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Research Article

Plant-Based Retinol Intake and Risk of Nonalcoholic Fatty Liver Disease in American Adults: Insights from NHANES 2007-2014

Can Liu[1, 2], Zeming Bai[3], Jingmin Cheng[1, *]

[1]School of Management, Shanxi Medical University, Taiyuan, China
[2]School of Public Health, Shanxi Medical University, Taiyuan, China
[3]School of Medicine and Food Engineering, Shanxi University of Chinese Medicine, Jinzhong, China

Abstract

Existing evidence suggests a strong correlation between nonalcoholic fatty liver disease (NAFLD) risk and dietary factors, and this investigation aimed to examine the association between dietary factors and NAFLD risk in American adults. Utilizing data from the National Health and Nutrition Examination Survey (NHANES) conducted between 2007 and 2014, the study employed chi-square tests of independence and t-tests to analyze differences between the NAFLD and control groups, while logistic regression analysis was used to identify factors influencing NAFLD risk and assess the association of plant-based dietary retinol intake with such risk. The NAFLD group consisted of 1,286 males (53.5%) and 1,138 females (46.9%), and logistic regression analysis identified uric acid (UA), high-density lipoprotein (HDL), smoking, vigorous recreational activity, hypertension, diabetes, gender, BMI, race, annual household income, and plant-based retinol intake as significant predictors of NAFLD ($P < 0.05$), with notably higher dietary intake of plant-based retinol being associated with a lower risk of NAFLD (OR = 0.670, 95% CI: 0.532-0.842). This study demonstrates that specific dietary components, especially plant-based retinol, play an important role in influencing NAFLD risk among American adults, and further long-term research is needed to inform public health initiatives aimed at reducing NAFLD prevalence.

Keywords

NAFLD, Dietary Factor, Plant-based Retinol, Logistic Regression Model, NHANES

1. Introduction

Nonalcoholic fatty liver disease (NAFLD) is a disease process and a set of symptoms that are distinguished by the deposition of fat in the liver. Individual who consumes excessive amounts of alcohol or suffers from other liver disorders are not affected by this disease [1]. Liver damage progresses through a series of stages, commencing with simple hepatic steatosis and progressing to nonalcoholic steatohepatitis (NASH), liver fibrosis, cirrhosis, and ultimately hepatocellular carcinoma (HCC) [2-5]. In recent years, there has been a significant rise in the global prevalence of NAFLD, estimates indicate that 10% to 35% of the population is affected by NAFLD [6]. Nearly 30% of adults in the United

*Corresponding author: 72-87@163.com (Jingmin Cheng)

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States are affected by this condition [7]. Research suggests that NAFLD is associated with an increased risk of chronic diseases, including cardiovascular disease, obesity, diabetes, and hypertension [8-10].

Epidemiological studies have shown a correlation between dietary factors and the prevalence of nonalcoholic fatty liver disease (NAFLD) [11, 12]. Studies have shown a positive correlation between the consumption of refined grains, fried foods, processed meats, and fructose-rich foods and an elevated risk of NAFLD [13-15]. On the other hand, a diet rich in fruits, vegetables, legumes, probiotic dairy products, and whole grains is believed to lower the risk of developing NAFLD [15-18]. Furthermore, studies have shown that the intake of vitamin A (retinol), known for its antioxidant properties, significantly influences the prevalence of NAFLD [19, 20]. Researchers have conducted research to investigate the potential correlation between dietary retinol and non-alcoholic fatty liver disease (NAFLD). Despite examining a potential association between dietary retinol and NAFLD, the research yielded conflicting results due to differences in ethnic background, dietary habits, study design, and sample sizes. Higher intakes of retinol were associated with a reduced risk of developing NAFLD in an Iranian study [6]. In an additional cross-sectional study that involved 80 individuals, individuals with NAFLD consumed a greater amount of vitamin A than healthy controls [21]. Consequently, it is crucial to investigate the risk of NAFLD in addition to dietary factors. This cross-sectional study employed a logistic regression model to examine the factors that influence NAFLD risk, thereby improving the administration of adult health.

