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Introduction

e triglyceride glucose index (TyG index) has garnered considerable interest among researchers due to its simplicity, cost-e ectiveness, and e cacy as an assessment tool [1]. Research has demonstrated a strong correlation between the TyG index and insulin resistance, indicating its e cacy as a dependable marker for assessing this physiological condition [2–3] and e ective predictor of diabetes mellitus [4]. Several investigations have identi ed a robust correlation between TyG index and the onset and progression of hypertension [5], metabolic syndrome [6], ischemic stroke [7], atherosclerosis [8–9], cardiovascular disease [10–12] and overall health status [13]. Furthermore, a noteworthy association has been observed between the TyG index and overall mortality in critically ill individuals with hemorrhagic stroke, indicating its potential as a novel assessment tool for overall mortality in this patient population [14]. In addition to its association with adverse cardiovascular and metabolic outcomes, an elevated TyG index has been linked to risks of osteoarthritis [15], breast cancer [16], occurrence and recurrence of colorectal adenomas [17], and depression [18–19]. In summary, the TyG index is regarded as a signi cant marker that has emerged as a potential risk the questionnaire regarding whether they had informed their doctor of these conditions in the past.

The height and weight of the individuals were documented, and their BMI was computed and categorized accordingly. The smoking status was classified into three categories: nonsmoker (or smoked less than 100 cigarettes), past smoker (smoked more than 100 cigarettes but has since quit), and current smoker. The drinking habits were classified into three groups: heavy drinker, low to moderate drinker, and nondrinker, based on their self-identified mean daily alcohol consumption. A heavy drinker was described as someone who consumes at least one alcoholic beverage per day for women and two or more drinks per day for men. In contrast, a moderate drinker was identified as an individual who consumes less than one alcoholic beverage per day for women and less than two drinks per day for men.

Physical activity was assessed by calculating the total minutes of activity weekly, which included moderate-intensity activity (in minutes) plus twice the minutes of vigorous-intensity activity, and classified into three categories: inactive (no moderate or vigorous-intensity activity), sufficiently active (more than 150 min/week), and insufficiently active (engagement in some activity but not meeting the criteria for being sufficiently active).

Statistical analysis

Continuous variables displaying a normal distribution were presented as mean ± SD, and subjected to comparison through one-way analysis of variance (ANOVA). Conversely, for continuous variables exhibiting skewed distributions, the Kruskal-Wallis H test was utilized for comparison, and the median (interquartile range) was provided. Categorical or dichotomous variables were expressed as absolute values (percentages), then chi-squared statistics was used for comparison. The collection and evaluation of PIR concentrations and distributions were conducted. To ascertain normality in continuous variables, the Shapiro-Wilk statistical test was utilized.

Linear regression was utilized to compute β coefficients and their corresponding 95% confidence intervals (CIs) for assessing the correlation between SES/BMI and the TyG index. Individuals were stratified according to tertiles of SES/BMI: PIR ≤ 1, 1< PIR<4, PIR ≥ 4; Edu 1(Less than High school), Edu 2 (High school) and Edu 3 (Some college or more); BMI(< 25 kg/m^2, 25–30 kg/m^2, and ≥ 30 kg/m^2. Further, the reference group for comparison

2 further incorporated adjustments for drinking status, smoking status, physical activity, hypertension, and CVDs.

Moreover, potential interactions a ecting the association between SES and the TyG index were evaluated, considering variables such as sex, age (<60 vs. ≥60 years), physical activity (Irregular/No vs. Regular), hypertension (No vs. Yes), and CVD (No vs. Yes). With the exception of the strati cation factor itself, all other variables within

Discussion

is study conducted an analysis on a nationally representative subset of Americans to assess the association between SES and the TyG index. e results indicate that in the cross-sectional survey involving 11,358 participants, lower SES among American adults is independently associated with higher TyG index. Furthermore, the results of this research indicate that BMI mediates the association between SES and the TyG index, with the proportion of mediation in PIR and educational level being 14% and 8.57%, respectively. In all adjusted models, these associations are independent of major underlying risk factors, including sex, age, marital status, drink status, smoke status, physical activity, hypertension, and CVDs.

