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RESEARCH

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Dairy-derived saturated fats were not associated with risk of type 2 diabetes mellitus and metabolic syndrome: Tehran Lipid and Glucose Study

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Abstract

Emerging evidence indicates that the health effects of saturated fatty acids (SFA) may differ depending on the food source from which they are derived. We aimed to determine the association between dairy-derived SFA and the risk of type 2 diabetes mellitus (T2DM) and metabolic syndrome (MetS). This research was carried out in the Tehran Lipid and Glucose Study, a cohort study of 2256 T2DM-free adults and 1713 MetS-free adults. Adjusted hazard ratios and 95% confidence intervals of T2DM and MetS were calculated in tertile categories of dairy-derived SFA. The risk of T2DM and MetS was estimated through multivariable Cox regression to substitute dairy-derived SFA with other sources of SFA. Participants in the second tertile of dairy-derived SFA had a higher risk of T2DM (HR = 1.59, 95% CI = 1.14–2.21); however, the association did not remain significant in the third tertile (*P* for trend = 0.082). There were no associations between dairy-derived SFA and the risk of MetS. Substituting dairy-derived SFA for other dietary sources of SFA was not related to the risk of T2DM or MetS. The association between dairy-derived SFA and the risk of T2DM and MetS is still an ongoing research topic. When making dietary choices, it is advisable to consider an overall balanced diet and lifestyle factors.

Keywords Dairy products, Saturated fats, Type 2 diabetes mellitus, Metabolic syndrome

Introduction

Metabolic disorders, such as type 2 diabetes mellitus (T2DM) and metabolic syndrome (MetS), represent pressing public health challenges on a global scale. These conditions contribute significantly to morbidity, mortality, and the burden on healthcare systems worldwide. Among the many factors influencing these disorders, dietary fats, particularly saturated fatty acids (SFAs), have been scrutinized as potential contributors to their development and progression [28]. While SFAs have traditionally been viewed with caution, recent evidence suggests a more nuanced picture. A recent meta-analysis suggests no definitive link between dietary SFA intake and the risk of T2DM [11]. However, a well-documented association exists between SFAs and hyperlipidemia, a core component of MetS [8, 16]. Additionally, a prospective cohort study hints at a possible connection between higher SFA intake and increased hypertension risk, another hallmark of MetS. Notably, this evidence is less robust compared to the well-established relationship between SFA and hyperlipidemia, leaving room for further exploration [20].

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The complexity suggests that the impact of SFAs on metabolic health may not be uniform but rather shaped by various factors such as overall dietary quality, individual metabolic differences, and lifestyle choices [7, 10, 28]. Moreover, the source of SFAs appears to play a pivotal role in the association between dietary SFA and the risk of metabolic abnormalities [11, 19]. Dairy products, including milk, cheese, and yogurt, are major dietary sources of SFAs. Previous studies have investigated the association between dairy product consumption and T2DM and MetS incidence. Two systematic reviews and meta-analyses of observational studies revealed that higher dairy intake was associated with a statistically significant reduced risk of developing T2DM and MetS [3, 18]. Whether this protective effect stems from the SFAs in dairy or from other beneficial components, such as bioactive peptides, calcium, potassium, or magnesium [3] remains an open question.

Given the limited research explicitly addressing the role of dairy-derived SFAs in metabolic health, this study aims to bridge this gap by evaluating their association with T2DM and MetS risk within the Tehran Lipid and Glucose Study (TLGS) cohort. Furthermore, it explores whether substituting dairy-derived SFAs with SFAs from other sources affects these risks. Understanding these relationships is vital for crafting informed dietary guidelines and public health strategies. By shedding light on the unique role of dairy-derived SFAs, this research hopes to provide deeper insights into the interplay between diet and metabolic health.