2. Materials and Methods

2.1. The Subjects and Data Collection

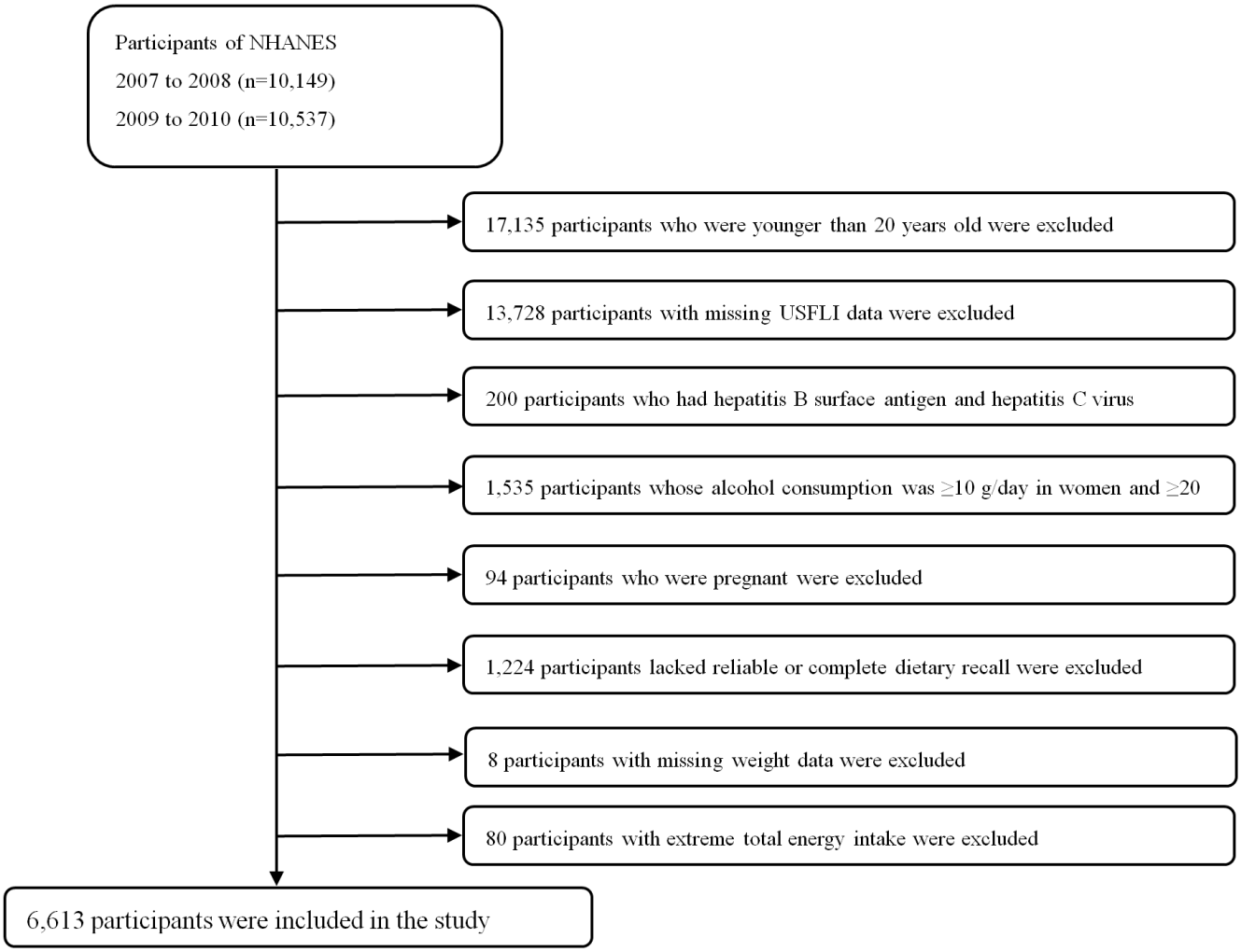

Figure 1. *Flowchart of individual selection.*

This cross-sectional study used data from four consecutive two-year cycles (2007-2014) of the National Health and Nutrition Examination Survey (NHANES). The survey utilized a multistage, stratified sampling design to obtain a representative sample of the noninstitutionalized civilian population of the United States [22]. Data collection involved conducting household interviews with participants along with medical examinations to obtain blood and urine samples. We collected specimens during household visits for participants unable to attend medical examinations due to health limitations [22]. The NHANES dataset initially included 40,617 participants (20,180 males and 20,437 females), with the analysis focused on 23,482 individuals aged 20 years or older. We conducted subsequent analyses on 9,754 participants, excluding those with the United States Fatty Liver Index (USFLI; n = 13,728). Additionally, the study excluded 200 participants who tested positive for hepatitis B surface antigen or hepatitis C virus antibodies. The study also excluded participants who consumed alcohol at a rate of less than 10 g/day for women and less than 20 g/day for men (n = 1,535). People who were pregnant (n = 94), had unreliable or incomplete dietary recall data (n = 1,224), were missing weight data (n = 8), or had an average energy intake that was more than or less than three standard deviations from the mean (n = 80) were also not included (Figure 1). Ultimately, the final analysis included 6,613 participants (3,067 males and 3,546 females). The Research Ethics Review Board of the National Center for Health Statistics approved the study protocol, and all participants provided written informed consent.

2.2. NAFLD Measurement

The United States Fatty Liver Index (USFLI), with a cut-off value of 30, assessed NAFLD based on age, race, waist circumference, fasting glucose, gamma-glutamyl transferase, and fasting insulin [23]. As previously reported, the USFLI is a reliable, noninvasive measure of NAFLD and serves as an independent predictor of liver-related and all-cause mortality [24-26].

2.3. Dietary Retinol Intake

