Association between dietary niacin intake and dyslipidemia prevalence in the National Health and Nutrition Examination Surveys (NHANES)

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Mengqi Gao MM[1†], Youming He MM[2†], Ying Xiao MM[1], Lili Yang MD[1]

[1]Department of Nutrition, Guangdong Provincial Key Laboratory of Food, Nutrition and Health, School of Public Health, Sun Yat-sen University, Guangzhou, China
[2]Zhongshan Ophthalmic Center, Sun Yat-sen University, Guangzhou, China
[†]Both authors contributed equally to this work

Authors' email addresses and contributions:
M.G.: gaomq3@mail2.sysu.edu.cn
Contribution: Conceptualization, Writing-original draft, Methodology, Investigation, and Formal analysis.
Y. H.: heyouming@gzzoc.com
Contribution: Writing - original draft, Methodology, Investigation, Formal analysis, and Data curation.
Y. X.: xiaoy325@mail2.sysu.edu.cn
Contribution: Investigation.
L.Y.: yangll7@mail.sysu.edu.cn
Contribution: Conceptualization, Writing - review & editing, Methodology, and Investigation.

Corresponding Author: Prof. Lili Yang, School of Public Health, Sun Yat-sen University (Northern Campus), 74 Zhongshan Road 2, Guangzhou, Guangdong Province 510080, China. Tel: +86-20-87330625. Email: yangll7@mail.sysu.edu.cn

ABSTRACT

Background and Objectives: The association of niacin intake with dyslipidemia remains uncertain. The aim of this study was to explore the association between dietary niacin intake and the prevalence of dyslipidemia among adults in the United States (US). **Methods and Study Design:** Data were obtained from the National Health and Nutrition Examination Survey (NHANES) conducted between 2005 and 2014. The exposure variable was dietary niacin intake, measured through 24-hour dietary recall interviews and treated as both a continuous and categorical variable. Dyslipidemia, defined by diagnostic criteria, was the outcome. Logistic regression and restricted cubic spline models were applied to examine the association between niacin intake and the prevalence of dyslipidemia. **Results:** Among the 19,275 individuals, the prevalence of dyslipidemia was 78.8%. Compared with individuals with lower niacin consumption Q1 (≤15.9 mg/day), the adjusted OR values for dietary niacin intake and dyslipidemia in Q3 (22.7 – 31.8 mg/day) and Q4 (≥31.8 mg/day) were 0.78 (95% CI: 0.64–0.94, p = 0.011) and 0.77 (95% CI: 0.61–0.98, p = 0.033), respectively. The association between niacin intake and the prevalence of dyslipidemia followed a L-shaped dose-response curve (non-linear, p = 0.009). Participants with a niacin intake of <22.3 mg/day exhibited an OR of 0.98 (95% CI: 0.96–0.99, p = 0.040) for dyslipidemia. In subgroup analyses, the inverse associations of niacin intake with the prevalence of dyslipidemia remained robust only in female. **Conclusions:** In the 2005-2014 NHANES population, higher levels of niacin intake were associated with decreased odds of dyslipidemia overall. Further studies are needed to examine the potential protective effects of niacin on dyslipidemia risk.

Key Words: diet, niacin, dyslipidemia, NHANES

INTRODUCTION

Dyslipidemia, a metabolic abnormality marked by elevated LDL cholesterol (hypercholesterolemia), often occurs in conjunction with low HDL cholesterol and high triglycerides.[1] A recent study found that the prevalence of dyslipidemia is high in both developed and developing countries.[2] Dyslipidemia serves as a major risk factor for atherosclerotic cardiovascular disease (CVD). Extensive observational studies have shown a strong correlation between higher LDL-C levels or lower HDL-C levels and an increased risk of atherosclerotic coronary heart disease (CHD) events.[3, 4] Current therapeutic strategies for

managing CVD primarily focus on controlling risk factors, with a specific emphasis on decreasing the prevalence of dyslipidemia.

Niacin is a nutrient known for its antioxidant and anti-inflammatory properties, and its ability to regulate abnormal serum lipid metabolism and enhance endothelial function.[5-7] The utilization of niacin in the treatment of dyslipidemia dates back to as early as 1955. One study found that niacin lowers plasma cholesterol in hypercholesterolemic patients, which is a risk factor for CVD and mortality.[8, 9] High dosage of niacin reduced the levels of LDL-C, TG and lipoprotein(a), and elevated the level of HDL-C.[10-12] Current guidelines recommend considering niacin therapy to reduce CVD risk,[13, 14] and its application in the US is increasing steadily.[15] However, it is worth noting that many clinical trials were relatively small scale and investigated the effects of relatively high doses of pharmaceutical niacin over a short period.[10-12, 16] There was one report that a high-dosage of niacin was associated with an increased risk of cardiac arrhythmias.[17] Another randomized trial found that the addition of niacin did not significantly reduce the risk of major vascular events but did increase the risk of serious adverse events among participants with atherosclerotic vascular disease.[18] Therefore, the efficacy and safety of high-dose niacin therapy in dyslipidemia remained uncertain.

