Higher lifestyle oxidative balance scores are associated with lower metabolic dysfunction-associated fatty liver disease and fibrosis risk in US adults, while dietary scores lack impact on fibrosis.

Keywords
liver fibrosis, Metabolic dysfunction associated steatotic liver disease, oxidative balance score, lifestyle oxidative balance score

Abstract

Introduction
Metabolic dysfunction related steatotic liver disease (MASLD) is a long-term liver disease.Oxidative stress plays a key role in MASLD. The oxidative balance score (OBS) measures oxidative and reactive stress, but its relationship with MASLD and fibrosis remains unclear.

Material and methods
The National Health and Nutrition Examination Survey records from 1999 to 2018 were used in this study. We used weighted multivariate logistic regression, subgroup studies, and limited cubic spline regression to look at the links between OBS and MASLD and fibrosis. Sensitivity studies were done to see how strong the results were.

Results
A total of 12,272 people enrolled in the study.There was a strong negative relationship between OBS and MASLD, and all p values for interactions were less than 0.05.After adjusting for potential confounders, people with higher OBS had a lower chance of MASLD (OR=0.37, 95%CI(0.27–0.51), p for trend <0.001).Then,the stratified studies showed that lifestyle OBS was significantly linked to MASLD in both men and women, but dietary OBS was only significantly linked to MASLD in men (OR=0.95, 95%CI(0.93, 0.98), p<0.001).Finally, lifestyle OBS showed a strong association with MASLD-related fibrosis (OR = 0.37, 95%CI (0.24, 0.56), p for trend < 0.0001). In the subgroup studies, the findings stayed consistent.

Conclusions
OBS was linked to a lower chance of MASLD, and lifestyle OBS showed strong protective effects against MASLD and fibrosis. Because of this, people who have MASLD and fibrosis should focus on researching and looking into antioxidant treatment that is based on dietary and lifestyle, with particular emphasis on lifestyle factors.

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Keywords: Metabolic dysfunction associated steatotic liver disease;liver fibrosis; oxidative balance score; lifestyle oxidative balance score

1.Introduction

Nonalcoholic fatty liver disease (NAFLD), a prevalent chronic liver condition characterized by abnormal fat buildup in the liver, is closely associated with metabolic syndrome [1]. The prevalence of NAFLD is continuously on the rise, with around 25% of the global population currently affected [2]. As a result, NAFLD has become a significant public health concern [3-4].In 2020, it was suggested that the name and description of NAFLD should be changed to metabolic dysfunction related steatotic liver disease (MASLD) and that at least one of five cardiometabolic risk factors should be present. This would better reflect the cause of the disease.The term "steatotic liver disease" (SLD) was kept to include all the different causes of steatosis, such as MASLD, MetaALD (people with MASLD who drink more alcohol), Other specific aetiology SLD (like alcoholic liver disease(ALD), drug-induced liver injury(DILD), and monogenic diseases), and cryptogenic SLD (with no metabolic parameters and no known cause)[5]. Oxidative stress (OS) plays a significant role in MASLD as indicated by a recent study[6]. It is characterized by an imbalance between pro-oxidants and antioxidants,, which leads to more reactive oxygen species (ROS) in redox processes. ROS can damage lipids, proteins, and DNA through oxidative damage[7-8].Prior research has shown that getting more of certain nutrients, like calcium, vitamin E,D and C, zinc, magnesium, and selenium, makes you less likely to get oxidative stress (OS). In contrast, bad habits like smoking and drinking too much alcohol increase the production of reactive oxygen and nitrogen species (RONS), which speeds up the cell harm linked to OS[9-11].However, because pro-oxidants and antioxidants work with each other in a complicated way, a single OS-related factor has a small impact on the oxidative/antioxidant system.The oxidative balance score (OBS) was created to measure a person's oxidative and antioxidant state. It has two parts: the dietary OBS and the lifestyle OBS[12].

OBS is negatively associated with a variety of diseases, such as metabolic syndrome, hypertension,chronic kidney disease,and so on. However, few

observational studies have investigated the association of OBS risk with MASLD and fibrosis. The study hypothesizes that OBS, including dietary OBS and lifestyle OBS, are negatively correlated with MASLD and MASLD-related fibrosis. Using data from the National Health and Nutrition Examination Survey (NHANES), this study goes on to find that a different result is more likely.

2.Materials and methods

2.1 Study population

This cross-sectional study included subjects from the nationally representative consecutive NHANES 1999 - 2018.To ensure a representative sample, we consolidated sociodemographic information, personal life history, dietary records, and laboratory data from ten cycles of the NHANES. Of the 59204 subjects who aged 20 years or older in the NHANES 1999-2018,individuals were excluded if (1) missing data on the US fatty liver index (US FLI)、Fibrosis-4 Index (FIB-4) or NAFLD fibrosis score(NSF) (n=35029); (2)with a history of excessive alcohol consumption (>2 drinks/day and >3 drinks/day for women and men respectively) (n=2259);(3)and exhibiteding any indication of other causes of chronic liver disease such as MetALD, viral hepatitis infection, autoimmune hepatitis, liver cancer or cryptogenic SLD (n =2977); (4) less than 16 items for a total of 20 components of the OBS (n = 939);(5)missing data on several covariates and weighting(n =4588);(6) we further excluded 499 participants with pregnant, and 641 participants who had missing diet data or extreme diet data (total energy intake of <800 or >4200 kcal day− 1 for males and <500 or >3500 kcal day− 1 for females).The percentage of missing data for each covariate was less than 5%,so missing values were not imputed. Ultimately, a total of 12272 subjects were enrolled in this research (Fig. 1).

The National Centre for Health Statistics' Ethical Review Committee approved NHANES, and all participants provided written informed consent. This research adhered to the applicable guidelines and regulations (https://www.cdc.gov/nchs/data_access/restrictions.htm).