Dietary vitamin A intake, primarily through retinol, was quantified using two 24-hour dietary recall interviews to calculate retinol activity equivalents (mcg) [27]. We conducted the initial recall at the mobile examination center and conducted the second recall by telephone 3 to 10 days later. We used the average retinol intake from the two recalls for analysis. Detailed methodologies of the dietary recall interviews are available in previous publications [28]. Based on specific food codes, we identified the sources of dietary retinol intake, which included animal-derived sources like meat, eggs, dairy products, poultry, and fish, as well as plant-based sources like legumes, nuts, seeds, fruits, and vegetables. We quantified the animal-derived retinol intake using the conversion factor of 1 mcg retinol activity equivalents (RAE), which corresponds to 1 mcg of all-trans retinol from animal-based foods. We estimated plant-based retinol using the following equation: 1 RAE (mcg) = 1/12 beta-carotene (mcg) + 1/24 other provitamin A (mcg).

2.4. Covariates

Researchers have used the food frequency questionnaire, known for its validity and reliability, to assess average dietary intakes [29, 30], which include those from milk and milk products, meat, poultry, fish, mixed dishes, eggs, legumes, nuts, seeds, grain products, fruits, and vegetables. Multiple potential factors were assessed, which includes gender (male and female), age groups (20-44 years, 45-59 years, 60-74 years, and ≥75 years), race/ethnicity (Mexican-Americans, other Hispanics, non-Hispanic Whites, non-Hispanic Blacks, and other races), body mass index (BMI) categories (normal: <25 kg/m^2; overweight: 25 to <30 kg/m^2; obese: ≥30 kg/m^2), educational level (less than high school, high school, and post-high school), annual household income (<$20,000, $20,000-$44,999, $45,000-$74,999, and ≥$75,000), smoking history (ever smoked at least 100 cigarettes or never), participation in vigorous recreational activity (yes or no), diabetes status (yes or no), hypertension status (yes or no), and biochemical parameters including low-density lipoprotein (LDL), high-density lipoprotein (HDL), total cholesterol (TC), and uric acid (UA). Additionally evaluated the mean energy consumption, overall dietary retinol intake, retinol intake from animal sources, and retinol intake from plant sources. Diabetes is shown by fasting blood glucose levels of ≥7.0 mmol/L and 2-hour plasma glucose levels of ≥11.1 mmol/L, using diabetes medicines or insulin, or saying that a doctor told you that you have diabetes [31]. Hypertension is characterized by a mean systolic blood pressure of ≥130 mmHg and/or a mean diastolic blood pressure of ≥80 mmHg, the utilization of antihypertensive medication, or self-reported physician-diagnosed hypertension [32].

