomly selected free-living men and women between 25 and 74 years of age. The second survey included 6,322 men and women between 35 and 88 years of age. For the present study participants aged 35–74 years ($n = 8{,}195$) from both surveys were included. Final analysis was performed in 3,704 men and 4,070 women after excluding participants with unrealistic dietary energy intake, defined as energy intake less than 800 kcal d^{-1} or more than 4,500 kcal d^{-1} ($n = 412$).

The protocol was approved by an Ethics Committee (CEIC-IMAS, Barcelona, Spain), and the results of the examination were sent to all participants.

Dietary assessment

Food consumption and nutrient intake were measured by a validated food frequency questionnaire (FFQ) [12] administered by a trained interviewer. An optical readable FFQ asked for the usual intake over the preceding year from a 165-item food list, including alcoholic and non-alcoholic beverages. Participants indicated their usual consumption from one of ten frequency categories for each item, from never or <1 time/month to ≥6 times/day. Instead of using standard questions about portion size, this FFQ used medium servings defined by natural (e.g., 1 orange, 1 standard slice) or household (e.g., 1 cup, 1 spoonful) units. TFA intake was calculated from Spanish food composition tables [13].

In a recently finished validation/calibration study, we performed one unannounced 24-h recall (in 150 participants) each month for 1 year; 107 participants completed all of the 12 dietary recalls and the FFQ. The Pearson correlation coefficient and intraclass correlation coefficient for TFA consumption (food and energy-containing beverages) between the reference method (monthly 24-h recalls over 1 year) and the FFQ were 0.52 and 0.46, respectively, indicating that the FFQ provides a reasonable estimate of TFA intakes.

Diabetes

Blood samples were obtained after a 12-h fast. Serum was immediately frozen at −120°C in liquid nitrogen for transport and stored at −80°C for final conservation. Glycaemia measurement was made in an aliquot of serum. The diagnostic criteria of the American Diabetes Association were used for the present study [14]. Diabetes was defined as fasting blood glucose ≥126 mg dL^{-1} (7.0 mmol l^{-1}) or self-reported history of diabetes. Medical history of diabetes was not verified by reviewing physician records.

Measurement of non-dietary variables

Information on demographic and socio-economic variables, medical history, diet, and lifestyle factors including tobacco smoking and alcohol consumption was obtained through structured standard questionnaires administered by trained personnel.

The Minnesota leisure-time physical activity questionnaire, previously validated for Spanish men and women, was also administered by a trained interviewer [15, 16].

Statistical analysis

Differences in continuous variables were compared using the Student t test. The Mann–Whitney U test was used for nonparametric variables. Categorical variables were tested using the Chi-square goodness of fit test. General linear modelling (PROC GLM; SAS Institute Inc., Cary, NC, USA; version 8.0) was used to estimate dietary, lifestyle, anthropometric and socioeconomic variables according to the quartile distribution of TFA intake. Linear trend was tested by including the categorized variable (quartile distribution of TFA) as continuous in this model, and the p for linear trend was calculated using polynomial contrast for continuous variables and age-adjusted logistic regression for dichotomous variables (educational level and current smokers) according to quartile distribution of TFA (PROC LOGISTIC procedure of SAS; SAS Institute Inc., Cary, NC, USA; version 8.0).

Multiple logistic regression analysis (PROC LOGISTIC procedure of SAS; SAS Institute Inc., Cary, NC, USA; version 9.1) was used to analyse the relationship of TFA consumption and the risk of type 2 diabetes. Differences were considered significant if $p < 0.05$.

Results

Energy intake, alcohol consumption, time spent in leisure time physical activity and prevalence of smoking was higher in men than in women (Table 1). TFA intake was higher in men than in women (Table 2). The main sources of TFA intake were prepared food and dairy products in both genders.

TFA intake was inversely associated with age in both genders (Table 3). Energy intake and alcohol consumption increased across quartiles of TFA intake. In men, prevalence of smoking was positively associated with TFA intake.

TFA intake was directly associated with total, saturated and polyunsaturated fat consumption and inversely associated with carbohydrate consumption in both genders. Protein consumption decreased across quartile distribution of TFA intake in women (Table 4). An inverse association was found between TFA intake and the consumption of vegetables, fruit, fish, legumes, white bread and olive oil in both genders (Table 5). Intakes of sausages and pastry products increased across quartiles of TFA intake in both men and women.

Multiple logistic regression analysis adjusted for age, leisure-time physical activity, educational status, smoking, alcohol consumption and dietary fibre intake revealed an insignificant association of TFA consumption and risk of type 2 diabetes in both men and women (Fig. 1).