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Table 2 Association between SES and BMI with TyG index in the multiple regression model

Variable	Total	Crude		Model1		Model2	
		β(95%CI)	*P*-value	β(95%CI)	*P*-value	β(95%CI)	*P*-value
Continuous PIR	11,358	-0.03 (-0.03~-0.02)	< 0.001	-0.04 (-0.05~-0.03)	< 0.001	-0.02 (-0.03~-0.02)	< 0.001
PIR categories							
PIR ≤ 1	2559	0(Ref)		0(Ref)		0(Ref)	
1< PIR<4	5989	-0.02 (-0.05 ~ 0.01)	0.303	-0.07 (-0.1~-0.04)	< 0.001	-0.05 (-0.08~-0.02)	0.004
PIR ≥ 4	2810	-0.1 (-0.13~-0.06)	< 0.001	-0.17 (-0.21~-0.13)	< 0.001	-0.11 (-0.15~-0.07)	< 0.001
P for trend		-0.05 (-0.07~-0.03)	< 0.001	-0.09 (-0.1~-0.07)	< 0.001	-0.05 (-0.07~-0.03)	< 0.001
Education level							
Edu 1	2828	0(Ref)		0(Ref)		0(Ref)	
Edu 2	2541	-0.09 (-0.13~-0.06)	< 0.001	-0.07 (-0.11~-0.04)	< 0.001	-0.07 (-0.1~-0.03)	< 0.001
Edu 3	5989	-0.22 (-0.25~-0.19)	< 0.001	-0.17 (-0.2~-0.14)	< 0.001	-0.12 (-0.15~-0.09)	< 0.001
P for trend		-0.11 (-0.12~-0.09)	< 0.001	-0.09 (-0.1~-0.07)	< 0.001	-0.06 (-0.08~-0.04)	< 0.001
BMI		0.03 (0.02 ~ 0.03)	< 0.001	0.03 (0.02 ~ 0.03)	< 0.001	0.02 (0.02 ~ 0.03)	< 0.001
BMI categories							
BMI<25	3358	0(Ref)		0(Ref)		0(Ref)	
25 ≤ BMI ≤ 30	3791	0.34 (0.31 ~ 0.37)	< 0.001	0.29 (0.26 ~ 0.32)	< 0.001	0.28 (0.25 ~ 0.31)	< 0.001
BMI>30	4209	0.49 (0.46 ~ 0.52)	< 0.001	0.47 (0.44 ~ 0.5)	< 0.001	0.45 (0.42 ~ 0.48)	< 0.001
P for trend		0.24 (0.23 ~ 0.26)	< 0.001	0.23 (0.22 ~ 0.25)	< 0.001	0.22 (0.21 ~ 0.24)	< 0.001

Modle1: Sex, age, Marital status; Modle2:Modle1 + drink status + smoke status + physical activity + Hypertension + CVDs