Methods

Research participants

Data for the present study were obtained from the TLGS, an ongoing community-based prospective cohort study aimed at evaluating risk factors for non-communicable diseases. The TLGS began in 1999, with the first examination conducted among 15,005 males and females residing in district No. 13 of Tehran. Subsequent examinations were conducted every three years [6]. We included 10,091 adults aged 19 years and older who participated in the third phase of the TLGS. Participants with incomplete data, as well as participants with a history of T2DM or MetS at baseline were excluded. We also excluded participants with reported daily energy intakes <800 kcal or >4200 kcal to reduce the influence of extreme dietary misreporting, following previous epidemiologic studies using similar thresholds [26]. Although this approach has been commonly used, it does not account for individual variability in energy requirements. More precise methods such as the Goldberg cutoff, which uses basal metabolic rate (BMR)-based calculations, may offer improved accuracy and should be considered in future studies and those who were lost to follow-up in each study population were excluded from the analyses. Finally, 2256 healthy adults remained for T2DM analysis, and 1713 healthy adults remained for MetS analysis (Fig. 1). The eligible participants were followed up until the end of the study. Median follow-up periods for T2DM and MetS analyses were 8.5 and 7.6 years from the baseline examination, respectively. Written informed consent was obtained from all participants and the study protocol was approved by the ethics research council of the Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, the ethics number is IR.SBMU.ENDOCRINE.REC.1402.052.

Measurements

Trained interviewers administered a predefined questionnaire to collect anthropometric and demographic data. Systolic (SBP) and diastolic blood pressures (DBP) were measured using a calibrated standard mercury sphygmomanometer [4]. Details on anthropometric measurements, including weight, height and waist circumference of participants, as well as demographic variables and blood pressure measurements have been described elsewhere [12]. The participants' usual physical activity was assessed using the modifiable activity questionnaire (MAQ) and expressed as metabolic equivalent minutes per week (MET-min/week) [2]. Physical activity scores ≤600 METs-min/week were categorized as low physical activity, while scores >600 METs-min/week were considered moderate to high physical activity. The reliability and validity of the Persian version of the MAQ were previously examined [24].

Blood samples were taken from participants after an overnight fasting between 7:00 and 9:00 AM. Details regarding biochemical measurements (including Fasting plasma glucose (FPG), triglycerides (TG), and high-density lipoprotein cholesterol (HDL-C)) have been described elsewhere [12].

The participants' usual dietary intakes were evaluated using a validated 168-item food frequency questionnaire (FFQ) [23]. They were asked to provide information on the frequency of consumption (e.g., daily, weekly, monthly) and portion sizes (e.g., cup, spoon, and grams) for each food item over the past 12 months. The reported frequencies were then converted to daily intakes, and the portion sizes, expressed in household measures, were converted to grams. The United States Department of Agriculture (USDA) food composition table was used to determine the energy and macronutrient content per gram of each food type.

The FFQ items for dairy products included milk (low-fat, high-fat, and chocolate milk), yogurt (low-fat and high-fat), regular cheese (traditional Iranian cheese