Discussion

The main finding of the present study was that higher TFA intakes did not increase the risk of type 2 diabetes in either sex. Furthermore, the average TFA intake was low; higher TFA consumption was associated with less healthy dietary habits and lifestyle in both sexes.

In the twenty-first century, type 2 diabetes is one of the most important threats to human health worldwide. Medical costs in the management of diabetes and its complications place an enormous strain on the health care system. The prevalence of the disease appears to be increasing due to population growth, aging, urbanization and the increasing prevalence of obesity and physical inactivity [2, 3]. Estimates and projections suggest an epidemic expansion of diabetes incidence and prevalence in Europe; previous estimates have been surpassed in Spain, where it is now estimated that 10–15% of Spanish adults have diabetes [17, 18].

Diet is an important modifiable risk factor for type 2 diabetes [4, 19]. Generally, as suggested by animal studies, dietary fatty acids appear to be involved in diabetes pathophysiology [19–21]. Furthermore, it has been hypothesized that TFAs may reduce insulin sensitivity [1]. However, the literature on TFAs, insulin resistance and type 2 diabetes is not only conflicting but limited. Overall findings from intervention studies suggest that high TFA intakes in young, healthy, lean women and men have no

Table 1 Baseline characteristics of the study population

	Men (n = 3,704)	Women (n = 4,070)	p
Age (year)	54.5 ± 11.0	53.9 ± 10.9	0.435
Energy (kcal)	2,524 ± 705	2,446 ± 703	<0.001
Smokers (%)	31.1 (29.8–32.5)	16.7 (15.4–18.0)	<0.001
Educational level (%)[a]	47.4 (45.8–49.0)	45.4 (43.9–47.0)	0.001
BMI (kg/m^2)	27.8 ± 3.8	27.1 ± 5.14	0.631
Alcohol (g/d)	15.6 ± 18.2	4.5 ± 7.9	<0.001
Fasting blood glucose (g/dl)	105.0 ± 29.9	96.6 ± 22.9	<0.001

BMI body mass index

[a] Percentage of participants with more than basic education

Table 2 Food sources of *trans* fatty acid intake

	TFA intake in gram per day		TFA intake in percentage of total energy intake	
	Men (n = 3,704)	Women (n = 4,070)	Men (n = 3,704)	Women (n = 4,070)
Food sources				
Total intake	1.76 ± 1.57	1.51 ± 1.34*	0.59 ± 0.33	0.53 ± 0.28*
Dairy products	0.50 ± 0.43	0.58 ± 0.48*	0.18 ± 0.14	0.21 ± 0.15*
Pastry products	0.15 ± 0.26	0.12 ± 0.21*	0.05 ± 0.08	0.04 ± 0.07*
Vegetable oils	0.09 ± 0.68	0.14 ± 0.82*	0.03 ± 0.06	0.04 ± 0.08*
Sausages	0.02 ± 0.03	0.01 ± 0.02*	0.007 ± 0.007	0.005 ± 0.006*
Meat	0.21 ± 0.15	0.19 ± 0.13*	0.07 ± 0.04	0.06 ± 0.04*
Prepared food[a]	0.78 ± 1.17	0.47 ± 0.75*	0.26 ± 0.28	0.16 ± 0.21*

* $p < 0.001$ between genders

[a] Including pizza, croquettes, potato crisps, French fries and fast food products (Hamburger and Cheeseburger)

Table 3 Baseline population characteristics according to quartile distribution of *trans* fatty acid intake