2.5. Statistical Analysis

We used the student's t-test to evaluate inter-group differences for continuous variables and the chi-square test for categorical data. Categorical variables were depicted as percentage frequencies, while continuous data were presented as mean values (standard deviation [SD]). The factors that influence NAFLD were investigated using logistic regression analysis, which yielded odds ratios (ORs) and 95% confidence intervals (CIs). Multivariable-adjusted logistic regression model was utilized to assess the relationship between plant-based dietary retinol intake and NAFLD risk. Some potential confounders included gender, age, race, education level, smoking status, physical activity, income level, BMI, hypertension, diabetes, TC and UA. Stata 15.0 was employed to conduct statistical analyses, ensuring that the sample

weights and units were appropriate for national representativeness. A 2-tailed p-value of less than 0.05 was used to determine the statistical significance of all tests.

3. Results

3.1. Description of the Participants

Table 1 shows that 1286 males (53.55%) and 1138 females (44.95%) received a diagnosis of NAFLD. We found that the participants with NAFLD and the healthy controls exhibited statistically significant differences in the presence of influencing factors, including gender, age, race, BMI, education level, annual household income, smoking status, vigorous recreational activity, hypertension, diabetes, UA, HDL, animal-derived dietary retinol, and plant-based dietary retinol ($P < 0.05$).

3.2. Influencing Factors of NAFLD Risk

The characteristics that influence the risk of NAFLD as identified using logistic regression analysis (Table 2). Male gender compared to female had significant positive associations with NAFLD risk (OR = 1.694, 95% CI: 1.139-1.374), BMI (OR = 4.891, 95% CI: 4.410-5.425), smoking compared to non-smoking (OR = 1.305, 95% CI: 1.138-1.497), hypertension versus non-hypertension (OR = 1.531, 95% CI: 1.316-1.779), diabetes compared to non-diabetes (OR = 2.648, 95% CI: 2.250-3.118), and UA levels (OR = 1.360, 95% CI: 1.288-1.436). Conversely, we observed significant negative associations with NAFLD risk for factors such as race (OR = 0.608, 95% CI: 0.571-0.647), annual household income (OR = 0.908, 95% CI: 0.851-0.968), vigorous recreational activity (OR = 0.599, 95% CI: 0.495-0.726), HDL levels (OR = 0.958, 95% CI: 0.952-0.963), and plant-based dietary retinol intake (OR = 0.886, 95% CI: 0.847-0.926).

3.3. Association Between Plant-based Dietary Retinol Intake and NAFLD Risk

The association of plant-based dietary retinol intake with the risk of NAFLD was indicated according to multivariable-adjusted logistic regression model (Table 3, Figure 2). There was significantly negative relationship between plant-based dietary retinol intake and the risk of NAFLD (OR: 0.637, 95% CI: 0.515-0.788). This association remained significant after adjusting some potential confounders (OR: 0.670, 95% CI: 0.532-0.842).

