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The role of lipid profile in the relationship between skipping breakfast and hyperuricemia: a moderated mediation model

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Abstract

Background The prevalence of hyperuricemia is rising among oilfield workers in China. This study aimed to explore the underlying mechanisms between skipping breakfast and serum uric acid.

Methods A total of 21,676 participants aged 20-60 from a large oilfield company in China were included. Association analysis, multivariate logistic, subgroup analysis, and moderated mediation analysis were performed to assess the association between skipping breakfast and hyperuricemia.

Results We found that 24.48% of oilfield employees had hyperuricemia. The odds ratio of hyperuricemia linked to skipping breakfast was 0.78 (95%CI: 0.69-0.88). The association between skipping breakfast and hyperuricemia was mediated by TC (22.32%) and LDL-C (21.57%). Age moderated this mediation, with significant effects for skipping breakfast (*ß*: 0.553, 95%CI: 0.042-1.063) and TC (*ß*: -0.339, 95%CI: -0.586- -0.093). Similar results were observed for LDL-C mediation (*ß*: 0.522, 95%CI: 0.009-1.035; *ß*: -0.585, 95%CI: -0.894- -0.276).

Conclusion Skipping breakfast positively influenced hyperuricemia through TC and LDL-C. Age moderated the relationship between skipping breakfast and serum uric acid. Greater attention should be given to young employees in Chinese oilfield enterprises, with dietary interventions implemented to reduce abnormal lipids metabolism and hyperuricemia.

Keywords Hyperuricemia, Breakfast, Lipid profile, Age, Working population

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Introduction

Hyperuricemia is a chronic metabolic disorder resulting from the dysregulation of purine metabolism. It plays a central role in the pathogenesis of gout, the most common form of inflammatory arthritis in adult males, and is associated with a significant disease burden [1, 2]. From 2000 to 2019, the incidence of hyperuricemia has shown a steady upward trend [3], thereby presenting a significant public health challenge [4]. A comprehensive study conducted in the United States reported prevalence rates of 20.2% for hyperuricemia and 3.9% for gout among adults during the period of 2015–2016 [5]. Data from the 2018–2019 China Chronic Disease and Risk Factor Surveillance indicated a hyperuricemia prevalence of 14% among Chinese adults [6]. In contrast, a study conducted among PetroChina oilfield workers reported a higher prevalence, with 19.9% in males and 12.9% in females [7]. The increasing prevalence of gout due to hyperuricemia has led to a substantial rise in direct costs among oilfield workers, including medical treatments and medications [8]. Additionally, it has escalated indirect costs, such as absenteeism, reduced work performance, and lower productivity [9].

The dietary habits and lifestyles of people have undergone significant changes in parallel with socioeconomic progress. Numerous epidemiological and observational studies have identified associations between modifications in dietary habits, lifestyle factors, and serum uric acid (SUA) levels [10, 11]. Irregular dietary patterns have been implicated in the onset of metabolic syndrome, which encompasses conditions such as hyperuricemia, dyslipidsemia, hypertension, and diabetes [12, 13]. Although breakfast is traditionally regarded as the most important meal of the day, recent research highlights an increasing trend of breakfast omission. For example, a study conducted in the United States demonstrated a substantial rise in the proportion of individuals who skip breakfast, with up to 23.8% of participants reporting daily skipping breakfast over the past two decades [14, 15]. Similarly, in Southern China, the rate of skipping breakfast stands at 19.61% [16]. Compared with general population, oilfield workers often work in rotating shifts, including night shifts, and are exposed to challenging work conditions that can affect their eating habits and physical activity levels [17]. These workers frequently experience irregular meal times, which may contribute to unhealthy dietary patterns such as skipping meals or consuming high-fat, high-sodium foods [18]. Previous studies have demonstrated a significant association between the breakfast consumption and the incidence of metabolic syndrome (ORs: 0.31, 95%CI: 0.11–0.87) [19, 20], as well as a correlation between skipping breakfast and obesity [13]. However, there is a paucity of research investigating the relationship between skipping breakfast and SUA among individuals employed in oilfield occupations.

Numerous studies have indicated a potential association between the skipping breakfast and lipid profile [21, 22]. A substantial cross-sectional study conducted within Chinese occupational populations identified a negative correlation (ORs: 0.47, 95%CI: 0.28–0.77) between the breakfast consumption and the incidence of dyslipidsemia [22]. Furthermore, dyslipidsemia, along with overweight and obesity, has been recognized as a potential risk factor for hyperuricemia [23, 24]. A study conducted among a cohort of 300 randomly selected employees from a North China oilfield. The results indicated that hyperlipidsemia constituted an independent risk factor for hyperuricemia [25]. Additionally, some studies demonstrated that lipid profile mediated the relationship between obesity and SUA [26]. Therefore, lipid profile may mediate the association between skipping breakfast and SUA.

Age is another important factor in hyperuricemia [27]. Emerging trends indicate a decreasing age of onset for hyperuricemia, underscoring the need for age-specific investigations [24]. In mainland China, the prevalence of hyperuricemia among individuals aged 18–29 increased from 13.4 to 18.0% between the periods 2015–2016 and 2018–2019, demonstrating a more pronounced rise compared to other age demographics [6]. Previous research has demonstrated that elevated levels of TG and LDL-C are more commonly observed in young individuals with hyperuricemia compared to those without the condition [28]. In contrast, dyslipidsemia is more frequently detected in older individuals [22, 29]. Additionally, Dietary patterns of different age groups also influenced hyperuricemia [30]. Several studies conducted in the United States have revealed a positive correlation between age and the incidence of hyperuricemia among individuals aged 20 to 70 years [5]. However, this trend appears to differ within Chinese populations. Data from two nationally representative surveys in China showed that hyperuricemia prevalence was highest at 32.3% among individuals aged 18–29, then steadily declined with age, reaching its lowest point in the 60–69 age group [6, 24]. However, the role of age in moderating the impact of skipping breakfast on hyperuricemia has been scarcely studied among oilfield workers.