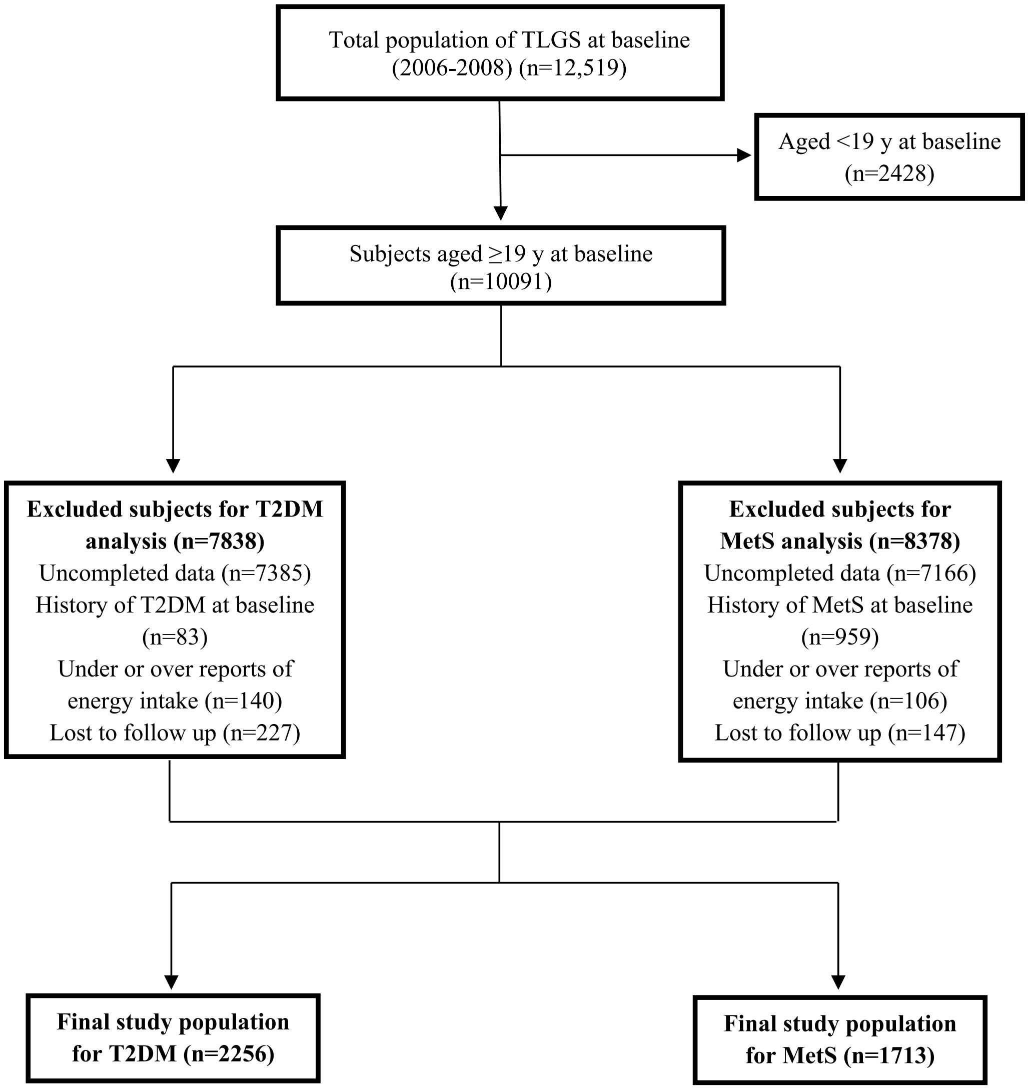

Fig. 1 Flow chart of the study

and feta cheese), cream cheese, ice cream, dried whey and Doogh (a traditional Iranian beverage made from yogurt). Dairy-derived SFA is calculated as the sum of the SFA content of each dairy product item in grams. Also, red meat-derived SFA, processed meat-derived SFA, poultry-derived SFA, snacks-derived SFA, and oils-derived SFA are calculated as the sum of SFA content of each related food item in grams.

Explanation of key terms and findings

Type 2 diabetes mellitus (T2DM) was defined based on fasting serum glucose (FSG) levels of ≥126 mg/dL, 2 h-SG ≥200 mg/dL, or self-reported use of anti-diabetic medications [1].

Metabolic syndrome (MetS) was diagnosed using the NCEP ATP III criteria [13]. Participants were classified as having MetS if they exhibited at least three of the following metabolic abnormalities:

1. **Hyperglycemia:** Fasting plasma glucose (FPG) ≥100 mg/dL (5.6 mmol/L) or self-reported use of blood glucose-lowering medications.
2. **Hypertriglyceridemia:** Serum triglycerides (TG) ≥150 mg/dL (1.69 mmol/L) or use of lipid-lowering medications.
3. **Low HDL-C levels:** Serum HDL-C <40 mg/dL (1.04 mmol/L) for men and <50 mg/dL (1.29 mmol/L) for women, or use of HDL-C-raising treatments.

4. **Hypertension:** Systolic blood pressure (SBP) or diastolic blood pressure (DBP) ≥130/85 mmHg or use of antihypertensive medications.
5. **Abdominal obesity:** Waist circumference (WC) ≥95 cm for both genders, based on modified cutoff points specific to Iranian adults [5].

Statistical analyses

Baseline characteristics of participants, expressed as mean (±SD) values for continuous variables and frequencies (%) for categorical variables, were compared based on the incidence of each outcome using an independent t-test and chi-square test, respectively. The incidence of type 2 diabetes mellitus (T2DM) and metabolic syndrome (MetS) during follow-up periods was treated as dichotomous variables (yes/no) in the models. Dairy-derived saturated fatty acids (SFA) were divided into tertiles, with the first tertile serving as the reference group.