2.2. MASLD and liver fibrosis assessment

The US fatty liver index (USFLI) was used to define MASLD in this study and was derived specifically for the NHANES database,with a cut-off of 30 to define MASLD [13].In addition,we calculated the Fibrosis-4 (FIB-4) score and MASLD fibrosis score(NSF) to assess liver fibrosis,and participants with FIB-4 scores≥2.67 or NFS > 0.676 were considered to have liver fibrosis[14].The formulas of USFLI and FIB-4 can be found in Supplementary Table 3.

2.3. Oxidative balance score

The OBS was made by adding up the numbers for each of the four lifestyle factors and the 16 nutrients, which include 5 pro-oxidants and 15 antioxidants.We found out how much of 16 nutrients people ate, such as fiber, total fat, carotene, riboflavin, niacin, calcium, zinc, magnesium, copper, selenium, iron, total folate, vitamins B12, C, and E, by asking people to remember what they ate for 24 hours. The estimate did not take into account dietary supplements or medicine sources. Physical exercise, body mass index (BMI), alcohol use, and smoking (nicotine amounts) were all lifestyle-based OBS factors [9]. Total fat, iron, drinking booze, smoking, and BMI were all thought to be pro-oxidants. Three groups were made up of people who drank alcohol: heavy drinkers (15 g/d for women and 30 g/d for men), light drinkers (0 to 15 g/d for women and 0 to 30 g/d for men), and nondrinkers. The questions in this section covered lifetime and recent (past 12 months) use of alcohol for ages 20 years and over. Each group was given a score between 0 and 1, and the nondrinkers got a score of 2 [9]. Then, the other parts were split into three groups based on their tertile. Antioxidants were assigned a score on a scale from 0 to 2, with the lowest tertile (tertile 1) receiving 0 points, the middle tertile (tertile 2) receiving 1 point, and the highest tertile (tertile 3) receiving 2 points. In contrast, the scoring for prooxidants was structured in an inverse manner. The highest tertile, which represents the greatest concentration or presence of prooxidants, was assigned 0 points, and the lowest tertile was given 2 points, reflecting the higher score for lower levels of prooxidants[9]. The groups were then split into two groups based on sex. The protective effect is stronger when the OBS score is higher.

2.4. Covariates

In our study,we have selected several variables previously displayed or may influence MASLD or OBS and collected the following information：age, sex , race (Mexican American,Other Hispanic, Non-Hispanic black, Non-Hispanic white, Other race including multiracial), education, marital status (having partner, no partner, unmarried), and poverty-to-income ratio (PIR) (<1.3, 1.3 to 3.5, >3.5), fasting glucose, fasting insulin, glycated hemoglobin, homeostasis model assessment insulin resistance (HOMAIR,=fasting glucose (mmol/L) * fasting insulin (mU/mL)/22.5), total cholesterol (TC), triglycerides (TG),high-density lipoprotein (HDL) and low-density lipoprotein (LDL), C-reactive protein (CRP),alanine aminotransferase, aspartate aminotransferase, gamma-glutamyl transferase,the 2015 version of the Healthy Eating Index (HEI) and total energy intake, hypertension, diabetes, and cardiovascular disease.

2.5. Statistical analysis

The scoring for this study was based on guidance from the Centers for Disease Control and Prevention (CDC). The data came from forms 1999–2000 and 2001–2002, so the formula was 2/5* WTDR4YR(Dietary day one 4-Year sample weight) or 3/5* WTDRD1(Dietary day one 2-Year sample weight) to take into account the NHANES's complex multistage cluster survey design.During data handling and analysis, we made sure that continuous variables had a normal distribution. For variables with a normal distribution, we used the weighted mean ± standard error (SE), and for variables with a nonnormal distribution, we used the interquartile range (IQR).Next, the weighted one-way ANOVA or Kruskal–Wallis's H tests were used to look at continuous variables. The weighted chi-square tests were used to look at categorical variables, which were given as numbers (weighted percentages).It was broken up into quartiles, with Q1 being the lowest (13–13), Q2 being the next lowest (13–19), Q3 being the next lowest (19–25), and Q4 being the highest (25–37).We looked at the link between different OBS and MASLD and MASLD-related fibrosis using weighted logistic regression models. The OBS were broken down into two

groups: dietary OBS and lifestyle OBS. In the unadjusted model, no factors were modified, while Model 1 was adjusted for age, sex, race, marital status,education, PIR, smoking status and alcohol intake. To assess trends, the median value of each variable was also used. Moreover, Model 2 included additional adjustments for SII and total energy intake (kcal), while Model 3 was further adjusted for ALT, ASST, GGT, Scr, BUN, total energy, TC, glucose, TG, DM, CVD, hypertension and stroke.Subgroup analyses were also done based on race, gender, age, family income to poverty ratio, amount of schooling, and marriage status.Once all of Model 3's factors had been changed, restricted cubic splines (RCS) were used to look at nonlinear relationships and show general trends between the different OBS and MASLD. Also, to test how stable the data were, sensitivity studies were done by taking out one part of the overall OBS at a time. A two-tailed p number less than 0.05 was thought to be statistically significant. R version 4.3.1 was used for all statistics studies (http:// www.R-project.org).

3. Results

3.1. Baseline characteristics

A total of 12,272 individuals participated in this study. Of these, 3,480 had MASLD, comprising 28.35% of the study sample.In Table 1, the baseline features of the subjects are shown, grouped by OBS quartiles.In the study, the average age of the people who took part was 50.34±0.29 years, and 72.47% of them were non-Hispanic white.