Taken together, breakfast, lipid profile and age all play important roles in the hyperuricemia, but the possible influence of these mechanisms on hyperuricemia is not clear among oilfield workers. Therefore, this study aims to assess the prevalence of hyperuricemia, explore whether lipid profile mediates the association between skipping breakfast and hyperuricemia, and evaluate a moderated mediation model. In the moderated mediation model, we hypothesized that lipid profile might play a role as a mediator between skipping breakfast and hyperuricemia among oilfield workers. In addition, age might work as a moderator in the direct and/ or indirect effect.

Methods

Participants

A total of 24,460 employees, aged between 20 and 60, from an oilfield company with extensive operations across 36 prefecture-level cities in northwest China, participated in a comprehensive census conducted between January 2022 and December 2022. The census included medical examinations, laboratory tests, and an online survey. Data collected through the electronic questionnaire encompassed general demographic information: smoke, type of work, alcohol, physical activity, and dietary patterns. Medical examinations and laboratory tests were conducted at the local staff hospital of the oilfield and third-party medical laboratories. These included routine urinalysis, blood tests, anthropometric measurements, and additional assessments. All interviews were conducted on the same day to minimize information bias. To further reduce potential bias, interviews were scheduled before health checkups, ensuring that both participants and interviewers were unaware of the health examination outcomes. Information on urate-lowering drugs, such as allopurinol or colchicine, was not available. However, their impact is likely minimal, as these medications are typically prescribed only for patients with gout [31]. A total of 24,460 respondents were initially included in the study. After excluding 2,784 individuals based on the following criteria, the final sample size was determined: (1) Individuals with stroke, cancer, and heart disease were excluded due to their potential confounding effect on lipid metabolism and uric acid levels. (2) Respondents with incomplete data on key variables (e.g., skipping breakfast, lipid profile, or SUA) were excluded to ensure data integrity. (3) Outliers were identified using the interquartile range (IQR) method and excluded if their values exceeded 1.5 times the IQR above or below the third or first quartile, respectively. The selection process is detailed in Fig.S1.

The questionnaire covering the variables involved in this study is provided in Supplementary Appendix_2.

This project has been approved by the Ethics Committee of Xiangya School of Public Health Central South University (review batch number: XYGW-2023-92). All participants were asked to provide written informed consent before completing the survey.

Measurement

Anthropometric measurements

We employed an online survey to collect data on various aspects such as overall health condition, disease history, and more. This questionnaire included information on demographics, daily dietary patterns, lifestyle, and medical history. Additionally, a physical examination was conducted, which involved measuring height and body weight.

Skipping breakfast

Skipping breakfast was measured by the question, “How many days a week do you have breakfast?”. The answers included “Less than four times a week” and “At least four times a week”. If a person chose “Less than four times a week”, he /she was defined as “Skipping breakfast” [22]. Otherwise, it was defined as “No skipping breakfast”.

Blood collection and laboratory test

Venous blood samples were drawn at overnight fasting condition (12 h). Through the automatic biochemical analyzer, the enzyme colorimetric method was used for detection. The diagnostic criteria of hyperuricemia are SUA > 420μmol/L in males and > 360μmol/L in females [32]. Except for HDL-C by selective inhibition method, the other lipid profile indexes were detected by enzyme reagent method.

Assessment of dietary pattern

A semiquantitative food frequency questionnaire (FFQ) applicable to the Chinese population was used. It has been validated with weighted food records [33]. It consisted of the following 7 food groups: whole grains, fruits, vegetables, red meat, sweetened beverages, low-fat dairy and, nuts and legumes, which was developed based on the Dietary Guidelines for Chinese People. For each participant, we used one dietary recall at the assessment to calculate the scores of a popular dietary pattern: DASH. The components and scoring criteria for DASH are summarized in detail in **Table S1**. DASH consists of 8 components designed by Fung et al. [34]. Of note, some modifications were made to accommodate the calculation of the dietary information in the study. For the DASH score, the intake of sodium was not collected, and therefore, this component was not calculated in our study. The intake of each component in DASH was divided into quintiles and given positive or reverse scores. For 5 components (fruits, vegetables, nuts and legumes, whole grains, and low-fat dairy products) in DASH, participants received 1 point for the lowest quintile and 5 points for the highest quintile. Conversely, for the other 2 components (red and processed meats, sweetened beverages), reverse scoring for quintiles was used. It is worth noting that the highest score for sweetened beverages is 4 points. The DASH score ranges from 7 to 34, with a median of 18. We classified dietary patterns based on DASH scores: a score of “≥18” indicated a healthy dietary pattern, while a score of "<18" indicated an unhealthy dietary pattern.

Covariates

The following demographic, health and work variables were also taken into account. Including age (years), sex (female, male), marital status (married or cohabited, unmarried, divorced, or widowed), education level (college and below, Bachelor, master and above), type of work (oil production worker, gas production worker, transport worker electrician office staff and others). BMI was calculated as weight (kg)/height (m^2) and used to define emaciation (BMI < 18.5), normal (18.5 ≤ BMI < 24.0), overweight (24.0 ≤ BMI < 28.0) and obesity (BMI ≥ 28.0). Smoke and alcohol were categorized as "yes" (former or current), or "no" (never). Physical activity was defined as "yes" (walking time per a day ≥ 120 min), or "no" (walking time per a day < 120 min).