* *P*<0.05

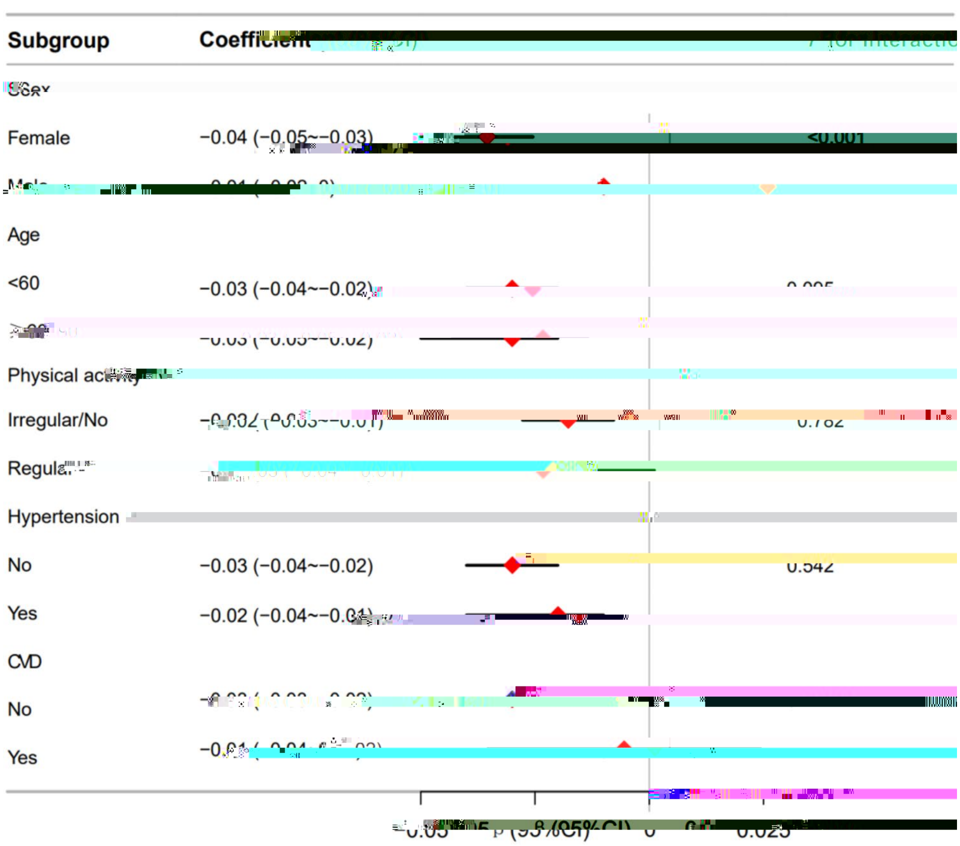

Fig. 2 Associations between PIR and TyG index in different subgroups
Except for the stratification component itself, each stratification factor was adjusted for sex, age, marital status, smoking status, drinking consumption, physical activity, hypertension, and CVDs. Stratified and interaction analysis indicated the association between PIR and TyG index was robust in different subgroups

Table 3 BMI as a mediator in the associations of SES with TyG index

Mediation effect	β	95% CI	*P*-value
PIR- BMI-TyG			
Indirect effect	-0.0036	-0.0057,-0.0017	0.002
Direct effect	-0.0213	-0.0294,-0.0134	< 0.001
Total effect	-0.025	-0.0337,-0.017	< 0.001
Edu-BMI-TyG			
Indirect effect	-0.0074	-0.0136,-0.0007	0.032
Direct effect	-0.0789	-0.1054,-0.0537	< 0.001
Total effect	-0.0863	-0.1138,-0.0604	< 0.001

Model was adjusted for: Sex, age, marital status, drink status, smoke status, physical activity, Hypertension, and CVDs

Convert education level into 2 categorical variables for analysis, high school /less than high school and some college or more

* *P*<0.05

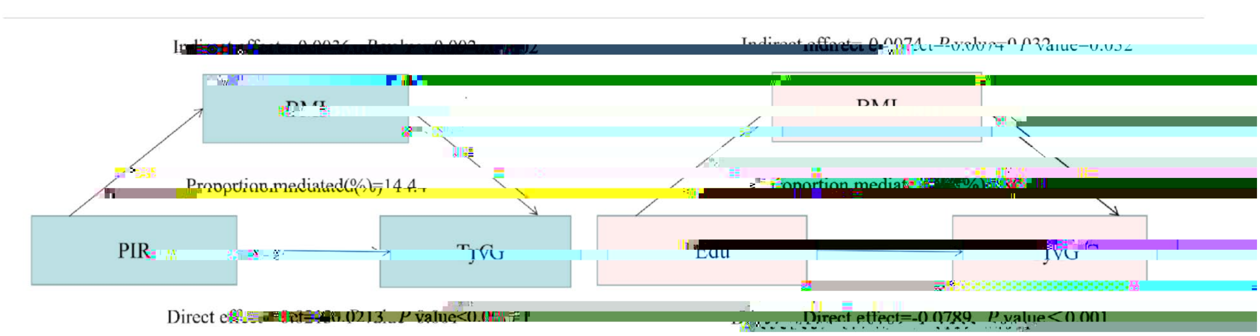

Fig. 4 Estimated proportion of the association between SES and TyG index mediated by BMI

Model was adjusted for: Sex, age, marital status, drink status, smoke status, physical activity, Hypertension, and CVDs. Convert education level into 2 catis essential for informing public policy towards effective and timely prevention strategies. Presently, the precise manner in which SES influences the TyG index remains uncertain.