People in the top quartile of OBS were younger and more likely to be Non-Hispanic White (78.04%) than people in the bottom quartile of OBS.People in the highest OBS quartile were wealthier, had more schooling, ate more, had higher HEI, higher HDL, lower CRP, lower GGT, lower LDH, lower CRP, lower HOMA IR, and were more likely to have partners than people in the lowest OBS quartile. The sex difference between the OBS groups was not important from a statistical point of view. As OBS went up, the number of people with MASLD and its associated diseases, such as

diabetes, high blood pressure, heart disease, stroke, and fibrosis caused by MASLD, slowly went down.

3.2. Association between different OBS and MASLD and MASLDrelated fibrosis

Table 2 shows the relationships between different OBS and MASLD, as well as MASLD related fibrosis. This study using weighted logistic regression analysis discovered a significant negative association between various OBS and MASLD. First, in Model 3 with all the changes made, the highest quartile of OBS (OR=0.37(0.27,0.51), $p < 0.001$) was more strongly linked to a lower risk of MASLD than the lowest quartile of OBS (OR=0.77(0.62,0.97), p=0.03). Second, the risk of MASLD went down with higher lifestyle OBS (OR=0.14(0.10–0.19), $p< 0.0001$).Lastly, having more dietary OBS was linked to a lower chance of MASLD (OR=0.48(0.36,0.66), $p< 0.0001$).Statistically, the falling trend was important ($p < 0.05$ for all trends), as shown by the trend test. While both the OBS and lifestyle OBS were negatively associated with fibrosis, no significant link was found between fibrosis and dietary OBS in MASLD patients (OR = 0.72(0.48, 1.08), p = 0.08).

3.3.Stratification and sensitivity analyses

We conducted stratification analyses to assess the robustness of the association between different OBS and MASLD and related fibrosis(Fig.2 and Supplementary Table 2A-B).When stratified by age and sex, the results showed that OBS was negatively associated with the prevalence of MASLD in all levels，but there was no inconclusive association between OBS and MASLD related fibrosis. Additionally, dietary OBS showed a significant negative association with MASLD, especially in men. When we separated the results by family income to poverty ratio (PIR) and education level, we saw that both OBS and dietary OBS were significantly linked to MASLD in people whose PIR was higher than 3.5 (OR=0.95(0.93,0.97)), or more than high school (OR=0.93(0.92,0.95)), or more than high school (OR=0.96(0.94,0.98)).On top of that, we discovered that the lifestyle OBS was strongly linked to MASLD and fibrosis at all stages.We did sensitivity studies by

taking out each OBS component one at a time, and the MASLD values stayed the same (Supplemental Table 1). But when body mass index, physical exercise, copper, magnesium, and vitamin C were taken out, the results for MASLD-related fibrosis were not clear and could not be interpreted in a useful way.We also found that eating OBS and lifestyle OBS did not affect each other in the whole group (p for interaction=0.677).

3.4. Analysis of restricted cubic spline regression

We found a nonlinear relationship between OBS and MASLD in restricted cubic spline regression (RCS) (Figure.3; p for nonlinear =0.0001; Figure.3A). We also found a significant nonlinear relationship in women and people aged 20 to 60 (p for nonlinear =0.0012; p for nonlinear =0.0001; Figure.3B and 3C).This picture (Fig. 2A, 2B, and 2C) shows that the risk of MASLD went down as OBS went up. This trend was seen in both men and patients aged 60 and up.Lifestyle OBS was linked to a lower risk of MASLD in a way that wasn't linear (p for nonlinear < 0.0001, Figure.3D), and this link stayed the same for both male and female subgroups and all age groups (p for nonlinear < 0.0001, Figure.3E and 3F).There was a negative linear relationship between dietary OBS and the chances of MASLD (P for nonlinear = 0.2923; Fig. 3H). There was also a negative linear relationship between dietary OBS and MASLD in different age or gender groups and in patients aged 60 or more (Fig. 3I and 3J). The nonlinear analysis of the RCS gave slightly different results, but the overall trends of the dependent and independent factors were generally negative.

4.Discussion

We did a cross-sectional study of 12272 people in the NHANES dataset to find out more about the link between OBS and MASLD.We saw that total OBS and lifestyle OBS were both linked to a lower chance of MASLD and fibrosis. This supports the idea that OBS has a major effect on the development and worsening of MASLD, and the link was the same for both men and women.Our research also discovered that having higher OBS and lifestyle OBS scores is not always linked to a lower chance of MASLD.Our research showed that dietary OBS were negatively

linked to the number of cases of MASLD but not to fibrosis related to MASLD. Also, dietary OBS were only negatively linked to MASLD in men.A previous study showed that women may have a better antioxidant capacity than men. This could be because estrogen has antioxidative effects and antioxidant enzyme activity varies between men and women [15,16]. It's not clear what exactly causes these differences between men and women, but they may have something to do with oxidative stress and the biology of MASLD [17]. Dietary habits and quality of life are both important factors that affect MASLD, but they may have a bigger effect on men.