Statistical analysis

Depending on the type of variable (categorical/continuous), the characteristics of participants were described, using n (%), mean (SD) or median (P25, P75). Multiple logistic regressions were used to estimate the odds ratios (ORs) for the factors associated with the outcome variables of interest. All confidence intervals (CIs) are 95%CIs. Interaction terms between covariates and skipping breakfast were included in the regression model to evaluate their potential interaction effects. Additionally, stratified subgroup analyses were performed to further investigate the influence of interaction effects on the association between skipping breakfast and hyperuricemia. The mediation and moderated mediation model were analyzed using the PROCESS 3.5. In mediation analyses, we utilized simple mediation model and moderated mediation model. In simple mediation model, we tested whether the association between skipping breakfast and SUA was mediated by lipid profile. In moderated mediation model, considering the influence of age on breakfast skipping and lipid metabolism [35, 36], we tested whether age moderated the indirect and /or direct effects of skipping breakfast on SUA. Specifically, the relationship between skipping breakfast and SUA was examined at high age groups (one standard deviation above the mean value) and low age groups (one standard deviation below the mean value) respectively. Bootstrapping, which offers high power for detecting mediation effects, was used in this study with 5,000 resamples to enhance the robustness of the results [37]. Two models were performed to ensure robustness of the results. In model 1, we adjusted age, sex, marital status and education level, while model 2 further adjusted for type of work, smoke, alcohol, physical activity and BMI. The R package "misFroest" was used to impute missing values of covariates in the data [38].

Sensitivity analysis

Several sensitivity analyses were performed. First, to test the strength of unmeasured confounding which might explain away the observed relation between skipping breakfast and hyperuricemia such as work pressure, and some unknown factors, we calculated the *E*-values [39]. Second, to test satisfaction of the sequential ignorability assumption in the mediation analysis, we performed sensitivity analyses of mediation analyses [40].

All the tests were bilateral, and $P < 0.05$ was considered to be statistically significant. SPSS Statistics 26.0 and R 4.3.1 were used for statistical analysis in this study.

Results

Characteristics of the study population

After data cleaning, 21,676 oilfield workers were included in this study, with an average age of 41.7 years (SD: 7.61). In the sample, men (65.30%) were more than women (34.70%) and the median (P25, P75) of SUA was 344.2 (280.0, 411.0) μmol/L. 79.2% of participants who skipped breakfast. Nearly half of the respondents had BMI ≥ 24. Oil production workers accounted for the largest proportion of the participants, accounting for 38.7%. (Table 1).

Skipping breakfast, lipid profile, and hyperuricemia

The associations between skipping breakfast, lipid profile, and hyperuricemia are presented in Table 2 and Table S2. Among the 21,676 participants, 12,874 followed a healthy dietary pattern, while 8,802 adhered to an unhealthy dietary pattern. In the unhealthy dietary pattern group, model 1, which adjusted for age, sex, marital status, and education level, showed that skipping breakfast significantly reduced the likelihood of hyperuricemia. This association remained consistent in model 2 after further adjustment for type of work, smoking, alcohol consumption, physical activity, and BMI, with an ORs of 0.78 (95%CI: 0.69–0.88).

We also analyzed the interaction effect between covariates and skipping breakfast, and there was no interactive effect (P for interaction > 0.05) in most subgroups, suggesting this association was robust across different subgroups, except for marital status. Fig. S2 and Fig. S3 also showed the results of subgroup analysis. In comparison to overall population, the negative effect of skipping breakfast on hyperuricemia was stronger in the unhealthy dietary pattern group.

Lipid profile was positively associated with hyperuricemia in both dietary patterns. In the unhealthy dietary pattern group, for each one-unit increase in total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein

Table 1 Basic characteristics of the participants ($n = 21676$)

