



OPEN Current status survey and risk factor analysis of metabolic dysfunction-associated steatotic liver disease among adolescents in Hainan Province

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To investigate the prevalence and associated risk factors of MASLD among adolescents in Hainan Province, providing a scientific basis for formulating targeted prevention and control strategies. A stratified random sampling method was employed to select junior and senior high school students from eight middle schools across five cities in Hainan Province from May to October 2024. A total of 1,750 questionnaires were distributed, with 1,611 valid responses collected (effective recovery rate: 92.06%). Demographic information, lifestyle habits, dietary patterns, fasting abdominal B-ultrasound and FibroScan[®] CAP detection results were collected to diagnose MASLD. Univariate analysis was performed using the χ^2 test, and multivariate analysis was conducted. All participants underwent both examinations, with CAP values only used for severity grading of MASLD-positive cases. The prevalence of MASLD among adolescents in Hainan Province was 7.64%. Multivariate analysis revealed that obesity and overweight ($OR = 1.46$, 95% $CI = 1.38-1.56$, $P < 0.001$), family history of MASLD ($OR = 9.92$, 95% $CI = 4.37-22.54$, $P < 0.001$), (a result with potential overestimation due to small exposed subgroup sample size, $n = 60$), frequent dining out ($OR = 4.72$, 95% $CI = 2.73-8.16$, $P < 0.001$), and regular consumption of hot dogs/grilled skewers ($OR = 2.46$, 95% $CI = 1.39-4.37$, $P = 0.002$) were independent risk factors for MASLD among adolescents. Conversely, regular consumption of fresh vegetables and fruits ($OR = 0.23$, 95% $CI = 0.13-0.42$, $P < 0.001$) was identified as a protective factor. Interactive effect analysis showed that frequent dining out \times frequently staying up late ($OR = 1.34$, 95% $CI: 0.114-1.73$, $P = 0.023$) and overweight \times exercising < 3 times a week ($OR = 1.01$, 95% $CI: 0.379-2.70$, $P = 0.032$) suggest synergistic risk effects, but the 95% CI s cross 1, indicating limited statistical stability; family history of MASLD \times light diet ($OR = 0.14$, 95% $CI: 0.018-1.00$, $P = 0.050$) had a definite protective effect. The overall prevalence of MASLD among adolescents in Hainan Province was 7.64%. Obesity and overweight, family history of MASLD, and frequent dining out were identified as independent risk factors, while regular consumption of fresh vegetables and fruits served as a protective factor.

Keywords Metabolic Dysfunction-Associated Steatotic Liver Disease, Adolescents, Prevalence, Risk Factors, Hainan Province

Abbreviations

MASLD Metabolic Dysfunction-Associated Steatotic Liver Disease

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With rapid global economic development and significant improvements in living standards, dietary patterns and lifestyles have undergone profound changes. Metabolic Dysfunction-Associated Steatotic Liver Disease (MASLD) has emerged as a major global public health concern. Originally more prevalent among adults, MASLD incidence among adolescents has been steadily increasing in recent years¹. Early-stage MASLD often presents without obvious clinical symptoms, leading to its frequent neglect. However, if left untreated, it can progress to liver dysfunction, fibrosis, cirrhosis, and even hepatocellular carcinoma, and is strongly associated with systemic metabolic disorders including insulin resistance, type 2 diabetes mellitus, dyslipidemia and cardiovascular disease. Notably, MASLD is a core component of the emerging Cardiovascular-Renal-Hepatic-Metabolic (CRHM) syndrome framework, which highlights the multi-organ damage cascade induced by metabolic dysfunction. This systemic impact makes the identification of high-risk adolescent populations and early screening particularly crucial, as routine screening for MASLD in adolescents is currently not implemented in clinical practice. MASLD is characterized by excessive fat accumulation in hepatocytes due to metabolic risk factors, involving complex mechanisms such as insulin resistance, lipid metabolism disorders, oxidative stress, lipid peroxidation, chronic inflammation, genetics, malnutrition, and drug factors^{2–4}. These factors interact and collectively contribute to the onset and progression of MASLD. Early-stage MASLD often presents without obvious clinical symptoms, leading to its frequent neglect. However, if left untreated, it can progress to liver dysfunction, fibrosis, cirrhosis, and even hepatocellular carcinoma, posing a significant threat to patient health^{5,6}. Recent research indicates that the occurrence of MASLD in adolescents results from the interplay of genetic, environmental, and lifestyle factors^{7,8}.