	Men ($n = 3,704$)					Women ($n = 4,070$)				
	Quartiles of *trans* fatty acid intake [Range (g/day)]					Quartiles of *trans* fatty acid intake [Range (g/day)]				
	1st (0.00–0.97) $n = 926$	2nd (0.98–1.46) $n = 926$	3rd (1.47–2.07) $n = 926$	4th (2.08–higher) $n = 926$	p for trend[a]	1st (0.00–0.82) $n = 1017$	2nd (0.83–1.31) $n = 1018$	3rd (1.32–1.87) $n = 1018$	4th (1.88–higher) $n = 1017$	p for trend[a]
Age (year)	58.3	55.9	52.8	50.8	<0.001	57.3	55.1	53.2	50.2	<0.001
	57.6–59.0	55.3–56.7	52.1–53.5	50.1–51.5		56.6–57.9	54.4–55.7	52.5–53.8	49.6–50.9	
Energy (MJ)	8.7	9.9	11.0	12.5	<0.001	8.5	9.7	10.5	12.2	<0.001
	8.6–8.9	9.7–10.1	10.8–11.2	12.3–12.7		8.4–8.7	9.5–9.8	10.3–10.6	12.1–12.4	
LTPA (kcal/d)	373	353	376	379	0.472	244	252	241	238	0.402
	348–397	329–377	352–400	308–379		229–259	237–267	226–256	222–253	
Educational level (%)[b]	45.6	48.3	47.2	48	0.354	47.5	47.0	45.1	42.0	0.005
	42.5–48.9	45.2–51.4	44.0–51.5	45–51		44.6–50.3	44.6–50.3	42.3–47.9	39.1–44.8	
BMI (kg/m^2)	27.9	27.9	27.8	27.8	0.175	27.1	27.1	27.2	27.1	0.960
	27.7–28.2	26.6–28.1	27.6–28.0	27.4–27.4		26.8–27.4	26.8–27.4	26.9–27.5	26.8–27.4	
Alcohol (g/d)	14.4	15.4	16.7	16.2	0.016	4.1	4.2	4.6	5.1	0.004
	13.2–15.5	14.3–16.6	15.6–17.9	15.0–17.4		3.6–4.6	3.7–4.7	4.1–5.1	4.6–5.6	
Smoker (%)	30.0	29.0	29.8	35.8	0.009	16.3	15.7	19.3	23	0.079
	27.0–33.0	26.0–31.9	26.8–32.7	32.8–38.7		14.1–18.5	13.5–17.9	17.1–21.5	19–27	

[a] p for trend adjusted for age and total energy intake

[b] Percentage of participants with more than basic education

LTPA leisure time physical activity

BMI body mass index

Table 4 Population dietary macronutrient consumption by quartiles of *trans* fatty acid (TFA) intake

	Men ($n = 3,704$)					Women ($n = 4,070$)				
	Quartiles of *trans* fatty acid intake [Range (g/day)]					Quartiles of *trans* fatty acid intake [Range (g/day)]				
	1st (0.00–0.97) $n = 926$	2nd (0.98–1.46) $n = 926$	3rd (1.47–2.07) $n = 926$	4th (2.08–higher) $n = 926$	p for trend[a]	1st (0.00–0.82) $n = 1,017$	2nd (0.83–1.31) $n = 1,018$	3rd (1.32–1.87) $n = 1,018$	4th (1.88–higher) $n = 1,017$	p for trend[a]
Carbohydrates (%)[a]	42.0	41.2	40.2	40.3	<0.001	42.7	41.6	41.5	40.4	<0.001
	41.5–42.5	40.7–41.6	39.8–40.7	39.9–40.8		42.3–43.2	41–42.1	41.0–41.9	39.9–40.8	
Proteins (%)[b]	17.3	17.1	17.2	17.0	0.123	18.1	18.2	18.0	17.7	0.002
	17.2–17.5	16.9–17.2	17.0–17.4	16.9–17.3		17.9–18.3	18.1–18.4	17.8–18.2	17.5–17.9	
Total fat (%)[b]	38.9	40.3	41.2	41.8	<0.001	40.5	41.4	41.7	43.1	<0.001
	38.6–39.4	39.9–40.7	40.8–41.6	41.4–42.3		40.1–40.9	40.9–41.8	41.3–42.1	42.7–43.6	
Saturated fat (%)[b]	10.9	11.9	12.4	13.2	<0.001	10.9	11.8	12.4	13.4	<0.001
	10.8–11.1	11.7–12.0	12.2–12.5	13.1–13.4		10.8–11.1	11.7–12.0	12.3–12.5	12.2–12.5	
Polyunsaturated fat (%)[b]	5.8	6.0	6.2	6.6	<0.001	5.9	5.9	6.0	6.3	<0.001
	5.7–5.9	5.9–6.1	6.1–6.2	6.5–6.7		5.8–6.0	5.8–6.0	6.2–6.4	6.2–6.4	
Monounsaturated fat (%)[b]	19.7	19.9	20.1	19.5	0.337	21.0	21.0	20.7	21.0	0.431
	19.5–20.0	19.7–20.2	19.8–20.3	19.2–19.8		20.8–21.3	20.7–21.3	20.4–20.9	20.7–21.3	

[a] p for trend adjusted for age and total energy intake

[b] Means expressed as a percentage of total energy intake

significant effect on insulin sensitivity. In contrast, being overweight, having type 2 diabetes and consuming higher amounts of TFA could cause or exacerbate insulin resistance [22, 23].