Variable	Total ($n = 21676$)	Hyperuricemia		*P*-value
		No ($n = 16370$)	Yes ($n = 5306$)	
Age (year)	41.70 (7.61)	42.04 (7.48)	40.67 (7.92)	< 0.001
Sex				< 0.001
Female	7517 (34.70)	6854 (41.90)	663 (12.50)	
Male	14,159 (65.30)	9516 (58.10)	4643 (87.50)	
Marital status				< 0.001
Married or cohabited	17,891 (82.50)	13,800 (84.30)	4091 (77.10)	
Unmarried, divorced, or widowed	3785 (17.50)	2570 (15.70)	1215 (22.90)	
Education level				< 0.001
College and below	15,005 (69.20)	11,604 (70.90)	3401 (64.10)	
Bachelor	6354 (29.30)	4543 (27.80)	1811 (34.10)	
Master and above	317 (1.50)	223 (1.40)	94 (1.80)	
Type of work				< 0.001
Oil production worker	8389 (38.70)	6343 (38.70)	2046 (38.60)	
Gas production worker	1103 (5.10)	835 (5.10)	268 (5.10)	
Transport worker	839 (3.90)	662 (4.00)	177 (3.30)	
Electrician	840 (3.90)	654 (4.00)	186 (3.50)	
Office staff	4143 (19.10)	2946 (18.00)	1197 (22.60)	
Others	6362 (29.40)	4930 (30.10)	1432 (27.00)	
Smoke				< 0.001
No	13,966 (64.40)	11,084 (67.70)	2882 (54.30)	
Yes	7710 (35.60)	5286 (32.30)	2424 (45.70)	
Alcohol				< 0.001
No	12,306 (56.80)	10,034 (61.30)	2272 (42.80)	
Yes	9370 (43.20)	6336 (38.70)	3034 (57.20)	
Physical activity				0.542
No	12,619 (58.20)	9511 (58.10)	3108 (58.6)	
Yes	9057 (41.80)	6859 (41.90)	2198 (41.40)	
BMI				< 0.001
Emaciation	756 (3.50)	726 (4.40)	30 (0.60)	
Normal	9917 (45.80)	8605 (52.60)	1312 (24.70)	
Overweight	7990 (36.90)	5473 (33.40)	2517 (47.40)	
Obesity	3013 (13.90)	1566 (9.60)	1447 (27.30)	
Dietary pattern (DASH score)				0.080
< 18	8802 (40.60)	6593 (40.30)	2209 (41.60)	
≥ 18	12,874 (59.4)	9777 (59.70)	3097 (58.40)	
Skipping breakfast				< 0.001
No	4510 (20.80)	3150 (19.20)	1360 (25.60)	
Yes	17,166 (79.20)	13,220 (80.80)	3946 (74.40)	
Lipid profile				
TC (mmol/L)	4.48 (3.97, 5.05)	4.41 (3.91, 4.95)	4.72 (4.21, 5.32)	< 0.001
TG (mmol/L)	1.47 (0.98, 2.24)	1.31 (0.90, 1.96)	2.10 (1.44, 3.04)	< 0.001
HDL-C (mmol/L)	1.21 (1.05, 1.41)	1.23 (1.06, 1.45)	1.14 (1.02, 1.31)	< 0.001
LDL-C (mmol/L)	2.57 (2.15, 3.04)	2.50 (2.11, 2.96)	2.79 (2.36, 3.29)	< 0.001
SUA (μmol/L)	344.20 (280.00, 411.00)	314.20 (263.00, 360.00)	461.75 (434.00, 505.00)	< 0.001

Data were summarized as mean (SD), n (%) or median (P25, P75)

Abbreviations: SD, Standard Deviations; BMI, Body Mass Index; DASH, Dietary Approaches to Stop Hypertension; TC, Total Cholesterol; TG, Triglycerides; HDL-C, High-density Lipoprotein Cholesterol; LDL-C, Low-density Lipoprotein Cholesterol

cholesterol (LDL-C), the ORs for developing hyperuricemia were 1.45 (95% CI: 1.36–1.55), 1.29 (95%CI: 1.24–1.34), 0.73 (95%CI: 0.59–0.90), and 1.47 (95%CI: 1.36–1.59), respectively.

Table S2 further showed that skipping breakfast was associated with a higher likelihood of altered lipid profiles in both dietary patterns. Specifically, In the unhealthy dietary pattern group skipping breakfast resulted in

Table 2 Association between skipping breakfast, serum lipids and hyperuricemia in different dietary pattern

	Total (*n* = 21676)	Variable	Hyperuricemia		*E*-value[†]
			Model 1, OR (95%CI)	Model 2, OR (95%CI)	
Overall population	**21,676 (100.0)**	**Skipping breakfast**			
		No	1.00 (reference)	1.00 (reference)	
		Yes	0.89 (0.83–0.97) **	0.85 (0.78–0.92) ***	1.63
		Serum lipids			
		TC (mmol/L)	1.50 (1.45–1.56) ***	1.41 (1.36–1.47) ***	2.17
		TG (mmol/L)	1.35 (1.32–1.39) ***	1.25 (1.22–1.28) ***	1.81
		HDL-C (mmol/L)	0.48 (0.42–0.55) ***	0.71 (0.62–0.82) **	2.17
		LDL-C (mmol/L)	1.60 (1.53–1.68) ***	1.45 (1.38–1.53) ***	2.26
Unhealthy dietary pattern (DASH score < 18)	**8802 (40.6)**	**Skipping breakfast**			
		No	1.00 (reference)	1.00 (reference)	
		Yes	0.83 (0.74–0.93) ***	0.78 (0.69–0.88) ***	1.88
		Serum lipids			
		TC (mmol/L)	1.56 (1.46–1.65) ***	1.45 (1.36–1.55) ***	2.26
		TG (mmol/L)	1.39 (1.34–1.44) ***	1.29 (1.24–1.34) ***	1.90
		HDL-C (mmol/L)	0.46 (0.37–0.56) ***	0.73 (0.59–0.90) **	2.08
		LDL-C (mmol/L)	1.64 (1.52–1.77) ***	1.47 (1.36–1.59) ***	2.30
Healthy dietary pattern (DASH score ≥ 18)	**12,874 (59.4)**	**Skipping breakfast**			
		No	1.00 (reference)	1.00 (reference)	
		Yes	0.95 (0.85–1.05)	0.92 (0.82–1.02)	
		Serum lipids			
		TC (mmol/L)	1.47 (1.40–1.55) ***	1.39 (1.32–1.46) ***	2.13
		TG (mmol/L)	1.33 (1.29–1.37) ***	1.23 (1.19–1.27) ***	1.76
		HDL-C (mmol/L)	0.49 (0.42–0.58) ***	0.70 (0.59–0.83) ***	2.21
		LDL-C (mmol/L)	1.58 (1.48–1.68) ***	1.45 (1.36–1.54) ***	2.26