Given the problems discussed above, the consumption of foods rich in niacin may be the safest and most effective way to control lipid profiles. Uncertainties persist regarding the sufficiency of current niacin intake in the US, and the potential association of niacin intake with the prevention of dyslipidemia. Through this research, we aim to investigate whether an elevated dietary niacin intake is associated to a lower prevalence of dyslipidemia.

MATERIALS AND METHODS

Study design and participants

We combined 5 consecutive National Health and Nutrition Examination Survey (NHANES) cycles from 2005 to 2014 according to the NHANES analytical guidelines (https://wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx). NHANES employed a stratified, multistage, and clustered probability sampling approach to acquire a nationally representative sample of noninstitutionalized civilians in the US.[19] The exclusion criteria were as follows: (1) participants aged ≤ 20 years, (2) participants who were pregnant, (3) participants missing an assessment of dyslipidemia, (4) participants without reliable dietary recall status. The selection process was shown in Figure 1. Ultimately, 19,275 participants were included in the subsequent analysis.

Statement of ethics

The work presented in this manuscript is not considered human subjects research, because it used only de-identified, publicly available data from the National Health and Nutrition Examination Survey and is therefore not subject to IRB review.

Exposure and outcomes

Dietary niacin intake was obtained using 24-hour dietary recall interviews conducted as part of the NHANES survey.[20] During these interviews, participants recounted their food and beverage consumption from the previous day. The quantitative intake of specific nutrients was then calculated based on the information provided in these interviews. NHANES survey staff analyzed the data to determine niacin levels in food, including levels from fortification. Niacin intake was analyzed (1) as a continuous variable per 1 mg increase; (2) as a binary variable with sex-specific thresholds based on recommended daily allowances (RDAs) proposed by the National Institutes of Health—16 mg for adult males and 14 mg for adult females,[21] and (3) as a categorical variable stratified into quartiles. The RDA for a given nutrient is defined as the average daily intake level that meets the nutritional needs of 97% to 98% of healthy individuals. The determination of niacin intake quartiles was based on the weighted NHANES population of individuals included in our analysis.

Dyslipidemia was defined as having any one of the followings:

a. High TG level: TG $\geq$ 150 mg/dL (3.89 mmol/L).

b. Hypercholesterolemia: total cholesterol (TC) $\geq$ 200 mg/dL (5.18 mmol/L), LDL-C $\geq$ 130 mg/dL (3.37 mmol/L), and HDL-C $<$ 40 mg/dL (1.04 mmol/L [males]) and 50 mg/dL (1.30 mmol/L [females]).[22]

Covariates

Demographic variables were obtained using a questionnaire that encompassed age, gender, race, marital status, education level, family poverty income ratio (PIR), smoking and drinking habits. Smoking habits were categorized as never, former, or current smokers. Individuals who reported having smoked 100 cigarettes in their lifetime but were not presently smoking were classified as former smokers.[23] Alcohol consumption was classified into three categories: never or fewer than 12 drinks a year, moderate drinking, and excessive drinking. Excessive drinking was defined as consuming more than 14 drinks per week for men or more than 7 drinks per week for women on average during the past year.[24] Physical activity was categorized as either “physically inactive” or “physically active” according to the 2018

Physical Activity guidelines.[25] Hypertension was defined as having a systolic blood pressure (SBP) ≥ 140 mmHg, a diastolic blood pressure (DBP) ≥ 80 mmHg, or current use of antihypertensive medication. Diabetes was defined as meeting one or more of the following criteria: a 2-hour plasma glucose level ≥ 200 mg/dL, HbA1c level ≥ 6.5%, fasting plasma glucose (FPG) level ≥ 126 mg/dL, taking insulin or diabetic pills, or self-reported physician diagnosis.[26]

Statistical analysis

This is a secondary analysis of publicly accessible datasets. Categorical variables were represented by numbers (weighted percentages), while continuous variables were described by mean ± standard deviation (SD). To compare the differences between groups based on dyslipidemia status, the Chi-square test for categorical variables and t-tests for continuous variables were undertaken. The odds of dyslipidemia associated with dietary niacin intake were estimated using logistic regressions. The models included the following adjustments:

a. The crude model, which was unadjusted.

b. Model 1, which was adjusted for age, sex, and race.

c. Model 2, which further included marital status, education levels, PIR, smoking status, alcohol consumption, as well as intakes of fat, protein, carbohydrate, fiber, vitamin B2, and vitamin B6.