Genetic predisposition plays a crucial role, with individuals from families with a history of MASLD facing a significantly higher risk compared to those without such a history⁹. Specific genetic variants or susceptibilities may increase an individual's sensitivity to hepatic fat accumulation, among which gene variants such as PNPLA3, GCKR, TM6SF2, MBOAT7, and HSD17B13 represent core risk loci for hepatic steatosis, inflammation, and fibrosis^{10–12}. However, these genetic risks do not operate in isolation; their effects can be significantly amplified by environmental and metabolic factors such as obesity and unhealthy dietary patterns¹³. Beyond genetics, lifestyle changes, including inadequate physical activity, frequent late nights, and insufficient sleep, have become common among adolescents, severely disrupting normal physiological rhythms and impairing liver metabolic function¹⁴. Furthermore, unhealthy dietary habits, characterized by excessive intake of high-sugar, high-fat, and high-calorie foods and insufficient consumption of dietary fiber and vitamins, are associated with exacerbate liver burden and promote fat accumulation in hepatocytes^{15,16}. Metabolic disorders such as obesity, hypertension, and dyslipidemia are also closely linked to the development of MASLD in adolescents. Obesity, in particular, is a significant risk factor, with overweight adolescents often exhibiting more severe liver fat accumulation¹⁷. Hypertension and dyslipidemia may further be related to aggravate MASLD by affecting liver blood circulation and fat metabolism^{17,18}. The coexistence of these metabolic disorders not only increases the risk of MASLD but also complicates its treatment.

While many countries have conducted epidemiological studies on adolescent MASLD^{19–21}, revealing varying prevalence rates (e.g., 0.7% in children aged 2–4 in North America diagnosed via liver biopsy, 13% in children and adolescents aged 2–19 in the United States, 13% in 17-year-olds in Australia, 5% in children and adolescents aged 7–18 in China, and 2.6% in children aged 2–12 in Japan), research in Hainan Province, China, remains scarce. Given Hainan's unique geographical location, climate, and dietary habits, which may differ from other regions in China, it is essential to fill this research gap. This study aims to conduct a large-scale epidemiological investigation, collecting data on physical indicators, lifestyle habits, dietary patterns, and family medical history among adolescents across different cities and counties in Hainan Province. Through systematic analysis, we aim to reveal the prevalence and risk factors of MASLD among adolescents in Hainan, providing a scientific basis for its prevention and treatment.

Subjects and methods

Study subjects

The study population comprised junior and senior high school students in Hainan Province whose guardians provided informed consent. Inclusion criteria were: residence in Hainan for at least one year, aged 10–19, no history of alcohol consumption, and no use of antibiotics, proton pump inhibitors (PPIs), prednisone, or corticosteroids within the past month. Exclusion criteria were: positive hepatitis B surface antigen or other types of hepatitis; presence of organic diseases (e.g., biliary obstruction, hepatolenticular degeneration, drug-induced liver injury, genetic liver diseases, chronic viral hepatitis, autoimmune liver diseases, cirrhosis); severe renal dysfunction; acute infection or trauma; and long-term hormone use.

Sample size calculation

The required sample size was estimated using a cross-sectional epidemiological formula and SPSS 26.0 software. Based on previous epidemiological findings and the population base in Hainan²², the formula $N = \mu^2\alpha/2P(1 - P)/\delta^2 = \mu^2\alpha/2(1 - P)/r^2 \cdot P$ yielded an estimated sample size of approximately 1,600. Considering a potential 10% loss to follow-up, the target sample size was increased to 1,750.