Abbreviations: OR, Odds Ratio; CI, confidence interval; BMI, Body Mass Index; DASH, Dietary Approaches to Stop Hypertension; TC, Total Cholesterol; TG, Triglycerides; HDL-C, High-density Lipoprotein Cholesterol; LDL-C, Low-density Lipoprotein Cholesterol

Model 1 adjusted for age, sex, marital status and education level. Model 2 further adjusted for type of work, smoke, alcohol, physical activity and BMI

[†] The *E*-value calculated the minimum strength of association that could explain away by an unmeasured confounder

* *P* < 0.05, ** *P* < 0.01, *** *P* < 0.001 (2–tailed)

Table 3 Mediating effects of lipid profile between skipping breakfast and serum uric acid

Mediator	Effect	ß	SE	Bootstrap 95%CI		Std ß	Ratio of effect
				Lower	Upper		
	Total effect	-6.464***	1.919	-10.225	-2.703	-0.068	-
TC (M_1)	Direct effect	-5.021**	1.893	-8.731	-1.310	-0.052	77.68%
	Indirect effect	-1.443***	0.344	-2.133	-0.782	-0.015	22.32%
LDL-C (M_3)	Direct effect	-5.070**	1.901	-8.796	-1.345	-0.053	78.43%
	Indirect effect	-1.394***	0.311	-2.021	-0.809	-0.015	21.57%

Adjusted for age, sex, marital status, education level, type of work, smoke, alcohol, physical activity and BMI

Abbreviations: *ß*, Unstandardized Coefficient; SE, Standard Error; CI, confidence interval; Std *ß*, Standardized Coefficients; TC, Total Cholesterol; LDL-C, Low-Density Lipoprotein Cholesterol

* *P* < 0.05, ** *P* < 0.01, *** *P* < 0.001 (2–tailed)

a change of -0.096 (95% CI: -0.138 - -0.053) in TC and − 0.085 (95% CI: -0.118 - -0.051) in LDL-C.

No association was observed between skipping breakfast and hyperuricemia in the healthy dietary pattern group, as indicated in Table 2, and skipping breakfast was not associated with HDL-C or TG in either dietary pattern group (Table S2). Table S3 also revealed no significant differences in the other main variables between the two dietary patterns, aside from skipping breakfast. Consequently, we focused on testing the mediating effects of TC and LDL-C in the overall population and the unhealthy dietary pattern group.

Testing for the mediation model

According to the results of mediation models testing in the unhealthy dietary pattern group, as shown in Table 3, total effect of skipping breakfast on SUA was − 6.464 (95%CI: -10.225- -2.703). Lipid profile mediated skipping breakfast associated with SUA, indicating decreased TC and LDL-C explain 22.32% and 21.57%, respectively. The results of mediation models testing in the overall population group are shown in Table S4.

Testing for the moderated mediation model

The results of moderated mediation models testing in the unhealthy dietary pattern group are shown in Table 4; Fig. 1. The moderated effects of age were significant in skipping breakfast (*ß*: 0.553, 95%CI: 0.042–1.063) and TC (*ß*: -0.339, 95%CI: -0.586 - -0.093) when the mediating variable is TC. Similarly, when LDL-C is the mediator variable, the moderating effect of age on the relationship between skipping breakfast (*ß*: 0.522, 95%CI: 0.009–1.035) and LDL-C (*ß*: -0.585, 95%CI: -0.891 - -0.276) is also significant.

Figure 2 presented the moderating effect graphically and showed that the effect of skipping breakfast, TC and LDL-C on SUA varied with the level of age in the unhealthy dietary pattern group. It further depicted that for lower level of age, the positive effects of TC and LDL-C on SUA, and the negative effect of skipping breakfast were stronger. In comparison, in higher level of age, the positive effect of TC and LDL-C, the negative effect of skipping breakfast weakened. These findings provided evidence of the moderating effect of age on the relationship between skipping breakfast and SUA.

The results of moderated mediation models testing in the overall population group are shown in Table S5, Fig. S4 and Fig. S5.

Sensitivity analysis

The estimation of the *E*-value showed that the possibility of unmeasured confounders could overturn the observed association was small, and Table 2 showed the more specific information. The sensitivity analyses about the mediation assumption indicated that the mediation effect of TC and LDL-C were quite robust (Fig. S6 and Fig. S7).

Discussion

This research investigated the association between the skipping breakfast and hyperuricemia among a cohort of oilfield workers from diverse provinces in China. Additionally, the study examined the potential mediating role of lipid profile and the moderating influence of age on the relationship between skipping breakfast and SUA.

This study found that 24.48% of the participants had hyperuricemia, with a sex-adjusted prevalence of 21.10%, notably higher than the 14% prevalence reported in China's chronic disease surveillance data [6]. Additionally, 79.2% of participants reported skipping breakfast, significantly exceeding the 19.6% prevalence found in a previous study [16]. These discrepancies may be attributed to the unique occupational characteristics of the oilfield worker population, many of whom work night shifts in a rotating three-shift system. This group also benefits from substantial welfare provisions but frequently engages in social activities that involve high-energy, high-protein, and high-fat foods, as well as alcohol consumption. Furthermore, they face considerable work-related stress, heavy workloads, smoking habits, and challenging outdoor living conditions, which hinder the