The inclusion of vitamins B2 and B6 was motivated by their role as necessary cofactors in the conversion of tryptophan to niacin. Additionally, this study incorporates gender-stratified models to examine the potential impact of gender as a modifier in the link between niacin intake and dyslipidemia, considering the variations in recommended niacin intake values between males and females. Finally, a restricted cubic spline function with three knots (25, 50 and 75 percentiles) was applied to examine the potential nonmonotone trend of dietary niacin intake on the prevalence of dyslipidemia. Weighted analyses were carried out using survey weights, which is fundamental to NHANES, to account for the complex survey design, survey non-response, post-stratification, and oversampling. All statistical analyses were completed through R language (version 4.1.0). Statistical significance was determined at p-value < 0.05 (two-sided).

RESULTS

Characteristics of study population

The baseline characteristics of the study subjects are presented in Table 1. Among the 19275 participants, 15180 were identified as having dyslipidemia. In comparison to those without dyslipidemia, individuals with dyslipidemia tend to be older, with higher percentages of females and current smokers, overweight and obese individuals. They also exhibited lower levels of physical activity, higher prevalence of hypertension and diabetes.

Table 2 outlines the dietary niacin intake values. The average dietary niacin intake was 25.8 mg (SD = 15.3 mg), and the majority (79.3%) exceeded sex-specific RDAs. Furthermore, participants were categorized into quartiles based on dietary niacin intake, and the quartile boundaries were detailed.

Association between niacin intake and the prevalence of dyslipidemia

Multivariable analyses of the association between dietary niacin intake and the prevalence of dyslipidemia are presented in Table 3. When niacin intake was evaluated as a binary variable, higher dietary niacin intake showed a significant 18.5% lower prevalence of dyslipidemia [OR = 0.82, 95% CI = (0.69, 0.97). When niacin intake was analyzed in quartiles, the third quartile of dietary niacin intake was associated with a 22.3% lower prevalence of dyslipidemia [OR = 0.78, 95% CI = (0.64, 0.94)], and the highest quartile of dietary niacin intake was associated with a 22.7% lower prevalence of dyslipidemia in the fully adjusted model [OR = 0.77, 95% CI = (0.66, 0.98)]. Consistently, when niacin intake was expressed as mg/1000 kcal (energy density form), the lower prevalence of dyslipidemia was found in those with higher niacin intake (Supplementary Table 1). Similar trends were found in models with further adjustments for hypertension and diabetes (Supplementary Table 2).

Results from gender-stratified analyses are presented in Table 4. In these analyses, it was observed that higher niacin intake was associated with lower prevalence of dyslipidemia among women only.

Dose-response relationship between dietary niacin and dyslipidemia

The spline curve illustrates the ORs and 95% CIs for the dose-response relationship between dietary niacin intake and the prevalence of dyslipidemia (Figure 2). After adjusting for potential confounders, we observed a decrease in the prevalence of dyslipidemia with increasing niacin intake, the shape of the association of niacin intake with the prevalence of dyslipidemia was approximately L-shaped (non-linear, $p = 0.009$).

In the threshold analysis, participants with niacin intake of <22.3 mg/day exhibited an OR of 0.98 (95% CI: 0.96–0.99, p = 0.040) for the prevalence of dyslipidemia (Table 5). This implied a 2.0% reduction in the prevalence of dyslipidemia with each 1 mg increase in daily dietary niacin consumption. Conversely, when the daily niacin intake was ≥ 22.3 mg/day (Table 5), no significant association was observed. Consequently, the prevalence of dyslipidemia no longer decreases with an increase in dietary niacin intake (≥ 22.3 mg/day).

DISCUSSION

In this study, we assessed the association between dietary niacin intake and the prevalence of dyslipidemia in the 2005-2014 NHANES population. We observed that individuals with a higher dietary niacin intake had a lower prevalence of dyslipidemia. This association followed a L-shaped dose-response curve, with an inflection point of 22.3 mg per day. In women, there was also a significant association between higher levels of niacin intake and lower prevalence of dyslipidemia. No similarly significant associations were found in men.

Accumulated clinical trial studies have consistently demonstrated niacin's positive impact on serum lipid profiles, including reductions in LDL-C, TG and TC, as well as an increase in HDL-C levels.[7-9] Our findings align with the results of previous clinical trials. However, there have been relatively few epidemiological studies investigating the relationship between dietary niacin intake and the risk of dyslipidemia. One epidemiological study investigated the longitudinal association between dietary niacin intake and dyslipidemia in a Korean population and showed that an increased intake of dietary niacin was inversely associated with the risk of dyslipidemia.[27] The dose-response relationship in the Korean survey was linear within the specified ranges of dietary niacin intake, which differs from our results. There are two main possible reasons for this discrepancy. First, the Korean survey only included participants aged 40 years and older, whereas our study had a broader age range. Second, niacin consumption in the Korean population is significantly lower than in the American population; the average daily intake in Korea is approximately 14 mg, compared to 25.8 mg in the United States. This suggests that the health effects of niacin intake may vary across different intake ranges.