Several oxidative stress biomarkers, including malondialdehyde and nitric oxide, were found to be higher in the serum of people with MASLD compared to controls. At the same time, concentrations of several antioxidant biomarkers, including glutathione, glutathione peroxidase, and super oxide dismutase, were significantly lower [18,19]. In the pathophysiology of MASLD/NASH, hepatic lipotoxicity leads to failure in several ROS-producing cell compartments. This causes too much production and release of ROS, which throws off the balance of redox signals. Also, more and more clinical evidence suggests that adding a variety of antioxidants to a person's diet, such as beta-carotene, vitamins A, E, and C, along with making lifestyle changes like doing aerobic exercise, may help improve some clinical indicators by lowering oxidative stress in MASLD/NASH patients[20,22]. Since there aren't many accepted drug treatments for MASLD, changes to dietary and lifestyle are still the most important things that people can do to help.[23]. The OBS is very useful because it can be used to check a person's general redox balance. A lot of different study groups have looked into how it might be linked to different metabolic illnesses or conditions. For example, studies have shown that a higher OBS is linked to a lower chance of having new-onset hypertension and metabolic syndrome. It is also linked to better control of blood sugar, especially in adults with type 2 diabetes.[24-26].The aim of this study was to find out how OBS, which shows the balance of pro-oxidants and antioxidants, is related to the number of cases of MASLD. As with other studies [27], OBS in ours has parts that have been studied before, like dietary fiber, total fat, carotene, riboflavin, niacin, calcium, zinc, magnesium, copper, selenium, iron, total

folate, vitamins B12, C, and E, as well as information about smoking, physical activity, body mass index (BMI), and total folate.Even when all the other factors that were looked at were taken into account, OBS was still linked to the chance of MASLD and fibrosis. In the Q4 population, the chance of MASLD and fibrosis was 63% and 40% lower than in the Q1 population with OBS (p trend<0.0001).

Higher lifestyle OBS and dietary OBS were each independently linked to a lower risk of MASLD, showing reductions of around 86% and 52% in the population with OBS in the Q4 quartile compared to Q1, respectively. Notably, the chance of fibrosis was 63% lower in Q4 compared to the group with lifestyle OBS in Q1. However, dietary OBS was not linked to fibrosis in people with MASLD.So, lifestyle OBS seems to be linked to a lower chance of MASLD and fibrosis more than dietary OBS. The results of this study agree with those of a recent study using NHANES III[28], which found that dietary factors are less important than physical exercise for the outcome of people with MASLD.The basic processes are still not clear, so they need to be looked into more in future studies.

To learn more about the complex connection between different OBS and the risk of MASLD, we used restricted cubic splines . The links between OBS and lifestyle OBS and MASLD risk were not linear (p for nonlinearity <0.0001). For OBS, the turning point was 19 points, and for lifestyle OBS, it was 5 points. After achieving 19 and 5 points, respectively, threshold effect analysis showed that OBS and lifestyle OBS were tied to a significant drop in MASLD risk. The way MASLD patients are treated might change because of these results.

Stratified analysis showed that all p-values for interaction were greater than 0.05 across different subgroups, hence indicating that the link between OBS and risk of MASLD was consistent regardless of individual characteristics. These results also suggest that OBS, particularly lifestyle OBS, may reduce MASLD risk across diverse populations. It's interesting that the P value for interaction was less than 0.05 for age groups when we looked into how lifestyle OBS affected the risk of fibrosis in those groups.After that, we looked for interactions and found that lifestyle OBS was more

strongly linked to the risk of fibrosis in people aged 41 or older, who were most likely to benefit from a diet and lifestyle high in antioxidants (OR=0.8(0.7, 0.9)P<0.001).

Also, tests that took away each OBS component one at a time showed that the results of MASLD stayed the same. The factors that had the biggest effect on preventing fibrosis were vitamin C, magnesium, copper, physical exercise, and BMI. A new study from NHANES found a strong link between higher serum copper levels and a higher chance of both starting and getting worse MASLD and other metabolic disorders[29].A study in the U.S. population found a strong link between blood vitamin C levels and better scarring in people with MASLD [30,31].A lot of research has shown that exercise can help lower NASH and liver fibrosis by stopping fat from building up in the liver[32,33]. The clinical guidelines also say that people with MASLD should eat well and exercise to lose weight [34].

This study has a lot of good points. In the first place, the OBS as a whole gives a more complete picture of a person's total pro-oxidant and antioxidant intake. Second, the NHANES data was chosen using a complicated multi-stage chance sampling method, and it shows the general population of the US. Third, many other factors were taken into account in this study to greatly lessen the impact of factors that could have caused confusion. Fourth, sensitivity and stratified studies showed that our results were stable, and limited cubic spline regression helped us understand the relationships better.

However, our work has some limitations as well. In the first place, it might be hard to find a cause-and-effect link since the study was cross-sectional. This needs to be shown in future studies through large-scale prospective cohort studies and randomized controlled trials. Second, since the study only looked at people in the US, more research is needed to see if the results can be applied to people in other countries. Third, one big problem with this study is that it doesn't use liver biopsies to diagnose MASLD and fibrosis. Instead, it uses non-invasive markers, which could make the results less accurate. But liver biopsy is expensive, can have problems, and can't be used in large population-based studies. Non-invasive methods, on the other hand, are a good alternative that has been shown to be accurate [35]. Diagnosis using

non-invasive scores is well understood, and these effects probably won't change how reliable the results are. Additionally,, dietary OBS scores were calculated using a 24-hour dietary memory interview, which could have been skewed by remember bias. We also used two 24-hour dietary records to do sensitivity analyses, but the results of all the analyses in this study stayed pretty much the same. In the end, the dietary culture in the U.S. differs greatly from other countries, with fast food, processed foods, and high sugar and fat intake being common. In contrast, many other countries (e.g., Mediterranean and Asian nations) emphasize fresh foods, vegetables, and fruits. While the U.S. has abundant food supply in supermarkets and fast food chains, other countries may rely more on seasonal or self-sustaining diets. These differences could lead to inaccurate conclusions when using NHANES data for international comparisons.

Conclusion

It was concluded that OBS was linked to a lower chance of MASLD. Notably, both dietary and lifestyle OBS helped lower the risk of MASLD incidence, both on their own and together. Also, the higher lifestyle OBS was better than the dietary OBS at lowering the number of cases of MASLD-related fibrosis. Lifestyle OBS showed strong protective benefits for MASLD and fibrosis linked to MASLD. Our results show that following an antioxidant-rich lifestyle and dietary is a good way to stop MASLD from happening.