Table 4 Moderated mediation analyses

Mediator	Outcome variable	Variable	*ß*	SE	Bootstrap 95%CI	
					Lower	Upper
TC (M_1)	**TC (Y)**	Skipping breakfast (X)	0.093***	0.022	0.049	0.136
		Age (W)	0.012***	0.001	0.009	0.015
		X * W	-0.002	0.003	-0.007	0.004
	SUA (Y)	Skipping breakfast (X)	-3.879*	1.956	-7.713	-0.044
		TC (M_1)	15.138***	0.931	13.312	16.964
		Age (W)	-1.114***	0.126	-1.361	-0.867
		X * W	0.553*	0.260	0.042	1.063
		M_1 * W	-0.339**	0.126	-0.586	-0.093
LDL-C (M_3)	**LDL-C (Y)**	Skipping breakfast (X)	0.083***	0.018	0.048	0.117
		Age (W)	0.006***	0.001	0.004	0.008
		X * Age	-0.001	0.002	-0.006	0.004
	SUA (Y)	Skipping breakfast (X)	-3.940*	1.963	-7.788	-0.091
		LDL-C (M_3)	16.461***	1.182	14.144	18.779
		Age (W)	-1.033 ***	0.126	-1.280	-0.785
		X * W	0.522*	0.262	0.009	1.035
		M_3 * W	-0.585***	0.157	-0.894	-0.276

Adjusted for age, sex, marital status, education level, type of work, smoke, alcohol, physical activity and BMI

Abbreviations: TC, Total Cholesterol; LDL-C, Low-Density Lipoprotein Cholesterol; X, independent variable; M, mediating variable; W, moderated variable

* $P<0.05$, ** $P<0.01$, *** $P<0.001$ (2–tailed)

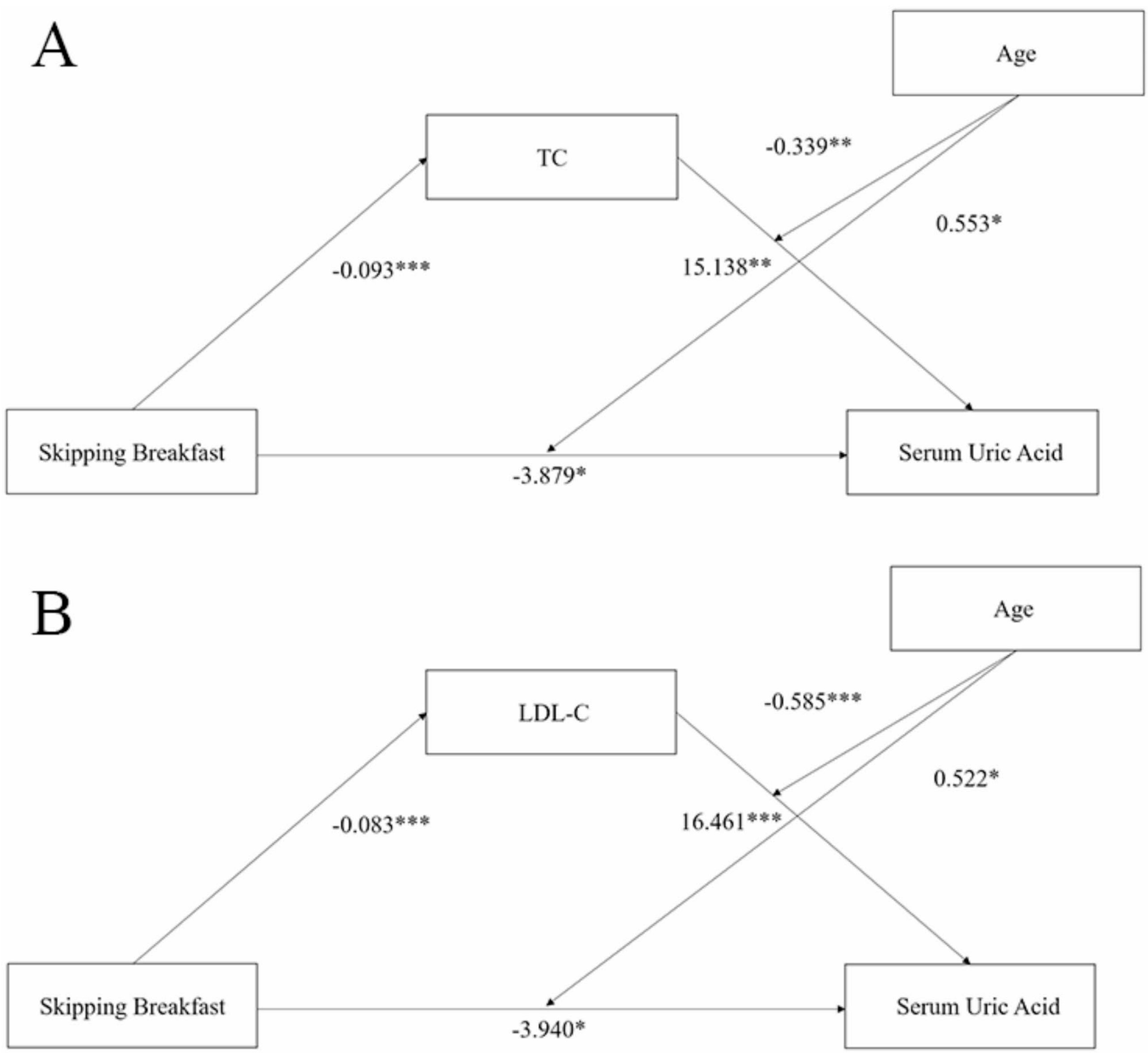

Fig. 1 Model of the moderating role of age on the direct and indirect relationship between skipping breakfast and SUA through A (TC) and B (LDL-C) Notes. TC, Total Cholesterol; LDL-C, Low-Density Lipoprotein Cholesterol; SUA, Serum Uric Acid; Values are unstandardized coefficients; Level of confidence: 95%; * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ (2–tailed)