To assess the association between dairy-derived SFA intake and the incidence of T2DM and MetS, Cox proportional hazards regression models were applied. Hazard ratios (HRs) and their 95% confidence intervals (CIs) were calculated. The models used person-years as the time metric, with the event date defined as the time of diagnosis for T2DM or MetS or, for censored cases, the time to the end of follow-up. For individuals lost to follow-up or censored, survival time was measured as the period between their first and last observation dates. The proportional hazards assumption for the multivariable Cox models was evaluated using Schoenfeld's global test of residuals. Potential confounders were identified through univariate analysis, with variables showing a *p*-value of less than 0.2 included as confounders in the models. We also assessed potential multi-collinearity among dietary variables using variance inflation factors (VIFs) and found no indication of problematic collinearity (all VIFs <2).

The potential impact of substituting 1 g/d of dairy-derived SFA with 1 g/d of red meat-, processed meat-, poultry-, snacks-, or oils-derived SFA, with risk of T2DM and MetS was evaluated using a multivariate model. These SFAs were treated as continuous variables within the same model, which accounted for non-dietary covariates and total energy intake. Substitution effects were calculated based on the differences in coefficients along with the variances and covariance of the estimates from the model [30].

All statistical analyses were conducted using the Statistical Package for Social Science (version 20; IBM Corp., Armonk, NY, USA), with a threshold of *P*-values <0.05 used to determine statistical significance.

Results

Baseline characteristics of participants with and without T2DM and MetS are depicted in Table 1. The average duration of follow-up was 8.5 years (inter-quartile range 6.33–9.41), among which the incidence rate of T2DM was 10.7%. The dietary intake of total SFA averaged 26.25 ± 11.53 g/day, from which 33.6% was from dairy products, 13.4% from oils, 13.2% from snacks, 6.6% from red meat, 5.7% from poultry, 2.1% from processed meat, and 25.5% from other dietary sources. Participants with T2DM tended to be older and had higher BMI, WC, SBP, and DBP than those with no T2DM incidence (*P*-value <0.005). Also, participants with T2DM had significantly lower daily intakes of total SFA, SFA from dairy products, SFA from snacks, and SFA from oils compared to those with no T2DM outcomes (*P*-value <0.05). Over a median of 7.64 (inter-quartile range = 4.09–9.13) years of follow-up, a total of 596 cases of MetS were identified among 1713 participants (incidence rate = 34.8%). Mean (±SD) dietary intake of total SFA was 27.19 ± 17.64 g/day, from which 33.4% was from dairy products, 14.0% from oils, 13.5% from snacks, 6.8% from red meat, 5.5% from poultry, 2.3% from processed meat, and 24.5% from other dietary sources. Similar to the T2DM, participants with MetS tended to be older, more likely to be male, and had higher BMI, WC, SBP, and DBP, compared to the participants with no MetS outcomes. Furthermore, participants with MetS had significantly lower daily intakes of total SFA and SFA from oils (*P*-value <0.05) compared to those without MetS incidence. There was no significant difference in other baseline characteristics between the two groups.

The HRs and 95% CIs of T2DM and MetS across tertile categories of dairy-derived SFA are shown in Table 2. After adjustment for confounding variables, participants in the second tertile of dairy-derived SFA had a significantly higher risk of T2DM (HR = 1.59, 95% CI = 1.14–2.21). However, the association did not remain significant in the third tertile of dairy-derived SFA (*P* for trend = 0.082). There were no significant associations between dairy-derived SFA and the risk of MetS in the crude and adjusted models.

Substitution analysis for estimating the replacement of 1 g/d of dairy-derived SFA for 1 g/d of red meat-derived SFA, 1 g/d of processed meat-derived SFA, 1 g/d of poultry-derived SFA, 1 g/d of snacks-derived SFA and 1 g/d of oils-derived SFA, while keeping total energy intake constant, and risk of T2DM and MetS are shown in Figs. 2 & 3, respectively. Substituting dairy-derived SFA for other dietary sources of SFA was not associated with risk of T2DM or MetS in the fully adjusted model.