Consent for publication

Not applicable.

Availability of data and materials

All the data generated or analyzed during this study are available from the NHANES.

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Authors' contributions

JF is responsible for making sure that the whole study is honest; YC is in charge of planning the study, doing the statistics, writing the paper, and correcting it. NC is in

charge of planning the study, defining the intellectual content, analyzing the data, and reviewing the paper. YWC is in charge of researching the books and gathering data.

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Ethics approval and consent to participate

No one has to pay to get any information from the NHANES service,without raw data collection, so ethics committee approval is not necessary.All data sources included in this study complied with local laws and all participants signed informed consent.

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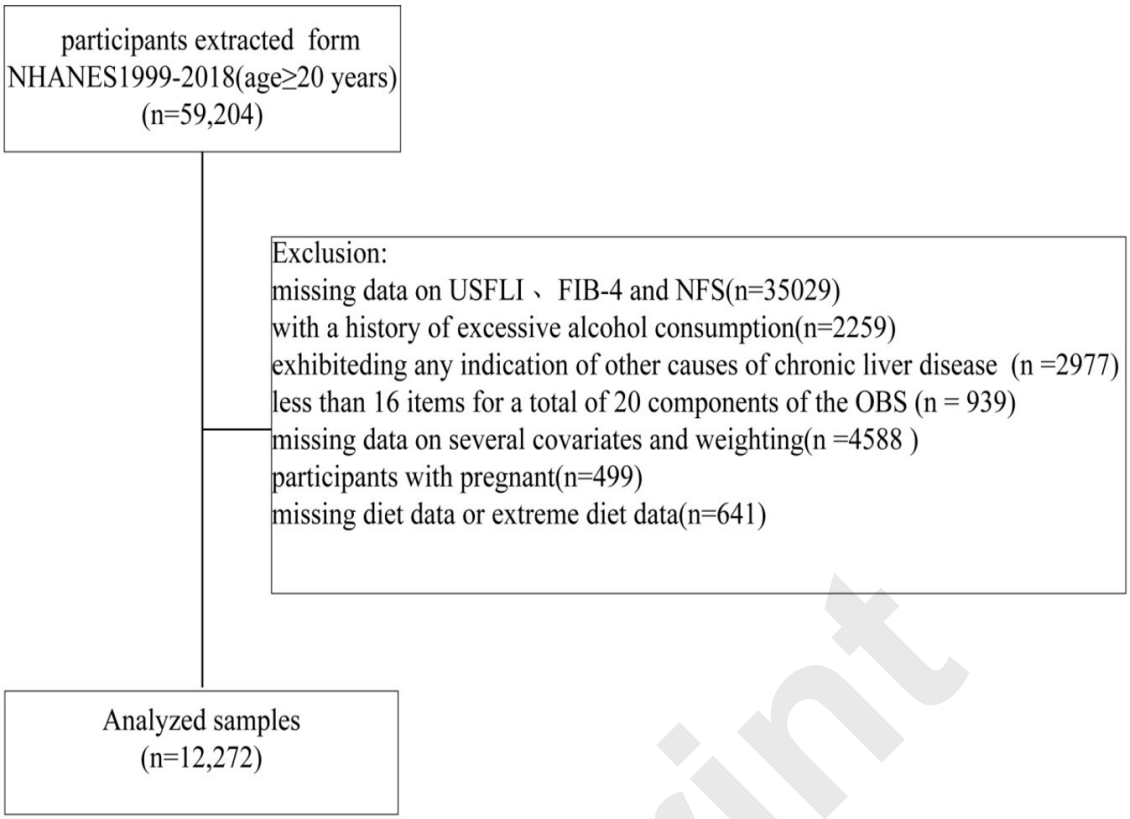

participants extracted form NHANES1999-2018(age≥20 years) (n=59,204)
Exclusion:
missing data on USFLI、FIB-4 and NFS(n=35029)
with a history of excessive alcohol consumption(n=2259)
exhibiteding any indication of other causes of chronic liver disease (n =2977)
less than 16 items for a total of 20 components of the OBS (n = 939)
missing data on several covariates and weighting(n =4588)
participants with pregnant(n=499)
missing diet data or extreme diet data(n=641)
Analyzed samples (n=12,272)

Table 1 The baseline characteristics by quartiles of the OBS: NHANES 1999-2018

Variable	total	Q1	Q2	Q3	Q4	Pvalue
Age	50.34±0.29	50.68±0.47	51.41±0.52	49.85±0.49	49.57±0.53	0.03
Sex n(%)						0.06
Female	6468(53.38)	1592(54.95)	1656(50.88)	1728(52.68)	1492(55.30)	
Male	5804(46.62)	1503(45.05)	1569(49.12)	1547(47.32)	1185(44.70)	
Race n(%)						< 0.0001
Mexican American	1807(5.96)	429(5.96)	509(6.37)	477(5.78)	392(5.76)	
Other Hispanic	894(4.24)	207(4.40)	237(4.75)	246(3.96)	204(3.95)	
Non-Hispanic Black	2440(10.19)	910(17.59)	680(11.86)	534(7.87)	316(5.23)	
Non-Hispanic White	6042(72.47)	1350(64.73)	1537(70.80)	1676(74.47)	1479(78.04)	
Other Race - Including						
Multi-Racial	1092(7.13)	199(7.28)	263(6.21)	344(7.92)	286(7.01)	
Marital status n(%)						< 0.0001
Having a partner	7807(66.70)	1818(60.72)	2043(64.91)	2143(67.99)	1803(71.77)	
No partner	2741(18.82)	808(22.74)	734(20.50)	701(18.42)	498(14.53)	
Unmarried	1724(14.48)	469(16.54)	448(14.59)	431(13.59)	376(13.71)	
Ratio of family income to poverty n(%)						< 0.0001
<1.3	3258(18.33)	1054(27.44)	890(19.44)	759(15.17)	555(13.48)	
1.3-3.5	4728(35.27)	1310(41.51)	1278(37.77)	1250(34.53)	890(28.68)	
>3.5	4286(46.40)	731(31.05)	1057(42.79)	1266(50.30)	1232(57.84)	
Education n(%)						< 0.0001
Less than high school	2889(14.67)	1006(22.86)	829(16.81)	690(12.70)	364(8.25)	