maintenance of a balanced diet, proper rest, and access to fresh foods [41]. These factors likely contribute to the higher prevalence of both hyperuricemia and skipping breakfast within this population [10, 30, 42]. Furthermore, the results of this study revealed a negative correlation between skipping breakfast and an elevated risk of hyperuricemia among oilfield workers who followed an unhealthy dietary pattern. It is worth noting that no such association was found among participants adhering to a healthy dietary pattern. This finding contrasts with previous research that did not differentiate between dietary patterns [10]. The main reason for this finding may be that participants following an unhealthy dietary pattern consumed higher amounts of foods rich in sodium, sugar, and unhealthy fats, such as sugary beverages, red meat, and highly processed meats. These foods are known to contribute to elevated SUA levels [30, 43]. Specifically, certain meats are high in purines, which may exacerbate hyperuricemia, while fructose corn syrup in sugary beverages is also a well-established contributor to increased uric acid production [44, 45]. In contrast, participants adhering to a healthy dietary pattern were more likely to choose low-fat, low-sugar foods such as fruits, vegetables, and whole grains [30]. These foods have been shown to lower SUA levels. For instance, polyphenols found

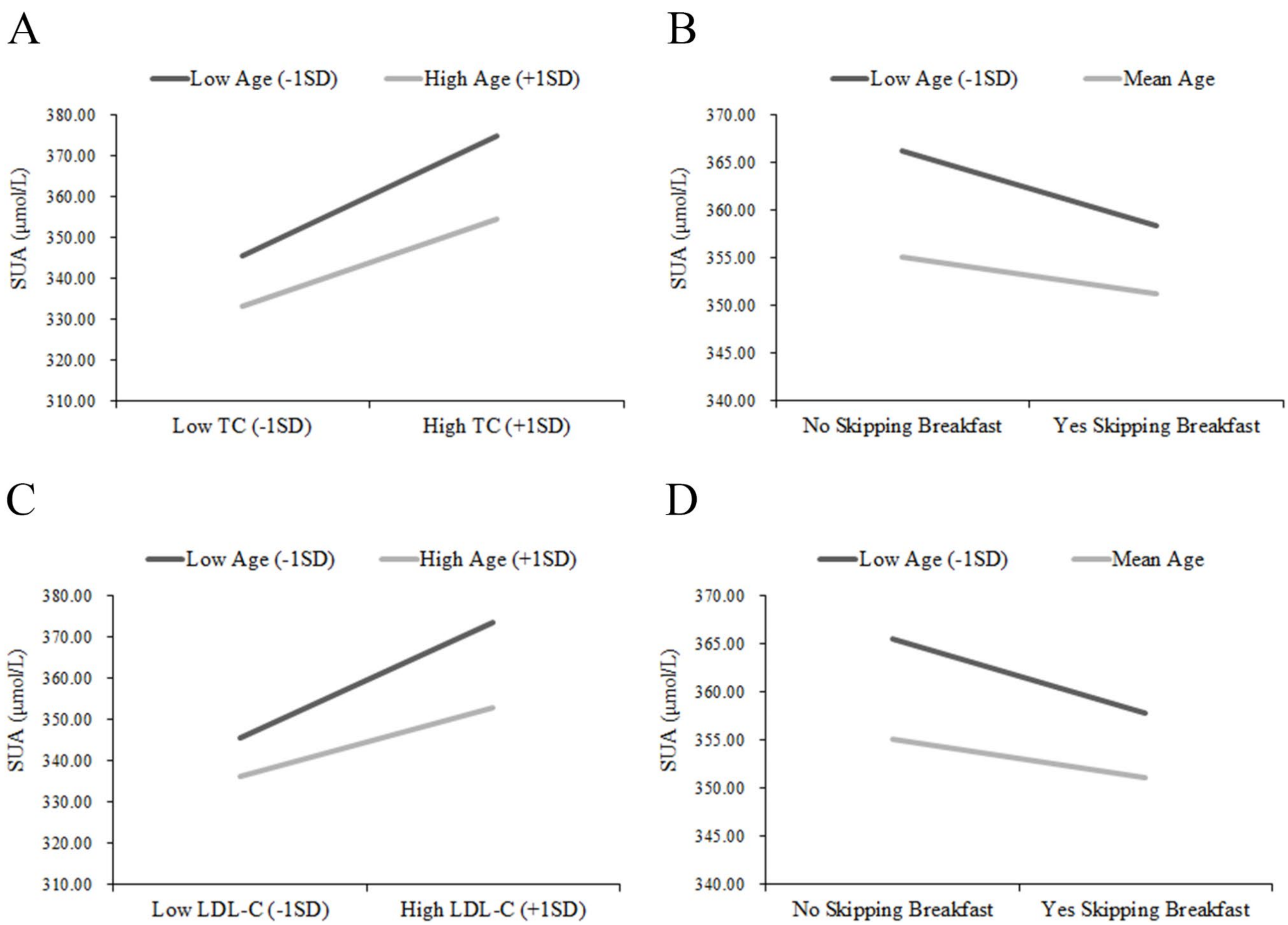

Fig. 2 Moderating effect of age on the relationship between **A** (TC), **B** (skipping breakfast; M: TC), **C** (LDL-C), **D** (skipping breakfast; M: LDL-C) and SUA
Notes. TC, Total Cholesterol; LDL-C, Low-Density Lipoprotein Cholesterol; SUA, Serum Uric Acid; SD: Standard Deviations

in fruits can inhibit the absorption of natural sugars, thereby contributing to a reduction in SUA levels [46].