Table 1. *Characteristics of the study individuals based on NAFLD.*

Group	NAFLD (total)[a]		*p*-value[b]
	no	yes	
Gender (n, %)			<0.001
Male	1781 (42.52%)	1286 (53.05%)	
Female	2408 (57.48%)	1138 (46.95%)	
Age Group (n, %)			<0.001
20-44 years	1890 (45.12%)	709 (29.25%)	
45-59 years	988 (23.59%)	655 (27.02%)	
60-74 years	862 (20.58%)	742 (30.61%)	
≥75 years	449 (10.72%)	318 (13.12%)	
Race/Ethnicity (n, %)			<0.001
Mexican American	488 (11.65%)	552 (22.77%)	
Other Hispanic	444 (10.60%)	294 (12.13%)	
Non-Hispanic White	1845 (44.04%)	1155 (47.65%)	
Non-Hispanic Black	931 (22.22%)	269 (11.10%)	
Other/Multiracial	481 (11.48%)	154 (6.35%)	
BMI (n, %)			<0.001
<25 kg/m^2	1716 (41.02%)	108 (4.46%)	

Group	NAFLD (total)[a]		*p*-value[b]
	no	yes	
25 to <30 kg/m^2	1568 (37.49%)	637 (26.32%)	
≥30 kg/m^2	899 (21.49%)	1675 (69.21%)	
Educational Level (n, %)			<0.001
< High school	902 (21.55%)	802 (33.14%)	
High school	954 (22.80%)	543 (22.44%)	
> High school	2329 (55.65%)	1075 (44.42%)	
Annual household income (n, %)			<0.001
<$20,000	780 (19.45%)	561 (24.14%)	
$20,000-$44,999	1352 (33.71%)	931 (40.06%)	
$45,000-$74,999	781 (19.47%)	409 (17.60%)	
≥$75,000	1098 (27.37%)	423 (18.20%)	
Smoking status (n, %)			<0.001
Yes	1576 (37.64%)	1131 (46.66%)	
No	2611 (62.36%)	1293 (53.34%)	
Vigorous recreational activity (n, %)			<0.001
Yes	1031 (24.61%)	270 (11.14%)	
No	3158 (75.39%)	2154 (88.86%)	
Hypertension (n, %)			<0.001
Yes	1648 (39.34%)	1539 (63.49%)	
No	2541 (60.66%)	885 (36.51%)	
Diabetes (n, %)			<0.001
Yes	505 (12.06%)	910 (37.54%)	
No	3684 (87.94%)	1514 (62.46%)	
Cholesterol: mean (SD), mg/dL	192.16 (41.19)	194.23 (41.79)	0.051
Uric Acid: mean (SD), mg/dL	5.14 (1.30)	6.03 (1.43)	<0.001
HDL: mean (SD), mg/dL [c]	56.28 (14.86)	45.78 (11.87)	<0.001
LDL: mean (SD), mg/dL [d]	114.86 (35.13)	115.34 (35.95)	0.605
Average energy intake: mean (SD), kcal/day	1903.27 (695.88)	1912.03 (711.51)	0.625
Total dietary retinol intake: mean (SD), μg/1000kcal/day	338.66 (284.09)	325.69 (279.77)	0.072
Animal-derived dietary retinol intake: mean (SD), μg/1000kcal/day)	122.70 (150.62)	134.97 (205.69)	0.005
Plant-based dietary retinol intake: mean (SD), μg/1000kcal/day)	198.80 (238.80)	171.24 (181.11)	<0.001

[a] Data are presented as No. (%) of participants, unless otherwise noted. Percentages have been rounded and may not add up to 100.
[b] The means of continuous variables were compared using independent 2-sample t tests. The distribution of categorical variables was compared using Pearson χ^2 tests.
[c] HDL, high-density lipoprotein.
[d] LDL, low density lipoprotein.

Table 2. Multivariate logistic regression analysis on relating factors of NAFLD.