The possible biological mechanisms underlying the beneficial effect of dietary niacin on the lipid profile is that niacin rapidly and significantly reducing plasma free fatty acid (FFA) levels.[28] The intricated mechanism of niacin's action involves its interaction with a Gi-protein-coupled orphan membrane receptor 109A (GPR109A), which is highly expressed in adipose tissue. Niacin binds to the adipocyte membrane-bound GPR109A, leading to the inhibition of

adenylyl cyclase, a reduction in intracellular cAMP concentrations, and consequent suppression of protein kinase A (PKA)-mediated activation of hormone-sensitive lipase (HSL).[29] This ultimately results in the suppression of adipose TG mobilization and FFA release, subsequently leading to lower circulating FFA levels. This, in turn, deprives the liver of an essential substrate required for the synthesis and secretion of VLDL, a precursor for LDL-C.[30] Studies involving GPR109A-knockout mice have failed to demonstrate reductions in FFA and TG levels with niacin, supporting this hypothesis.[31]

This study conducted a gender-stratified analysis to examine the relationship between dietary niacin intake and dyslipidemia, revealing variations in dyslipidemia prevalence among men and women. Specifically, higher niacin intake was associated with lower prevalence of dyslipidemia in female participants but not in males. Previous research suggested that sex hormones may influence both niacin metabolism and the risk of dyslipidemia.[32, 33] Our findings indicate the potential presence of scientific mechanisms that could explain the modification of the effect measure by sex. Further investigation is necessary to uncover sex-specific differences in the impact of niacin on dyslipidemia.

The correlation between niacin consumption in the diet and dyslipidemia exhibited an L-shaped pattern. The positive impact of increasing dietary niacin intake on dyslipidemia appeared to reach its peak among individuals with sufficient niacin intake levels. Specifically, the prevalence of dyslipidemia decreased as dietary niacin consumption increased in those with a dietary niacin intake of < 22.3 mg/day. However, the prevalence of dyslipidemia showed no further decline with higher dietary niacin intake in those with a dietary niacin intake of ≥ 22.3 mg/day. Based on the current statistical data analysis, it appears that the health benefits associated with increasing niacin intake are limited. Notably, the RDA for niacin in the US is 16 mg/day for men and 14 mg/day for women, with a Tolerable Upper Intake Level of 35 mg/day for all adults.[34] Excessive niacin supplementation can lead to side effects such as rash, fever, redness, diarrhea, constipation, and abdominal pain.16 Cases of niacin toxicity in the US, characterized by symptoms such as abdominal pain, nausea, vomiting, and fever, have been reported following prolonged consumption of energy drinks containing 30 mg of niacin per day for 2 weeks.[35] However, the likelihood of side effects is lower when obtaining niacin from dietary sources.[36] Consistent with previous research, our findings suggest that maintaining a balanced diet may help prevent metabolic disorders like dyslipidemia.

This study has the strength of increasing the statistical power with a large sample size weighted to be representative of the US population, and the results of the study showed an

association in the same direction. In addition, to the best of our knowledge, this study will have great implications in that it is the first population-based study to assess the association between dietary niacin intake and the risk of dyslipidemia in the general population of the US.

The current study presents several limitations that warrant consideration. Firstly, this study only observed dietary niacin intake as the primary exposure. We did not consider supplemental niacin intake, which was only recorded in NHANES surveys conducted after 2007-2008 and had too small a sample size to include in the analysis due to substantial missing data. This may have led to an overestimation of the health effects of dietary niacin intake. Secondly, we excluded tryptophan from our analysis, even though it can endogenously convert to niacin. This exclusion was due to the unavailability of tryptophan as a variable in the NHANES dataset. Thirdly, our estimation of niacin intake relied on data obtained from 24-hour dietary recall interviews, introducing potential uncertainties associated with recall and reporting biases. Although we controlled for certain confounding factors, it is possible that other confounders, such as a history of long-term medication use (e.g., steroids), may still influence the study outcomes. Lastly, due to the nature of a cross-sectional study, we cannot establish causality. Therefore, while our findings provide insights into associations, they cannot definitively establish causality. Future prospective studies with larger sample sizes will be necessary to explore causal relationships comprehensively.

Conclusion

In the 2005-2014 NHANES population, higher dietary niacin intake was associated with a lower prevalence of dyslipidemia overall. This association followed a L-shaped dose-response curve. In addition, we found that high niacin intake was inversely associated with dyslipidemia among women only. Considering the limited data on the effects of dietary niacin on metabolic diseases, this study is expected to provide basic data for the prevention and management of dyslipidemia. Larger prospective studies are needed to confirm our findings.