High school	2729(22.94)	828(30.48)	752(26.69)	686(20.88)	463(15.61)	
More than high school	6647(62.36)	1259(46.66)	1642(56.50)	1897(66.41)	1849(76.14)	
Smoke n(%)						< 0.0001
Former	3273(26.54)	796(25.13)	887(26.25)	872(26.73)	718(27.76)	
Never	7118(58.29)	1560(49.64)	1827(57.33)	1989(60.67)	1742(63.57)	
Now	1875(15.14)	736(25.23)	510(16.42)	413(12.60)	216(8.67)	
Alcohol consumption n(%)						< 0.0001
never	2126(14.10)	557(16.17)	592(16.07)	562(13.34)	415(11.37)	
former	2809(18.98)	891(26.07)	769(19.39)	673(17.21)	476(14.85)	
mild	5602(49.75)	1212(40.61)	1437(48.86)	1585(52.62)	1368(54.74)	
moderate	1735(17.18)	435(17.16)	427(15.68)	455(16.82)	418(19.04)	
Total energy, kcal/d	2027.49±10.98	1432.19±15.43	1836.37±18.08	2185.63±15.38	2512.74±19.56	< 0.0001
Healthy eating index(2015)	51.23(41.63,61.08)	43.06(35.33,51.45)	48.15(39.68,57.11)	51.98(42.81,61.12)	59.92(51.17,68.92)	< 0.0001
ALT IU/L	20.00(16.00,27.00)	20.00(15.00,27.00)	20.00(16.00,26.00)	21.00(16.00,27.00)	20.00(16.00,27.00)	0.01
AST IU/L	22.00(19.00,26.00)	22.00(19.00,26.00)	22.00(19.00,26.00)	22.00(19.00,26.00)	23.00(20.00,27.00)	0.002
GGT IU/L	64.00(52.00,78.00)	67.00(56.00,84.00)	65.00(54.00,79.00)	62.00(51.00,77.00)	61.00(50.00,74.00)	< 0.0001
TG mg/dl	102.00(71.00,151.00)	111.00(76.00,162.00)	104.00(75.00,152.00)	102.00(72.00,154.00)	93.00(64.00,137.00)	< 0.0001
TC mg/dl	192.00(166.00,221.00)	192.00(165.00,222.00)	194.00(166.00,221.00)	193.00(167.00,222.00)	191.00(165.00,217.00)	0.44
Scr mg/dl	0.86(0.72,1.00)	0.86(0.73,1.01)	0.88(0.73,1.00)	0.84(0.72,1.00)	0.85(0.71,0.98)	< 0.001
BUN mg/dl	5.30(4.40,6.30)	5.50(4.60,6.50)	5.40(4.50,6.40)	5.30(4.40,6.20)	5.10(4.30,6.00)	< 0.0001
CRP mg/dl	0.18(0.07,0.42)	0.25(0.10,0.58)	0.19(0.08,0.45)	0.17(0.08,0.40)	0.13(0.06,0.31)	< 0.0001
HLD mg/dl	52.00(43.00,64.00)	49.00(41.00,60.00)	52.00(44.00,62.00)	52.00(43.00,64.00)	56.00(45.00,67.00)	< 0.0001
LDL mg/dl	113.00(91.00,138.00)	115.00(91.00,140.00)	114.00(92.00,140.00)	113.00(92.00,138.00)	111.00(89.00,134.00)	0.02
HOMA IR	2.13(1.34,3.65)	2.41(1.50,4.11)	2.24(1.42,3.86)	2.10(1.33,3.62)	1.80(1.15,3.13)	< 0.0001
Glucose, mg/dL	5.50(5.11,5.98)	5.55(5.16,6.11)	5.55(5.16,6.05)	5.50(5.15,5.94)	5.39(5.05,5.83)	< 0.0001
Insulin, U/mL	8.50(5.60,13.82)	9.59(6.29,15.58)	8.86(5.89,13.93)	8.41(5.56,13.87)	7.51(4.76,12.20)	< 0.0001

DM n(%)						< 0.0001
No	8128(69.92)	1952(66.49)	2041(66.17)	2234(71.56)	1901(74.44)	
IFG	1057(8.41)	277(9.00)	278(9.34)	292(7.70)	210(7.82)	
IGT	761(6.57)	174(5.82)	213(6.86)	199(7.04)	175(6.36)	
DM	2326(15.11)	692(18.70)	693(17.63)	550(13.69)	391(11.38)	
CVD n(%)						< 0.0001
No	10830(90.16)	2596(86.67)	2834(88.59)	2954(92.16)	2446(92.26)	
Yes	1442(9.84)	499(13.33)	391(11.41)	321(7.84)	231(7.74)	
Hypertension n(%)						< 0.0001
No	6851(60.30)	1538(53.25)	1736(57.35)	1882(61.87)	1695(67.10)	
Yes	5418(39.67)	1555(46.75)	1488(42.65)	1393(38.13)	982(32.90)	
Stroke n(%)						< 0.0001
No	11771(96.70)	2904(94.83)	3097(96.54)	3167(97.26)	2603(97.96)	
Yes	491(3.24)	189(5.17)	126(3.46)	107(2.74)	69(2.04)	
MASLD n(%)						< 0.0001
NO	8792(73.49)	2101(68.89)	2261(71.45)	2331(72.87)	2099(79.82)	
YES	3480(26.51)	994(31.11)	964(28.55)	944(27.13)	578(20.18)	
Liver_Fibrosis						< 0.0001
no	11101(92.62)	2711(89.93)	2882(91.07)	3019(94.14)	2489(94.60)	
yes	1171(7.38)	384(10.07)	343(8.93)	256(5.86)	188(5.40)	

ALT, alanine aminotransferase; AST, aspartate transaminase; GGT, g -glutamyl transferase; TG, triglycerides; TC, total cholesterol; HDL, high-density lipoprotein; LDL, low-density lipoprotein; HOMA IR, homeostasis model assessment insulin resistance; ; CRP, C-reactive protein; OBS, oxidative balance score; FIB-4, Fibrosis - 4 Index.