Variable	B	SE	Wald χ2	*P*	OR (95%CI)
Gender	0.517	0.077	47.144	<0.001	1.694 (1.139,1.374)
BMI	1.587	0.053	902.079	<0.001	4.891 (4.410,5.425)
Race/Ethnicity	-0.498	0.032	239.729	<0.001	0.608 (0.571,0.647)
Annual household income	-0.097	0.033	8.662	0.003	0.908 (0.851,0.968)
Smoking	0.266	0.070	14.481	<0.001	1.305 (1.138,1.497)
Vigorous recreational activity	-0.512	0.098	27.334	0.001	0.599 (0.495,0.726)
Hypertension	0.426	0.077	30.652	<0.001	1.531 (1.316,1.779)
Diabetes	0.974	0.083	136.784	<0.001	2.648 (2.250,3.118)
Uric Acid	0.308	0.028	122.992	<0.001	1.360 (1.288,1.436)
HDL	-0.043	0.003	197.819	<0.001	0.958 (0.952,0.963)
Plant-based dietary retinol intake	-0.121	0.023	28.106	<0.001	0.886 (0.847,0.926)

SE, standard error; OR, odds ratio; CI, confidence interval.

Table 3. Association between plant-based dietary retinol intake and NAFLD risk.

Variables	Model1[a]		Mode2[b]		Mode3[c]	
	OR (95%CI)	*P* value	OR (95%CI)	*P* value	OR (95%CI)	*P* value
Plant-based dietary retinol intake (RAEs, μg/1000kcal/day)						
<70.37	1.00 (ref.)		1.00 (ref.)		1.00 (ref.)	
70.37 to <138.53	0.949 (0.781-1.152)	0.589	0.943 (0.766-1.160)	0.574	1.015 (0.820-1.258)	0.886
138.53 to <253.07	0.855 (0.704-1.038)	0.111	0.821 (0.668-1.010)	0.062	0.899 (0.710-1.138)	0.367
≥253.07	0.637 (0.515-0.788)	<0.001	0.588 (0.465-0.745)	<0.001	0.670 (0.532-0.842)	0.001

[a] Crude model.
[b] The model included covariates (i.e. gender and age).
[c] The model included covariates (i.e. gender, age, race, education level, smoking status, physical activity, income level, BMI, hypertension, diabetes, TC and UA).

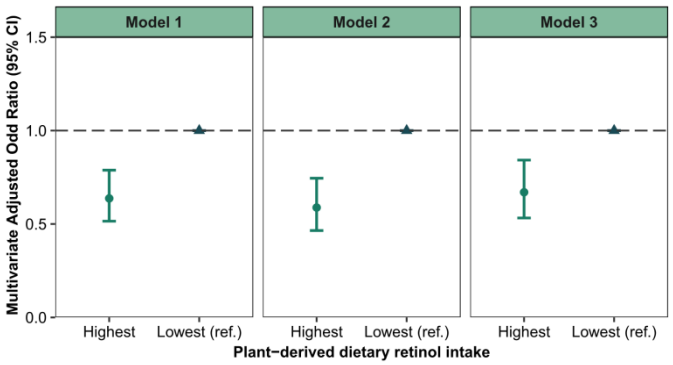

Figure 2. Association between plant-based dietary retinol intake and NAFLD risk. Hazard ratios and 95% confidence intervals (error bars) were calculated using covariate-adjusted method. Covariates were as follows: gender, age, race, education level, smoking status, physical activity, income level, BMI, hypertension, diabetes, TC and UA.

4. Discussion

The application of logistic regression models is of considerable significance in the field of public health research. By utilizing dietary factors to identify populations at a high risk of NAFLD, these models provide a valuable preliminary screening tool that informs targeted prevention strategies. Noninvasive methods can readily access and evaluate the variables employed in this model [33]. Additionally, the model's generalizability to the general population is further enhanced by its ability to be implemented through computer programs, which enables the automated calculation of NAFLD risk probabilities based on the factors that are included. However, additional research is necessary to ascertain the relevance of these risk estimates to individuals.