Data availability statement

The data used in this study are publicly available as part of the National Health and Nutrition Examination Survey, which is distributed and sponsored by the Centers for Disease Control and Prevention (https://www.cdc.gov/nchs/nhanes/index.htm).

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CONFLICT OF INTEREST AND FUNDING DISCLOSURE

The authors declare no conflict of interest.

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Table 1. Characteristics of study participants by the dyslipidemia status among the US adults[†]

Variables	Total	Dyslipidemia		p value
	N = 19275	No (n = 4095)	Yes (n = 15180)	
Age (years)	47.8±16.4	45.4±18.1	48.4±15.8	<0.001
Gender				<0.001
Men	9310 (48.1)	2162 (51.4)	7148 (47.2)	
Women	9965 (51.9)	1933 (48.6)	8032 (52.8)	
BMI (kg/m^2)				<0.001
Normal	5079 (27.9)	1655 (44.1)	3424 (23.6)	
Overweight	6449 (33.8)	1273 (31.0)	5176 (34.5)	
Obese	4249 (21.5)	670 (15.1)	3579 (23.2)	
Extreme obese	3299 (16.7)	457 (9.9)	2842 (18.6)	
Race				<0.001
Non-Hispanic White	8988 (69.9)	1871 (68.8)	7117 (70.2)	
Non-Hispanic Black	3732 (10.0)	978 (12.4)	2754 (9.4)	
Mexican American	3191 (8.5)	555 (7.5)	2636 (8.8)	
Other Races	3364 (11.5)	691 (11.3)	2673 (11.6)	
Marital status				<0.001
Married	11667 (64.9)	2376 (62.6)	9291 (65.5)	
Widowed/ Divorced/ Separated	4391 (18.9)	796 (14.8)	3595 (20.0)	
Unmarried	3212 (16.2)	923 (22.6)	2289 (14.5)	
Education				<0.001
Below high school graduate	5169 (17.8)	966 (16.2)	4203 (18.3)	
High school graduate	4459 (23.4)	871 (21.3)	3588 (23.9)	
College or above	9628 (58.8)	2252 (62.4)	7376 (57.8)	
PIR				0.975
<1.30	5738 (21.4)	1126 (21.3)	4612 (21.5)	
1.30-3.49	6598 (35.9)	1446 (36.0)	5152 (35.8)	
≥ 3.50	5664 (42.7)	1219 (42.6)	4245 (42.7)	
Smoking				0.001
Never smoke	10407 (53.9)	2323 (56.5)	8084 (53.2)	
Former smoker	4677 (24.5)	1016 (24.5)	3661 (24.4)	
Current smoker	4184 (21.7)	755 (19.0)	3429 (22.4)	
Alcohol use				0.316
Past drinking	5154 (26.1)	1046 (24.5)	4108 (26.5)	
Moderate drinking	9483 (64.1)	2098 (65.4)	7385 (63.7)	
Excessive drinking	1350 (9.8)	291 (9.9)	1059 (9.8)	
Hypertension				<0.001
No	11788 (67.3)	2672 (72.5)	9116 (65.9)	
Yes	7102 (32.7)	1341 (27.5)	5761 (34.1)	
Diabetes				<0.001
No	15646 (86.1)	3382 (87.7)	12264 (85.7)	
Yes	3599 (13.9)	706 (12.3)	2893 (14.3)	
Physical activity (MET min/week)				<0.001
Inactive	7697 (42.6)	1501 (37.8)	6169 (43.9)	
Active	8372 (57.4)	1937 (62.2)	6435 (56.1)	
Total energy (kcal/d)	2171±99	2222±1004	2157±997	0.003
Carbohydrate (g/d)	259±127	262±124	259±127	0.211
Protein (g/d)	83.5±42.8	85.7±43.8	82.9±42.5	0.007
Fat (g/d)	82.7±46.6	85.5±47.5	81.±46.4	<0.001
Fiber (g/d)	16.6±10.1	17.1±10.0	16.5±10.2	0.003
Vitamin B2 (mg/d)	2.20±1.29	2.26±1.32	2.19±1.29	0.013
Vitamin B6 (mg/d)	2.08±1.52	2.18±1.51	2.06±1.52	0.001

NHANES, National Health and Nutrition Examination Survey; BMI, body mass index; IR, poverty income ratio; MET, metabolic equivalent
†Data are expressed as numbers (percent) for categorical variables and as mean ± SD for continuous variables.