Table 1 Baseline characteristics of the participants across the two groups with or without cardio-metabolic outcomes

Variables	T2DM		MetS	
	YES (n = 241)	NO (n = 2015)	YES (n = 596)	NO (n = 1117)
Age (year)	47.36 ± 13.02	39.34 ± 13.21*	41.81 ± 13.14	34.42 ± 12.36*
Male (%)	46.9	45.9	50.0	36.0*
Current smoker (%)	8.9	9.6	10.1	6.8
Low physical activity[a] (%)	39.9	38.5	38.5	39.0
BMI (kg/m^2)	30.25 ± 4.85	26.58 ± 4.60*	27.56 ± 4.53	24.68 ± 4.17*
WC (cm)	98.32 ± 10.50	88.42 ± 12.70*	91.27 ± 10.88	81.89 ± 11.75*
SBP (mmHg)	119.7 ± 18.23	110.3 ± 15.52*	111.2 ± 15.06	105.0 ± 12.68*
DBP (mmHg)	77.98 ± 10.71	72.79 ± 10.28*	73.53 ± 9.02	69.32 ± 9.41*
Dietary intakes				
Total energy (kcal/day)	2198 ± 723.9	2272 ± 712.4	2278 ± 734.5	2267 ± 702.3
Total fat (g/day)	74.88 ± 32.71	78.95 ± 31.01	78.09 ± 31.96	80.87 ± 31.54
Saturated fat (g/day)	24.29 ± 10.23	26.48 ± 11.65*	25.84 ± 11.38	27.91 ± 20.16*
Mono-unsaturated fat (g/day)	26.08 ± 12.39	27.29 ± 11.23	26.98 ± 11.72	28.02 ± 11.50
Poly-unsaturated fat (g/day)	15.90 ± 9.26	16.42 ± 7.78	16.38 ± 7.94	16.68 ± 7.95
Total dairy (serving/day)	2.18 ± 1.13	2.28 ± 1.31	2.25 ± 1.25	2.31 ± 1.33
High-fat dairy (serving/week)	5.61 ± 5.37	6.21 ± 5.85	6.12 ± 6.06	6.59 ± 5.98
Low-fat dairy (serving/week)	9.89 ± 5.93	10.06 ± 6.87	9.95 ± 6.11	9.92 ± 7.05
SFA from dairy products (g/day)	8.30 ± 4.18	8.88 ± 5.19*	8.72 ± 4.82	9.08 ± 5.33
SFA from red meat (g/day)	1.54 ± 1.70	1.70 ± 1.91	1.63 ± 1.65	1.80 ± 1.85
SFA from processed meat (g/day)	0.49 ± 0.94	0.55 ± 0.72	0.63 ± 1.88	0.62 ± 0.92
SFA from poultry (g/day)	1.29 ± 0.98	1.36 ± 1.20	1.37 ± 1.15	1.35 ± 1.15
SFA from snacks (g/day)	2.68 ± 2.98	3.47 ± 4.18*	3.30 ± 3.59	3.64 ± 3.90
SFA from oils (g/day)	3.36 ± 4.95	4.17 ± 6.10*	3.61 ± 4.69	4.68 ± 6.72*

Data are mean ± SD unless stated otherwise (independent t-test and chi-square test were used for continuous and dichotomous variable, respectively)

BMI body mass index, *SBP* systolic blood pressure, *DBP* diastolic blood pressure

[*] *P*_value <0.005

[a] Modifiable activity questionnaire (MAQ) scores ≤600 METs-min/week was considered as low physical activity

Discussion

In the present prospective cohort study, we found that participants whose SFA intake from dairy products was 6.28–10.08 g/d had a significantly higher risk of T2DM. However, the intake of dairy-derived SFA of more than 10.08 g/d was not associated with T2DM risk. Also, there was no significant association between dairy-derived SFA and the risk of MetS. The iso-caloric substitutions of dairy-derived SFA with other dietary sources of SFA were not associated with T2DM or MetS risk.

This study adds to the existing body of literature by specifically examining saturated fat intake from dairy sources rather than total dairy intake or total saturated fat. This distinction is important; as recent research suggests that the health effects of saturated fats may depend on their food source. For example, saturated fats in dairy may have a different metabolic impact due to the food matrix, presence of other nutrients (e.g., calcium, probiotics in yogurt), or fermentation processes in certain dairy products. Additionally, dairy-derived SFAs have been associated with alterations in gut microbiota, improved insulin sensitivity, and increased satiety, which may contribute to a reduced risk of T2DM and MetS. Furthermore, interactions with other dietary components—such as fiber intake or overall diet quality—may modify the effects of dairy-derived SFAs. These mechanistic pathways help contextualize our findings and highlight the importance of food-based approaches in dietary recommendations.