Table 2 The associations between different OBS and NAFLD and NAFLD-related fibrosis

	Q1	Q2	Q3	Q4	p for trend
MASLD					
OBSQ					
crude model	ref	0.88(0.75,1.04)	0.82(0.69,0.99)	0.56(0.47,0.66)	<0.0001
Model 1	ref	0.81(0.68,0.97)	0.81(0.67,0.98)	0.55(0.45,0.68)	<0.001
Model 2	ref	0.66(0.55,0.79)	0.54(0.44,0.68)	0.31(0.24,0.40)	<0.0001
Model 3	ref	0.77(0.62,0.97)	0.62(0.48,0.80)	0.37(0.27,0.51)	<0.001
OBS.lifestyleQ					
crude model	ref	0.54(0.46,0.63)	0.47(0.39,0.57)	0.12(0.09,0.16)	<0.0001
Model 1	ref	0.42(0.35,0.51)	0.35(0.28,0.44)	0.08(0.06,0.10)	<0.0001
Model 2	ref	0.42(0.35,0.51)	0.35(0.28,0.44)	0.08(0.06,0.10)	<0.0001
Model 3	ref	0.49(0.39,0.62)	0.51(0.39,0.68)	0.14(0.10,0.19)	<0.0001
OBS.dietaryQ					
crude model	ref	0.92(0.77,1.09)	0.90(0.76,1.07)	0.74(0.62,0.87)	0.001
Model 1	ref	0.88(0.73,1.07)	0.94(0.78,1.14)	0.80(0.64,0.98)	0.07
Model 2	ref	0.75(0.61,0.92)	0.71(0.56,0.89)	0.52(0.40,0.68)	<0.0001
Model 3	ref	0.74(0.57,0.95)	0.69(0.54,0.90)	0.48(0.36,0.66)	<0.0001
MASLD-related fibrosis					
OBSQ					
crude model	ref	0.88(0.70,1.09)	0.56(0.45,0.69)	0.51(0.39,0.67)	<0.0001
Model 1	ref	0.88(0.68,1.14)	0.66(0.52,0.84)	0.68(0.51,0.91)	0.002
Model 2	ref	0.87(0.67,1.13)	0.62(0.45,0.84)	0.60(0.42,0.87)	0.003
Model 3	ref	0.93(0.69, 1.25)	0.73(0.53, 1.02)	0.60(0.40, 0.91)	0.01
OBS.lifestyleQ					
crude model	ref	0.60(0.46,0.77)	0.52(0.39,0.70)	0.38(0.28,0.52)	<0.0001
Model 1	ref	0.46(0.35,0.61)	0.47(0.35,0.64)	0.33(0.24,0.46)	<0.0001
Model 2	ref	0.44(0.33,0.59)	0.46(0.33,0.63)	0.31(0.22,0.43)	<0.0001
Model 3	ref	0.49(0.36, 0.67)	0.56(0.38, 0.84)	0.37(0.24, 0.56)	<0.0001
OBS.dietaryQ					
crude model	ref	0.93(0.73,1.17)	0.62(0.49,0.77)	0.58(0.44,0.75)	<0.0001
Model 1	ref	0.98(0.75,1.28)	0.76(0.60,0.97)	0.82(0.62,1.07)	0.04
Model 2	ref	0.98(0.74,1.29)	0.76(0.57,1.01)	0.78(0.56,1.09)	0.07
Model 3	ref	1.01(0.73, 1.40)	0.83(0.61, 1.14)	0.72(0.48, 1.08)	0.08

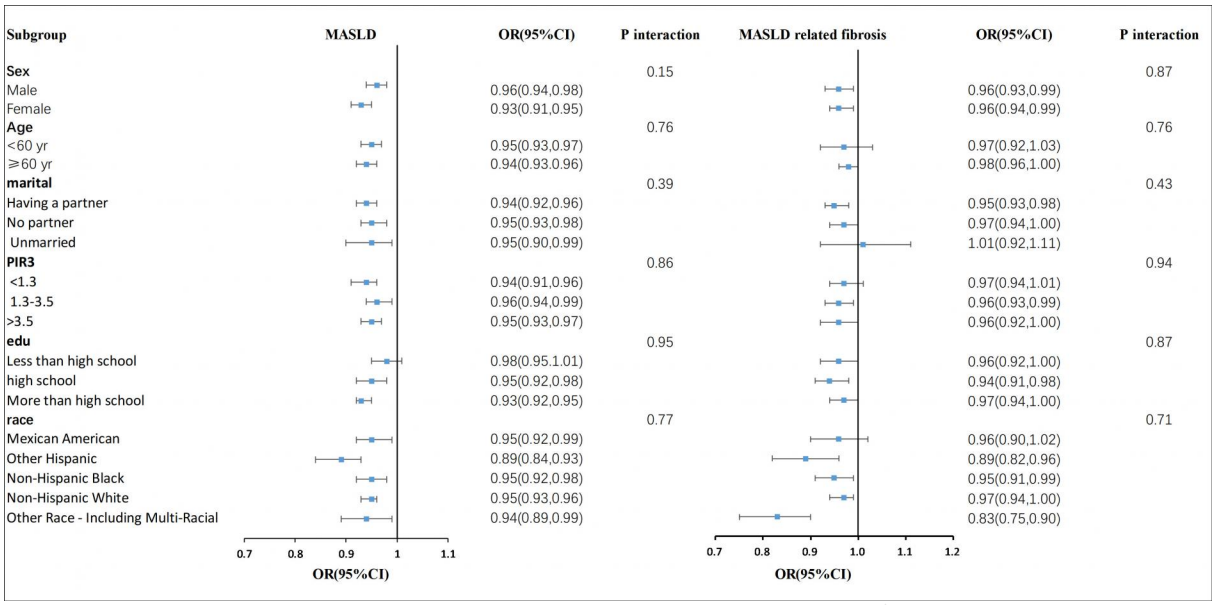
crudel model: Unadjusted model.