Table 2. Levels of dietary niacin intake by the dyslipidemia status among the US adults†

Dietary niacin intake (mg/day)	Total	Dyslipidemia		p value
	N = 19275	No (n = 4095)	Yes (n = 15180)	
Niacin	25.80±15.29	26.86±15.47	25.51±15.22	<0.001
Niacin Binary by sex				0.002
Below RDA	4650 (20.7)	907 (18.5)	3743 (21.3)	
At or above RDA	14625 (79.3)	3188 (81.5)	11437 (78.7)	
Niacin quartile				<0.001
Quartile 1 (< 15.872)	5469 (25.0)	1057 (22.3)	4412 (25.7)	
Quartile 2 (15.872 - 22.737)	4869 (25.0)	999 (23.8)	3870 (25.3)	
Quartile 3 (22.738 - 31.845)	4571 (25.0)	1017 (27.1)	3554 (24.4)	
Quartile 4 (≥ 31.846)	4366 (25.0)	1022 (26.8)	3344 (24.5)	

RDA, recommended daily allowance
†Data are expressed as numbers (percent) for categorical variables and as mean ± SD for continuous variables.

Table 3. Multivariate odds ratio for dyslipidemia according to dietary niacin intake

Dietary niacin intake (mg/day)	Crude Model		Multivariable Model 1†		Multivariable Model 2‡	
	OR (95%CI)	p value	OR (95%CI)	p value	OR (95%CI)	p value
Continuous	0.995(0.992-0.997)	<0.001	0.998(0.995-1.001)	0.114	0.996(0.988-1.004)	0.283
Binary by sex						
Below RDA	Ref.	-	Ref.	-	Ref.	-
At or above RDA	0.841(0.754-0.939)	0.002	0.89(0.797-0.995)	0.041	0.815(0.687-0.966)	0.020
Categorical by quartile						
Quartile 1	Ref.	-	Ref.	-	Ref.	-
Quartile 2	0.923(0.818-1.041)	0.187	0.937(0.829-1.058)	0.286	0.848(0.718-1.002)	0.053
Quartile 3	0.785(0.696-0.885)	<0.001	0.828(0.731-0.940)	0.004	0.777(0.643-0.940)	0.011
Quartile 4	0.796(0.696-0.911)	0.001	0.902(0.784-1.038)	0.148	0.773(0.611-0.978)	0.033

OR, odds ratio; CI, confidence interval; RDA, recommended daily allowance; Ref., reference.
†The multivariate model 1 was adjusted for age, gender and race, using appropriate sampling weights.
‡The multivariate model 2 was adjusted for BMI, education level, marital status, PIR, smoking, alcohol use, physical activity, carbohydrate, protein, fat, fiber, vitamin B2 and vitamin B6 in addition to model 1 using appropriate sampling weights.

Table 4. Multivariate odds ratio for dyslipidemia according to dietary niacin intake by gender

Dietary niacin intake (mg/day)	Crude Model		Multivariable Model 1[a]		Multivariable Model 2[b]	
	OR (95%CI)	p value	OR (95%CI)	p value	OR (95%CI)	p value
Men						
Continuous	0.999 (0.995-1.002)	0.413	0.999 (0.996-1.003)	0.627	0.997 (0.986-1.008)	0.580
Binary by sex						
Below RDA	Ref.	-	Ref.	-	Ref.	-
At or above RDA	0.954 (0.79-1.153)	0.626	0.965 (0.798-1.168)	0.713	0.806 (0.602-1.079)	0.143
Categorical by quartile						
Quartile 1	Ref.	-	Ref.	-	Ref.	-
Quartile 2	0.995 (0.804-1.230)	0.960	0.992 (0.802-1.225)	0.938	0.818 (0.591-1.132)	0.219
Quartile 3	0.938 (0.769-1.145)	0.526	0.944 (0.774-1.152)	0.566	0.840 (0.618-1.141)	0.256
Quartile 4	0.974 (0.791-1.200)	0.804	0.995 (0.803-1.232)	0.961	0.817 (0.564-1.185)	0.278
Women						
Continuous	0.988 (0.983-0.994)	<0.001	0.991 (0.986-0.997)	0.002	0.991 (0.976-1.005)	0.202
Binary by sex						
Below RDA	Ref.	-	Ref.	-	Ref.	-
At or above RDA	0.816 (0.720-0.925)	0.002	0.849 (0.752-0.960)	0.010	0.892 (0.716-1.111)	0.299
Categorical by quartile						
Quartile 1	Ref.	-	Ref.	-	Ref.	-
Quartile 2	0.927 (0.795-1.081)	0.329	0.936 (0.803-1.092)	0.395	0.923 (0.752-1.132)	0.432
Quartile 3	0.743 (0.646-0.855)	<0.001	0.776 (0.672-0.896)	<0.001	0.805 (0.612-1.058)	0.116
Quartile 4	0.728 (0.604-0.877)	0.001	0.805 (0.666-0.974)	0.026	0.781 (0.547-1.116)	0.169

OR, odds ratio; CI, confidence interval; RDA, recommended daily allowance; Ref., reference.
[†]The multivariate model 1 was adjusted for age and race, using appropriate sampling weights.
[‡]The multivariate model 2 was adjusted for BMI, education level, marital status, PIR, smoking, alcohol use, physical activity, carbohydrate, protein, fat, fiber, vitamin B2 and vitamin B6 in addition to model 1 using appropriate sampling weights..