The interaction between skipping breakfast and marital status may be attributed to the influence of eating behaviors associated with having a partner. Married individuals or those with a partner are less likely to skip breakfast [47]. This reduction in skipping breakfast could lead to increased food intake throughout the day, which may contribute to elevated SUA levels, especially in the context of an unhealthy dietary pattern.

This study provides additional insights into the mediating role of lipid profile in the relationship between skipping breakfast and SUA. Previous research has inadequately explored the mechanisms by which skipping breakfast affects SUA, and our study aims to fill this gap. The observed association between skipping breakfast and lipid profile is consistent with findings from a prior retrospective cohort study conducted among occupational populations [22]. The mechanism through which the skipping breakfast affects blood lipids levels remains unclear. This ambiguity may be due to variations in the nutritional composition of breakfast or the subsequent influence on dietary patterns at lunch [48, 49].

Elevated levels of TC and LDL-C were observed to stimulate endogenous cholesterol metabolism while impairing reverse cholesterol transport, culminating in augmented cholesterol accumulation within the kidneys. Further investigation demonstrated that ectopic cholesterol deposition induced lipotoxicity in renal tubular cells, precipitating mitochondrial dysfunction, oxidative stress, and endoplasmic reticulum stress [50]. The cellular damage observed in tubular cells induced mitochondrial fission and the activation of pro-apoptotic pathways [51, 52], culminating in renal filtration dysfunction and subsequent kidney failure [53]. Furthermore, a significant correlation was identified between renal excretion and SUA levels, with approximately two-thirds of uric acid being excreted via the kidneys [54]. This finding implies that the relationship between the skipping breakfast and hyperuricemia may be mediated by lipids-associated renal filtration dysfunction.

We found that age attenuated the lowering effect of skipping breakfast on SUA. The underlying mechanisms remain unclear, but they may have been related to endocrine changes (e.g., decreased estrogen levels) and increased oxidative stress that occur with aging [55, 56]. Additionally, older individuals often placed greater emphasis on dietary balance, which may mitigate the impact of skipping breakfast on SUA [57]. Furthermore, we observed that age also attenuated the effect of TC and LDL-C on the elevation of SUA. This may be due to an increase in insulin resistance with age, which reduces urate excretion, potentially diminishing the relative contribution of TC and LDL-C to the elevation of SUA [58].

This study has several strengths. Firstly, it is one of the few to focus on skipping breakfast, lipid profile, and hyperuricemia simultaneously. Secondly, we identified the mediating roles of TC and LDL-C, as well as the moderating effect of age, in the association between skipping breakfast and hyperuricemia. Thirdly, to ensure the robustness of our findings, we conducted sensitivity analyses on a large sample and adjusted for potential confounding factors, enhancing the reliability of the results. However, this study still has several limitations that should be mentioned. Firstly, the cross-sectional design precludes the establishment of causal relationships, highlighting the need for future longitudinal studies to address this issue. Secondly, the oilfield worker population may not fully represent the general population, which could limit the generalizability of the findings. To enhance the applicability of these results, future research should aim to include a more diverse and representative sample. Thirdly, dietary data were self-reported, which may introduce recall bias. Future studies should consider using objective measures, such as mobile phone consumption records, to obtain more accurate and reliable dietary data. Lastly, the influence of confounding factors, such as the use of lipid-lowering medications or other unmeasured variables, could not be fully controlled in this study. Future research should account for these potential confounders to improve the accuracy of the findings.

This investigation employed path analysis to examine the relationship between the skipping breakfast and SUA within an occupational cohort from oilfields. The findings indicate that the skipping breakfast exerts both direct and indirect effects on SUA levels, mediated through TC and LDL-C. Furthermore, age was identified as a moderating variable in the relationship between skipping breakfast and SUA. These results provide valuable insights for the management of hyperuricemia. The findings indicate that young workers in the oil industry should prioritize the management of dietary habits, undergo regular medical examinations, and participate in health education programs to mitigate the risk of hyperuricemia.

Abbreviations

BMI	Body Mass Index
ß	Unstandardized Coefficient
CI	Confidence Interval
DASH	Dietary Approaches to Stop Hypertension
FFQ	Food Frequency Questionnaire
HDL	C–High–Density Lipoprotein Cholesterol
LDL	C–Low–Density Lipoprotein Cholesterol
OR	Odds Ratio
SD	Standard Deviations
SUA	Serum Uric Acid
SE	Standard Error
Std	Standardized Coefficients
TC	Total Cholesterol
TG	Triglycerides

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions
Design, ZH.D., Y.Y.; Data analysis, ZH.D.; Software, ZH.D., G.T.; Data curation, ZH.D., FX.Z., Q.W.; Writing—original draft preparation, ZH.D.; Writing—review and editing, ZH.D.; Project administration, Y.Y. All authors have read and agreed to the final version of the manuscript.

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Data availability
The datasets generated and/or analyzed in this study are not publicly available, as data sharing was not included in the participants' written consent form but are available from the corresponding author (Yan Yan, yanyan802394@126.com) on reasonable request.

Declarations

Ethics approval and consent to participate
This project has been approved by the Ethics Committee of Xiangya School of Public Health, Central South University (Approval No.: XYGW-2023-92) and conducted in accordance with the Declaration of Helsinki. All participants were asked to provide written informed consent before completing the survey. All procedures followed the relevant ethical guidelines and regulations.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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