Reviewing the available meta-analyses exploring the association between dietary SFA intake and risk of metabolic outcomes indicated controversial results. A recent dose–response meta-analysis of 13 cohort studies revealed that the carbon chain length of the SFAs may influence the association between dietary SFA and the risk of T2DM [11]. There was no significant association between dietary total SFA, as well as dietary palmitic acid (C16:0) and stearic acid (C18:0) with the risk of T2DM

Table 2 Risk of type 2 diabetes mellitus and metabolic syndrome across tertiles of dairy-derived SFA: Tehran Lipid and Glucose Study

Dairy-derived SFA	T 1	T 2	T 3	*P* for trend
DM[a]				
Range of dairy-derived SFA (g/d)	≤6.28	6.29–10.08	≥10.9	
Median intake of dairy-derived SFA(g/d)	4.39	7.99	12.88	
Median intake of dairy products (serving/d)	1.15	2.14	3.28	
Participants/cases (n/n)	752/74	752/95	752/72	
Crude	1.00	1.29 (0.95–1.76)	0.93 (0.67–1.29)	0.657
Model 1	1.00	1.39 (1.03–1.90)	1.06 (0.76–1.45)	0.717
Model 2	1.00	1.59 (1.14–2.21)	1.42 (0.91–2.22)	0.082
MetS[b]				
Median intake of dairy-derived SFA(g/d)	4.44	8.06	13.12	
Median intake of dairy products (serving/d)	1.14	2.12	3.23	
Participants/cases (n/n)	571/199	571/200	571/197	
Crude	1.00	0.98 (0.81–1.20)	0.97 (0.79–1.18)	0.753
Model 1	1.00	0.99 (0.81–1.22)	1.03 (0.84–1.26)	0.752
Model 2	1.00	1.03 (0.83–1.28)	1.15 (0.88–1.50)	0.313

Data are hazard ratio (95% CI); proportional hazard Cox regression and logistic regression was used. *CI* confidence interval, *DM* diabetes mellitus, *MetS* Metabolic Syndrome

[a] Model 1 was adjusted for sex, age, body mass index, smoking, physical activity and diabetes risk score; model 2 was additionally adjusted for total energy intake (kcal/d), total fat (g/d), total saturated fat (g/d), and total fiber intake (g/d)

[b] Model 1 was adjusted for sex, age, body mass index, smoking, physical activity level; model 2 was additionally adjusted for total energy intake (kcal/d), total fat (g/d), total saturated fat (g/d), and total fiber intake (g/d)

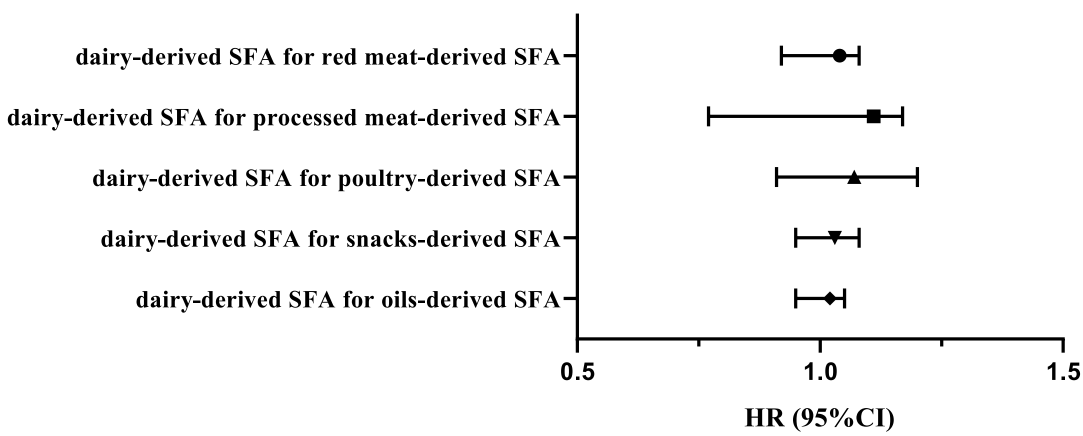

Fig. 2 Substitution of 1 g/d of dairy-derived saturated fat (SFA) for 1 g/d of red meat-derived SFA, 1 g/d of dairy-derived SFA for 1 g/d of processed meat-derived SFA, 1 g/d of dairy-derived SFA for 1 g/d of poultry-derived SFA, 1 g/d of dairy-derived SFA for 1 g/d of snacks-derived SFA, 1 g/d of dairy-derived SFA for 1 g/d of oils-derived SFA, while keeping total energy intake constant, and risk of type 2 diabetes mellitus. HR; hazard ratio, SFA; saturated fatty acids