Table 5. Threshold analyses of the relationship between dietary niacin intake with dyslipidemia

Dietary niacin intake (mg/day)	Adjusted Model†	
	OR (95%CI)	p value
Optimal cut-off		
Below (< 22.3)	0.980(0.960-0.999)	0.040
Equal or above (≥ 22.3)	0.999(0.991-1.007)	0.840

OR, odds ratio; CI, confidence interval; Ref., reference.
†The multivariate model was adjusted for age, gender, race, BMI, education level, marital status, PIR, smoking, alcohol use, physical activity, carbohydrate, protein, fat, fiber, vitamin B2 and vitamin B6.

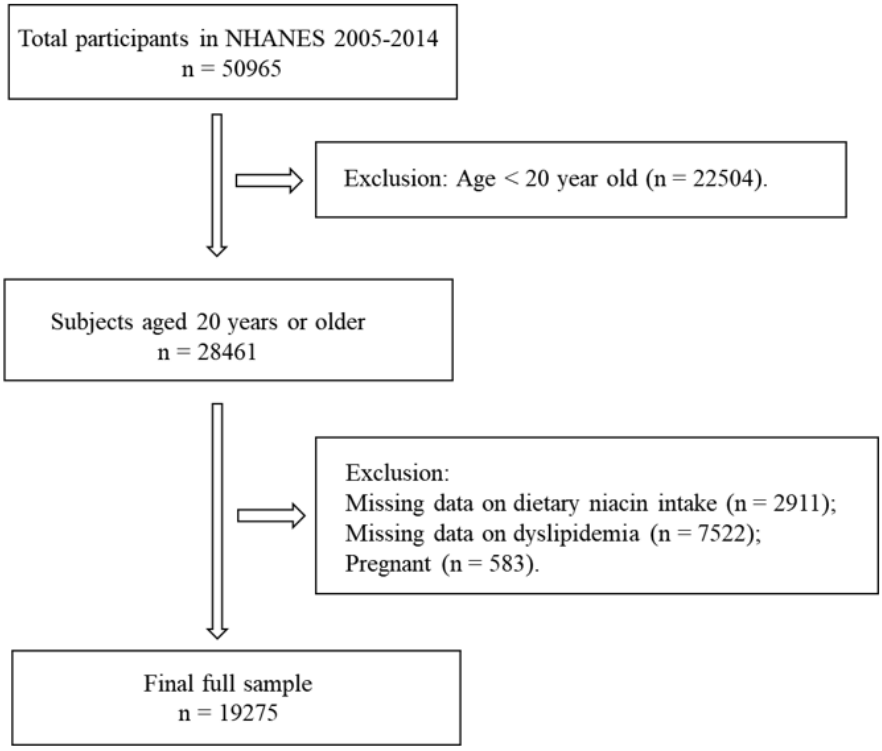


Figure 1. Flowchart for study population selection

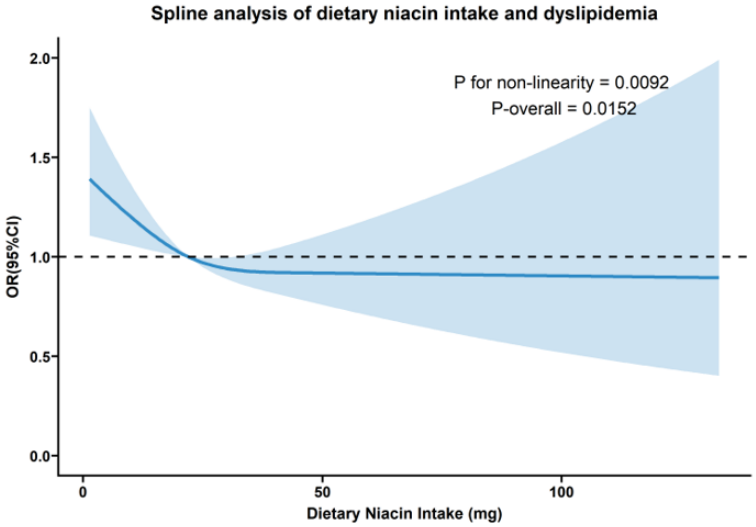
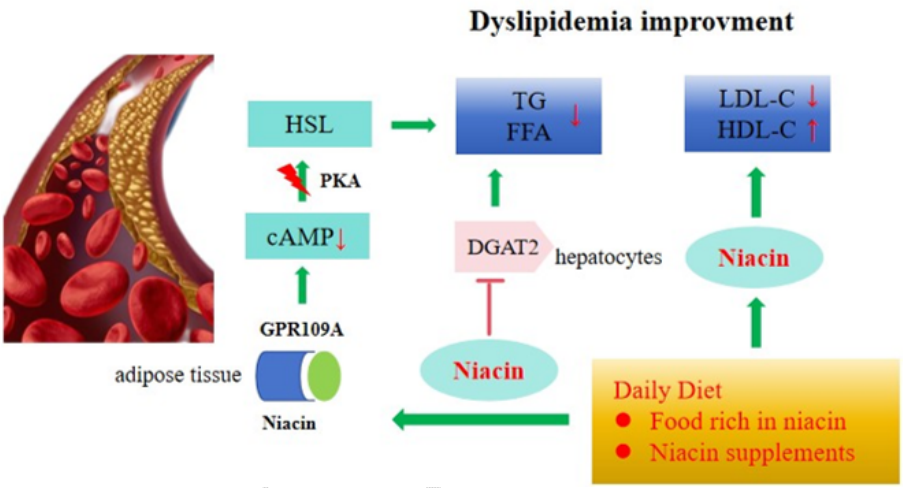


Figure 2. Fully adjusted dose-response association between dietary niacin intake and dyslipidemia



Graphical abstract.

Supplementary Tables

Supplementary Table 1. Multivariate odds ratio for dyslipidemia according to dietary niacin intake in energy density form (mg/1000 kcal)

Dietary niacin intake (mg/day)	Crude Model		Multivariable Model 1†		Multivariable Model 2‡	
	OR (95%CI)	p value	OR (95%CI)	p value	OR (95%CI)	p value
Continuous	0.995 (0.987-1.002)	0.175	0.996 (0.988-1.003)	0.236	0.997 (0.985-1.009)	0.642
Categorical by quartile						
Quartile 1	Ref.	-	Ref.	-	Ref.	-
Quartile 2	0.854 (0.743-0.981)	0.026	0.851 (0.741-0.978)	0.023	0.781 (0.646-0.945)	0.012
Quartile 3	0.855 (0.758-0.964)	0.011	0.848 (0.752-0.956)	0.008	0.790 (0.679-0.919)	0.003
Quartile 4	0.853 (0.739-0.984)	0.030	0.845 (0.734-0.972)	0.019	0.754 (0.611-0.929)	0.009

OR, odds ratio; CI, confidence interval; Ref., reference.