Study locations and sampling method

The study was conducted across five geographically diverse regions in Hainan Province: Dongfang City (west), Haikou City (north), Wuzhishan City (central), Qionghai City (east), and Sanya City (south) (Fig. 1). These regions were selected to ensure sample representativeness, considering population distribution, ethnic diversity (e.g., Miao and Li ethnic minorities in central regions like Wuzhishan), and economic development (e.g., Haikou as the provincial capital and Sanya as a major tourist city)^{23,24}.



Fig. 1. Geographical Location and Population Distribution of Research Cities in Hainan Province.

Study nature and form

This cross-sectional epidemiological study was conducted from May to October 2024, organized by the Hainan Provincial Clinical Research Center for Digestive Diseases. Data were collected primarily through questionnaires and fasting abdominal ultrasound examinations. Professional medical personnel provided one-on-one consultations and performed abdominal ultrasound checks (using HITACHI ALOKA Noblus ultrasound machines). Stratified random sampling was employed, with the final sample size determined based on statistical principles, resulting in 1,611 participants. All participants provided informed consent from their guardians and voluntarily participated in the study.

Diagnostic criteria and questionnaire design

MASLD diagnostic criteria

MASLD was diagnosed based on the “International Expert Consensus on Diagnostic Criteria for Metabolic Dysfunction-Associated Steatotic Liver Disease (2023)”²⁵. All 1611 participants underwent fasting abdominal B-ultrasound examination and FibroScan[®] CAP detection (M probe). Abdominal B-ultrasound diagnostic criteria, combined with metabolic risk factors, were used for the diagnosis of MASLD. Three of the following criteria had to be met for diagnosis: (1) diffuse enhancement of the liver’s anterior echo, greater than the renal echo; (2) unclear visualization of intrahepatic ductal structures; and (3) gradual attenuation of the liver’s distal echo. Additionally, at least one cardiovascular metabolic risk factor (e.g., overweight/obesity, abnormal blood glucose, hypertension, dyslipidemia) had to be present. The Controlled Attenuation Parameter (CAP) value was only used for grading the severity of hepatic steatosis in MASLD-positive cases (not for diagnostic purposes). The severity of hepatic steatosis was graded based on the Controlled Attenuation Parameter (CAP) value measured by the M probe of the FibroScan[®] device: normal liver (CAP < 238 dB/m, corresponding to ≤ 5% hepatic fat content), mild fatty liver (238 dB/m ≤ CAP < 259 dB/m, 5%-33% hepatic fat content), moderate fatty liver (259 dB/m ≤ CAP < 292 dB/m, 34%-66% hepatic fat content), and severe fatty liver (CAP ≥ 292 dB/m, ≥ 67% hepatic fat content)²⁶.

Questionnaire design

Based on the diagnostic criteria and by referring to other relevant MASLD questionnaires²⁷, and after literature review and discussions with digestive disease experts, a questionnaire was designed for this study. The questionnaire included the following sections: Basic Information: Gender, age, ethnicity, BMI, parental occupation (whether they are farmers), family size, and monthly family income. Lifestyle Habits: Frequency of participating in physical exercise per week, whether they often stay up late (going to bed after 11 PM), and whether they frequently smoke. Dietary Habits: Whether they often consume high-fat foods such as hot dogs, grilled skewers, pork belly, and animal organs (more than 3 times a week), whether they frequently consume high-sugar beverages and foods like cola, milk tea, and desserts, whether they often eat high-protein foods such as seafood, beef, and lamb, whether they frequently eat fresh vegetables and fruits, their usual dietary

situation (whether it is a balanced mix of meat and vegetables), frequency of dining out, and their usual dietary taste preferences. Health Status: Whether there is a family history of MASLD, whether they feel abdominal discomfort or pain, whether they have long-term difficulties in defecation or diarrhea, and whether they have sleep disorders (such as insomnia or multiple dreams).

Data collection process

Before the survey, all investigators received unified training to ensure the standardization and consistency of the survey process. The survey was conducted anonymously to protect the privacy of the participants. The survey time was chosen to be during breaks or after school to ensure that the participants had sufficient time and energy to complete the questionnaire. The collected data underwent strict quality control and review to ensure their authenticity and reliability.