in this meta-analysis; however, inverse associations were observed between SFAs with shorter carbon chain lengths; lauric acid (C12:0) and myristic acid (C14:0), and risk of T2DM [11]. A meta-analysis of prospective studies reported a protective association between circulating odd-chain SFAs and incident T2DM. Circulating SFAs may better reflect both dietary intake and endogenous synthesis compared to self-reported data [17]. Traditional dietary guidelines recommend reducing SFA intake to prevent cardio-metabolic disorders, as SFAs have long been considered a nutritional risk factor for chronic disease. However, recent systematic reviews and meta-analyses have questioned the strength of the evidence supporting a direct association between saturated fat intake and cardiovascular or metabolic risk [11, 22]. In particular, the effects of dietary SFA may

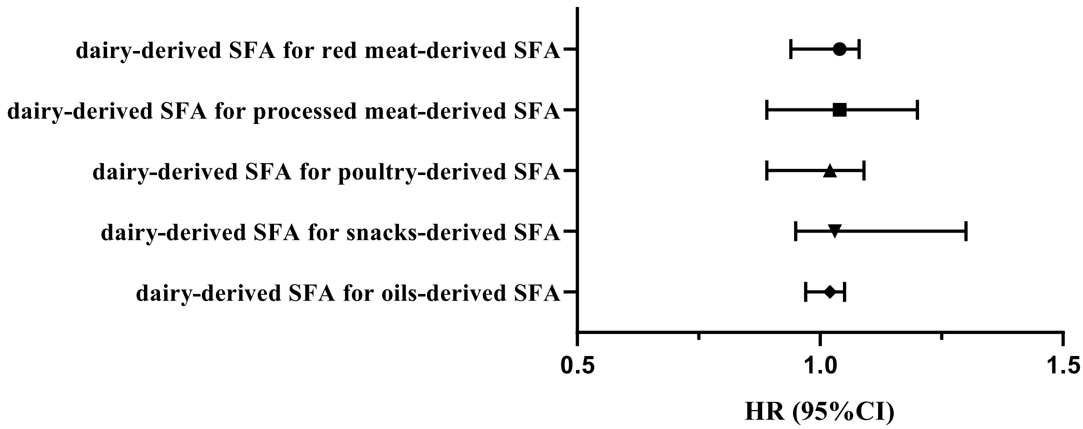

Fig. 3 Substitution of 1 g/d of dairy-derived saturated fat (SFA) for 1 g/d of red meat-derived SFA, 1 g/d of dairy-derived SFA for 1 g/d of processed meat-derived SFA, 1 g/d of dairy-derived SFA for 1 g/d of poultry-derived SFA, 1 g/d of dairy-derived SFA for 1 g/d of snacks-derived SFA, 1 g/d of dairy-derived SFA for 1 g/d of oils-derived SFA, while keeping total energy intake constant, and risk of metabolic syndrome. HR; hazard ratio, SFA; saturated fatty acids

vary by food source and fatty acid subtype. Odd-chain SFA, such as pentadecanoic acid (C15:0) and heptadecanoic acid (C17:0), found primarily in dairy fat, have been associated with a lower risk of type 2 diabetes and other chronic diseases, potentially reflecting beneficial metabolic effects of dairy-derived SFAs [25]. The overall diet quality, individual metabolism rate, genetic variations, lifestyle factors [7, 10, 28], and food sources from which the SFA is derived could play a critical role in the association between dietary SFA and risk of metabolic abnormalities.