Results from large prospective studies have been mixed. In an analysis based on a 14-year follow-up of the Nurses' Health Study (NHS), a high intake of TFA (2.2%) was positively associated with a higher risk of type 2 diabetes [24]. Two more prospective studies in the USA examining the association between type 2 diabetes and TFA failed to find a positive association [25, 26]. Interestingly, these studies reported relatively low intakes of TFA in their population (1.2% of total energy intake), compared with the NHS (2.2% of total energy intake) and other studies in the USA [11]. The average TFA intake was lower in studies reporting a null association than in those showing a positive relationship between TFA intake and type 2 diabetes. It is of interest to note that the average amount of TFA reported in these studies was higher than that reported for the top quartile of TFA consumption in our study. Therefore, differences in the amount of TFA consumed among study populations may partially explain the difference in the outcome.

The mechanisms linking TFA consumption with risk of type 2 diabetes are not well established [1]. There is evidence that TFA intake is positively associated with systemic inflammation, which is linked to pathophysiologic processes related to the risk of type 2 diabetes [27, 28]. However, it is unknown whether the association of TFAs and inflammation is dose dependent.

trans Fatty acid intake differs considerably among populations [11]. Average daily TFA intake in an American population has declined progressively, with mean intake of total TFAs decreasing from 3.0% of total energy in 1980–1982 to 2.2% of total energy in 1995–1997 ($P < 0.001$), due to changes in the food supply and consumer food choices, but is still higher than that reported in South Europe. Among European countries there is a wide range of intake, from a low of 0.6 and 0.7% for Greece and Spain, respectively, to 2.0% for Iceland [11, 29, 30]. Mean TFA intake of the present population was 0.59% of total energy intake for women and 0.63% for men, which is remarkably lower than that reported for the USA and North European countries but comparable with that of Spain and other South European populations [11, 29, 30].

The low TFA intake assessed in our study can be explained by low margarine consumption, which is an important determinant of TFA intake [31, 32]. This is consistent with the use of olive oil in Spain rather than partially hydrogenated oils as a primary source of dietary fat [33]. In contrast, prepared food and dairy products were major sources of TFA in our population. Meat, sausages, vegetable oils and margarines were considered minor sources of TFA intake. These findings were consistent with results from the TRANSFAIR study, conducted in eight European countries, which identified foods contributing most to the TFA intake [10, 29]. In the US, bakery products, including cakes, pies and cookies, are the major source of TFA, whereas in Europe as well as in Australia fatty spreads, oils and shortenings are the primary source.

Table 5 Food groups by quartiles of *trans* fatty acid (TFA) intake

	Men ($n = 3,704$)					Women ($n = 4,070$)				
	Quartiles of *trans* fatty acid intake [Range (g/day)]					Quartiles of *trans* fatty acid intake (Range (g/day)]				
	1st (0.00–0.97) $n = 926$	2nd (0.98–1.46) $n = 926$	3rd (1.47–2.07) $n = 926$	4th (2.08–higher) $n = 926$	p for trend[a]	1st (0.00–0.82) $n = 1,017$	2nd (0.83–1.31) $n = 1,018$	3rd (1.32–1.87) $n = 1,018$	4th (1.88-–higher) $n = 1,017$	p for trend[a]
Vegetables (g/4.18 MJ)	185	159	148	131	<0.001	238	210	189	169	<0.001
	178–191	152–165	142–155	124–138		231–246	203–218	181–196	161–176	
Fruit (g/4.18 MJ)	191	171	162	144	<0.001	267	230	218	190	<0.001
	183–199	163–179	153–170	136–152		257–277	220–239	208–228	180–200	
Fish (g/4.18 MJ)	37.7	33.6	32.7	29.4	<0.001	39.5	35.7	34.2	30.3	<0.001
	36.5–39.0	32.3–34.8	31.5–34.0	28.2–30.7		38.2–40.8	34.4–36.9	32.9–35.4	29.0–31.6	
Meat-sausages (g/4.18 MJ)	46.1	49.5	51.1	52.5	<0.001	39.3	43.8	44.9	45.1	<0.001
	44.6–47.6	48.0–50.9	49.6–52.6	51.0–53.9		37.9–40.61	42.5–45.1	43.6–46.2	43.8–46.4	
Poultry-rabbit (g/4.18 MJ)	19.6	17.1	17.6	15.4	<0.001	22.5	20.4	18.7	16.9	<0.001
	18.6–20.5	16.1–18.0	16.7–18.6	14.5–16.4		21.5–23.5	19.5–21.4	17.8–19.7	15.9–17.9	
Legumes (g/4.18 MJ)	23.2	21.4	20.4	18.5	<0.001	23.2	21.9	21.2	19.7	<0.001
	22.3–24.1	20.5–22.3	19.5–21.3	17.6–19.4		22.3–24.1	21.1–22.8	20.3–22.1	18.8–20.6	
White Bread (g/4.18 MJ)	52.9	50.5	47.3	41.5	0.001	38.9	37.8	38.2	35.5	0.011
	51.0–54.8	48.7–52.4	45.5–49.2	39.7–43.4		37.2–40.5	36.2–39.5	36.5–39.8	33.9–37.2	
Rice-pasta (g/4.18 MJ)	29.5	27.4	25.4	24.01	<0.001	29.6	29.4	27.5	25.2	<0.001
	28.1–30.9	26.1–28.8	24.1–26.8	22.6–25.4		28.3–30.8	28.3–30.8	26.3–28.8	23.9–26.4	
Olive oil (g/4.18 MJ)	11.5	10.8	9.9	8.4	<0.001	14.6	13.3	12.1	11.2	<0.001
	11.1–12.1	10.4–11.3	9.5–10.4	7.9–8.8		14.1–15.1	12.8–13.8	11.6–12.5	10.7–11.6	
Pastry (g/4.18 MJ)	8.1	11.0	12.6	16.8	<0.001	7.5	9.2	11.3	13.5	<0.001
	7.4–8.9	10.2–11.7	11.8–13.4	16.0–17.6		6.8–8.1	8.6–9.8	10.7–11.9	12.9–14.2	