Our results suggest that dietary factors significantly influence the risk of NAFLD. It is important to note that the intake of dietary retinol from plants was associated with lower odds of NAFLD. Despite the uncertainty surrounding the precise mechanisms underlying this relationship, numerous potential explanations have emerged. This effect may be influenced by the abundance of provitamin A carotenoids in plant-based diets. Our study estimated the intake of plant-based retinol by analyzing the consumption of foods such as legumes, beans, fruits, and vegetables. Research indicates that the antioxidant properties of carotenoids may mitigate oxidative stress in hepatocytes, thereby reducing the risk of NAFLD and protecting against liver injury [34]. A lot of research has also shown that high-sensitivity C-reactive protein (hs-CRP) and the inflammatory cytokines IL-6 and TNF-α are linked to NAFLD and may be biomarkers of inflammation that lead to endothelial cell injury [35, 36]. Iwaki et al. [37] also reported that vitamin A and its metabolites may either directly or indirectly regulate the expression of adiponectin. It is possible that adiponectin's anti-inflammatory properties could lower the risk of NAFLD by blocking the expression of nuclear factor-kappa B (NF-κB) and TNF-α, which fights inflammation [38]. Furthermore, vitamin A provides an additional protective mechanism by regulating hepatic glucose and lipid metabolism [39].

The progression of NAFLD is considerably influenced by lifestyle factors, including dietary choices and demographic characteristics, as evidenced by a variety of studies [12, 40]. For instance, prior research has shown that individuals with NAFLD are more likely to consume diets that are high in energy, total fat, saturated fat, and fructose, while they are lower in fiber and polyunsaturated fatty acids (PUFAs) than healthy individuals [41-46]. Additionally, research indicates that obesity is a significant risk factor for NAFLD, with its prevalence increasing as BMI increases [40]. A six-year study in China found that individuals with NAFLD had a greater risk of developing diabetes than healthy controls [47]. Smoking was identified as an independent risk factor for the onset and progression of NAFLD in our research [48]. This may be because of nicotine on the sympathetic nervous system, which increases the secretion of glucagon and catecholamines, thereby fostering the development of NAFLD [49].

There are numerous noteworthy advantages to our investigation. Initially, the use of a nationally representative sample of adults in the United States improved the statistical power and generalizability of our findings. Secondly, the study employed a logistic regression model that included dietary factors to assess the risk of NAFLD, thereby illustrating its potential for use in health management and NAFLD prevention initiatives among American adults.

Nevertheless, this investigation is subject to certain inherent limitations. Initially, the cross-sectional design obstructs the establishment of a causal relationship between dietary factors and NAFLD. Secondly, the use of two 24-hour dietary recall datasets may introduce recall bias. Third, we used a previously validated index instead of a clinical diagnosis to determine NAFLD status. We have effectively developed a highly accurate risk prediction model to assess the combined impact of individual dietary factors on NAFLD, despite these limitations.

5. Conclusions

In conclusion, this study demonstrated an inverse association between plant-based dietary retinol intake and NAFLD risk in a national adult population in America. The findings revealed that individual diet information could be applied to explore the risk of NAFLD in American adults. Further prospective studies are required to improve the health lever of human.

Abbreviations

NAFLD	Nonalcoholic Fatty Liver Disease
NHANES	National Health and Nutrition Examination Survey
HDL	High-density Lipoprotein
UA	Uric Acid
BMI	Body Mass Index
NASH	Nonalcoholic Steatohepatitis
HCC	Hepatocellular Carcinoma
USFLI	United States Fatty Liver Index
RAE	Retinol Activity Equivalents
LDL	Low-density Lipoprotein
TC	Total Cholesterol
SD	Standard Deviation
ORs	Odds Ratios
CIs	Confidence Intervals
hs-CRP	High-sensitivity C-reactive Protein
NF-κB	Nuclear Factor-kappa B
PUFAs	Polyunsaturated Fatty Acids

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Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Availability of Data and Materials

The datasets generated for this study is available in online repositories. The repository/repositories name and accession number(s) can be found below: https://www.cdc.gov/nchs/nhanes/index.htm.

Conflicts of Interest

The authors declare that they have no competing interests.

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