Education, as a core indicator of SES, has been widely utilized in the field of epidemiological research. Nonetheless, the correlation between education and health remains a topic of debate. Several studies suggest that elevated education levels are frequently correlated with enhanced health outcomes. Consistent with the study findings, Stephens et al. noted that individuals with higher education levels tend to exhibit improved metabolic health and significantly reduce the risks of waist circumference, systolic blood pressure, blood glucose, glycosylated hemoglobin, triglycerides, high-density lipoprotein abnormalities, and metabolic syndrome compared to those with lower education levels [28]. Furthermore, another study indicated a notable inverse correlation between education and the incidence of heart disease among non-Hispanic white populations in the United States [29]. However, in a large-scale study of middle-aged individuals in China, education was identified as a potential risk factor for dyslipidemia and heart disease [30]. Similarly, research on middle-aged individuals in Japan [31] and male individuals in South Korea [32] also found a notable positive correlation between education level and the Incidence of hyperlipidemia. The inconsistency in these research findings may stem from differences among countries, regions and races.

Income, as a core indicator of SES, is closely linked to a variety of significant health issues. Existing study has confirmed a clear causal relationship between higher household income and improved cardiovascular biomarkers, which in turn contributes to reducing the incidence of cardiovascular diseases [33]. However, It is also crucial to acknowledge that the relationship between low income and heart disease is significant [34]. Further multivariate meta-analyses have revealed positive correlations between middle-low income levels and elevated risk of coronary artery disease, stroke, cardiovascular events, and cardiovascular-related mortality [35]. The findings of this study imply an independent negative correlation between PIR and the TyG index. These findings not only underscore the important role of income status in maintaining individual health but also provide important evidence for the formulation of public health policies to further reduce the negative impact of socioeconomic inequality on health.

The specific mechanisms underlying the negative correlation between SES and the TyG index are not yet fully understood, but might involve several factors. Firstly, education level significantly influences individuals' dietary behaviors [36–38

However, there may also be other important factors beyond BMI, such as genetic factors, dietary intake, and systemic inflammation levels, which may also play significant roles in the relationship between socioeconomic status and the TyG index. Therefore, subsequent investigations should delve into these potential factors to garner a more thorough comprehension of how SES affects individual health.

Our study demonstrates a correlation between SES, BMI, and the TyG index. To effectively mitigate this health disparity, comprehensive public health intervention measures are imperative. These measures include, but are not limited to, improving public education levels, promoting healthy lifestyles, and actively controlling BMI. Primary healthcare services, as a critical pillar of the national health system, play an indispensable role. They are not only responsible for delivering basic medical services but also serve a key function in advancing health education and chronic disease prevention efforts, particularly among populations with lower socioeconomic status and higher metabolic health risks [55]. Therefore, public health policymakers should fully recognize the unique value of primary healthcare services in addressing health disparities and chronic disease prevention. By doing so, they can enhance the overall metabolic health of the population.

Strengths and limitations

This study has certain limitations. Primarily, the study is based on data from the United States, it remains uncertain whether these results are generalizable to other countries and populations. Secondly, given the cross-sectional design of the NHANES dataset, this study cannot capture the temporal order of events, thus precluding the establishment of a causal link between SES/BMI and the TyG index; causality remains undetermined. Additionally, despite rigorous methods employed to ensure data accuracy in NHANES, self-reported SES measures remain prone to recall bias. Thirdly, despite employing regression models and stratified analyses to account for potential confounders, there may still be residual confounding effects from unmeasured or unknown variables,

Data availability
NHANES data used in this work is publicly available. All raw data are available on the NHANES website (https://www.cdc.gov/nchs/nhanes/). Further enquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate

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