†The multivariate model 1 was adjusted for age, gender and race, using appropriate sampling weights.
‡The multivariate model 2 was adjusted for BMI, education level, marital status, PIR, smoking, alcohol use, physical activity, carbohydrate, protein, fat, fiber, vitamin B2 and vitamin B6 in addition to model 1 using appropriate sampling weights.

Supplementary Table 2. Multivariate odds ratio for dyslipidemia according to dietary niacin intake with further adjustments for other diseases

Dietary niacin intake (mg/day)	Crude Model		Multivariable Model 1†		Multivariable Model 2‡	
	OR (95%CI)	p value	OR (95%CI)	p value	OR (95%CI)	p value
Continuous	0.995(0.992-0.997)	<0.001	0.998(0.995-1.001)	0.114	0.996(0.988-1.004)	0.353
Binary by sex						
Below RDA	Ref.	-	Ref.	-	Ref.	-
At or above RDA	0.841(0.754-0.939)	0.002	0.89(0.797-0.995)	0.041	0.812(0.683-0.966)	0.020
Categorical by quartile						
Quartile 1	Ref.	-	Ref.	-	Ref.	-
Quartile 2	0.923(0.818-1.041)	0.187	0.937(0.829-1.058)	0.286	0.851(0.720-1.006)	0.059
Quartile 3	0.785(0.696-0.885)	<0.001	0.828(0.731-0.940)	0.004	0.773(0.635-0.940)	0.011
Quartile 4	0.796(0.696-0.911)	0.001	0.902(0.784-1.038)	0.148	0.773(0.608-0.981)	0.035

OR, odds ratio; CI, confidence interval; Ref., reference.
†The multivariate model 1 was adjusted for age, gender and race, using appropriate sampling weights.
‡The multivariate model 2 was adjusted for BMI, education level, marital status, PIR, smoking, alcohol use, physical activity, carbohydrate, protein, fat, fiber, vitamin B2, vitamin B6, hypertension and diabetes, in addition to model 1 using appropriate sampling weights.