[a] p for trend was adjusted for age

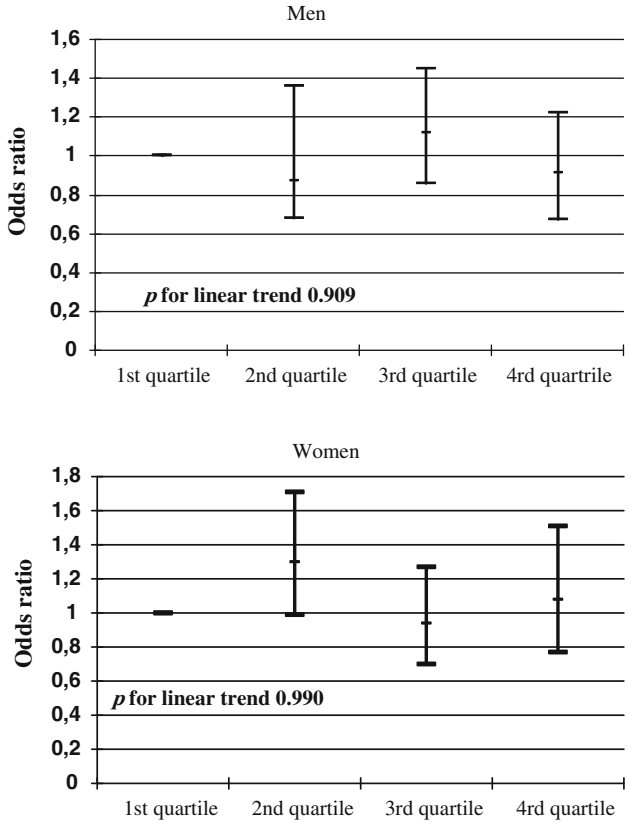

Fig. 1 Odds ratio (adjusted for age, leisure-time physical activity, educational status, smoking, alcohol consumption and dietary fibre intake) and 95% confidence interval of diabetes according to quartile distribution of *trans* fatty acid intake (percentage of energy intake) in men and women

Recent evidence suggests that tremendous variation exists between countries in the food sources of TFAs, which reflects real differences in the use of TFAs but also differences in the classification of foods into food groups [32].

In our study, men and women with a higher TFA intake were more likely to smoke, less likely to exercise and consumed more alcohol than their peers with low TFA intakes.

These findings were consistent with previously published reports [24–26].

Our study has several limitations. Prevalence of diabetes is slightly underestimated because only fasting blood glucose and medical history of diabetes was used to identify diabetes subjects; impaired glucose tolerance was not tested. The cross-sectional design precludes any conclusions about causation. Furthermore, all dietary instruments measuring past food intake are vulnerable to random and systematic measurement errors. Finally, misreporting of self-reported food intake is an acknowledged source of measurement error in prospective or retrospective methods of dietary assessment.

In conclusion, current TFA intake in this population was associated with less healthy lifestyle but not with a higher risk of type 2 diabetes.

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