It is still unclear how SFA from different dietary sources impacts the risk of cardio-metabolic disorders. Similar to our findings regarding the contribution to the total intake of SFA of food groups, in which dairy products contributed ~30% of total SFA, a large cross-sectional study from the National Health and Nutrition Examination Survey reported that dairy products and total meat contributed ~30 and ~20% of total SFA, respectively [29]. Therefore, dairy products could be considered the primary dietary source of SFA in many diets. However, dairy products also contain various bioactive compounds, such as calcium, vitamin D, and specific fatty acids, which may benefit metabolic health. Several studies have investigated the association between dairy consumption and the risk of T2DM and MetS. Epidemiological studies consistently indicate that consuming dairy products, milk, cheese, and fermented dairy products is associated with a lower risk of T2DM incidence or improvements in glucose homeostasis indices. [14, 31, 32] These findings are further supported by studies conducted on animal and cell models, which demonstrated a positive impact of dairy-rich diets or specific components found in dairy products on metabolic and inflammation factors relevant to T2DM and insulin resistance [15]. Regarding MetS, a study published in 2021 examined the association between dairy consumption and MetS in a large population. The findings suggested that a higher intake of full-fat dairy products was associated with a lower risk of MetS [18]. Furthermore, previous cohort studies and clinical trials revealed favorable or neutral associations between dairy consumption and hypertension [21, 27]. Systematic review and meta-analyses exploring the association between dairy products and T2DM and MetS incidence also indicated statistically significant inverse associations between dairy product consumption and risk of T2DM and MetS [3, 9].

Interestingly, in the present study, the second tertile of dairy-derived SFA intake showed a significant inverse association with T2DM risk, whereas the highest tertile did not. This non-significant result in the third tertile may indicate a non-linear or U-shaped relationship, where moderate intake is beneficial, but higher consumption may not confer additional advantages or may be influenced by other dietary or metabolic factors. Such a pattern has been suggested in other nutritional studies and highlights the complexity of interpreting dose–response relationships in observational data. Although we did not conduct a formal dose–response or spline-based analysis, this pattern may indicate that moderate intake confers some benefit, whereas higher intakes may not offer additional protection. Future studies are needed to investigate whether such non-linear associations exist and to determine the intake levels that may optimize metabolic outcomes.

To the best of our knowledge, evidence of such an association between the consumption of dairy-derived SFA and the risk of T2DM and MetS incidence is scarce. The prospective design of the present study, the long follow-up period, the general population the sample represents, the acceptable reliability and validity of all information-gathering processes, as well as the consideration of different dietary sources of SFA in substitution analysis are the advantages of the current study. However, caution must be taken about some limitations of the present study. First of all, while adding more variables to adjust the models might make the models more stable, it might also mean losing the power of the study. Thus, in our work, we conducted a univariate analysis to select the final confounders that would be adjusted for; hence, the residual confounders' effect was not considered. Secondly, as with all other prospective cohort studies, a participant's changing diet and other metabolic risk factors during the study follow-up may be misclassified, and unbiased estimates of HRs may be gained. Third, the food intake of SFA (as measured by FFQ) is a measurement-based variable, which means that potential measurement errors are more frequent. Fourth, the use of fixed energy intake thresholds (<800 kcal/day or >4200 kcal/day) to exclude potential misreports. While this approach is commonly applied in nutritional epidemiology, it does not account for individual variation in energy requirements. More precise methods, such as the Goldberg cutoff based on basal metabolic rate and physical activity level, could enhance the identification of implausible reporters and should be considered in future research. Fifth, like any other observational study, there is no direct link between the risk of incident T2DM or MetS and the amount of dairy SFA intake.

In conclusion, the association between dairy-derived SFA and the risk of T2DM and MetS is still an ongoing research topic. While some studies suggest the potential benefits of certain dairy products, such as yogurt and cheese, on metabolic health, more research is needed to fully understand the complex relationship between dairy consumption, SFA, and these health outcomes. It is advisable to consider an overall balanced diet and lifestyle factors when making dietary choices.

Abbreviations

BMI	Body mass index
CI	Confidence interval
DBP	Diastolic blood pressure
FFQ	Food frequency questionnaire
HDL-C	High-density lipoprotein cholesterol
HR	Hazard ratio
MET	Metabolic equivalent
MetS	Metabolic syndrome
SBP	Systolic blood pressure
SFA	Saturated fatty acid
TLGS	Tehran Lipid and Glucose Study
T2DM	Type 2 diabetes mellitus
WC	Waist circumference

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Author contributions
Z.G and P.M designed the study. Z.G analyzed the data. S.A and Z.G wrote the manuscript. F.A supervised the study and revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and material
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Written informed consents were obtained from all participants. The study protocol was approved by the ethics research council of the Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

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