model 1: Adjusted for age, sex, race, marital status, PIR, education, smoke, alcohol.user

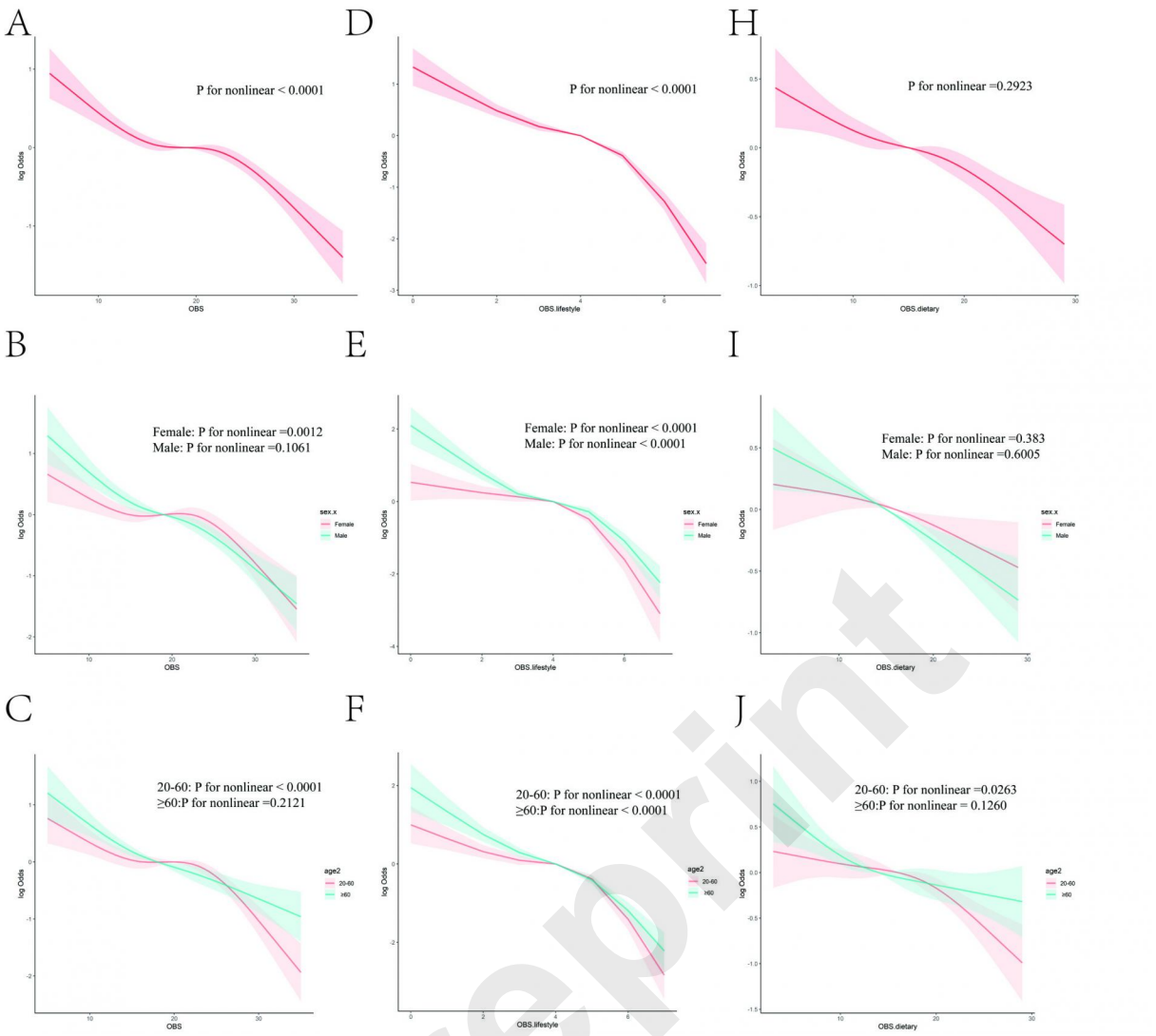
model 2: Additionally adjusted for SII, energy_kcal

model 3: Additionally adjusted for ALT, AST, GGT, Scr, BUN, Total energy, TC, Glucose, TG,DM, CVD, Hypertension, Stroke.

Test for trend based on the variable containing a median value for each quartile.



Subgroup analysis of associations between OBS and odds of MASLD and MASLD related fibrosis



Analysis of Restricted Cubic Spline Regression. Adjusted restricted cubic spline models adjusted for age, sex, race, marital status, HEI,PIR, education, smoke, alcohol.user,SII, total energy intake,ALT, AST, GGT, creatinine, BUN, Total energy, TC, Glucose, TG,DM, CVD, Hypertension, Stroke.