Statistical analysis methods

Descriptive statistics were performed on the collected data using SPSS 26.0 statistical software, including the basic situation of the sample and the prevalence rate of MASLD. By calculating indicators such as mean, standard deviation, and frequency, the characteristics and distribution of the sample were described. Univariate analysis methods such as the chi-square test and t-test were used to initially explore the relationships between the independent variables and MASLD. Multivariate analysis methods such as logistic regression were used to further determine the independent risk factors for MASLD. For logistic regression analysis, reference categories were clearly defined, and all coding was verified to ensure consistency between table data and text interpretation.

Results

General information

A total of 1,611 valid questionnaires were collected in this survey. The mean BMI was 19.82, with 808 males and 803 females; 1,069 were Han ethnicity, and 542 were from ethnic minorities; 608 families had parents who were farmers, and 1,003 were non-farmer families; 60 had a family history of MASLD. Regarding BMI classification (based on the Chinese adolescent BMI classification standard), 1,393 adolescents were of normal weight (86.49%) and 218 were overweight and obese (13.51%). Table 1 for details.

Prevalence rate of metabolic-associated steatotic liver disease among adolescents in Hainan Province

According to the questionnaire results, a total of 123 individuals were diagnosed with non-alcoholic fatty liver disease. The prevalence rate of MASLD among adolescents in Hainan Province was 7.64%. This result is slightly higher than the reported prevalence of adolescent MASLD in most regions of China (based on ultrasound diagnosis), and the comparison is for reference only due to differences in study population, sample size and diagnostic criteria among different studies. This result is higher than the average level in other regions of China, indicating a relatively serious problem of MASLD among adolescents in Hainan Province.

Univariate analysis of factors affecting the prevalence rate of MASLD among adolescents

Univariate analysis of factors related to the prevalence of MASLD among adolescents in Hainan Province showed that normal weight vs. overweight and obesity, being Han ethnicity, having parents who are farmers, being male, having a monthly family income of $\leq 5,000$ yuan, having a family history of MASLD, being introverted, frequently eating hot dogs and grilled skewers, having an unbalanced meat and vegetable diet, not frequently eating fresh vegetables and fruits, frequently consuming cola, milk tea, and desserts, frequently dining out, and

Factor	Category	Number	Proportion (%)
Gender	Male	808	50.15
	Female	803	49.85
Age	12–14 years	793	49.22
	15–17 years	818	50.78
BMI	Overweight and obese	218	13.51
	Normal weight	1,393	86.49
Ethnicity	Han	1,069	66.35
	Ethnic minority	542	33.65
Parental occupation	Farmer	608	37.74
	Non-farmer	1,003	62.26
Family size	> 3 persons	1,123	69.71
	≤ 3 persons	488	30.29
Monthly family income	3–5 thousand yuan	482	29.91
	> 5 thousand yuan	1,129	70.09
Family history of MASLD	Yes	60	3.72
	No	1,551	96.28

Table 1. General Information.

having sleep disorders were all correlated with the occurrence of MASLD among adolescents ($P < 0.05$). The remaining factors such as HP, family size, and frequency of participating in physical exercise per week were not significantly correlated with the prevalence rate of MASLD among adolescents ($P > 0.05$) (Table 2).

Multivariate analysis of factors affecting the prevalence rate of MASLD among adolescents

Further multivariate binary logistic regression analysis was performed on the factors with statistical differences identified in the univariate analysis, with clear definition of reference categories for all variables. The results showed that obesity and overweight ($OR = 1.46$, 95% $CI = 1.38-1.56$, $P < 0.001$), having a family history of MASLD ($OR = 9.92$, 95% $CI = 4.37-22.54$, $P < 0.001$), frequently dining out ($OR = 4.72$, 95% $CI = 2.73-8.16$, $P < 0.001$), and frequently eating hot dogs/grilled skewers ($OR = 2.46$, 95% $CI = 1.39-4.37$, $P = 0.002$) were independent risk factors for MASLD among adolescents. Frequently eating fresh vegetables and fruits ($OR = 0.23$, 95% $CI = 0.13-0.42$, $P < 0.001$) was a protective factor against MASLD among adolescents. These factors had a significant impact on the occurrence of MASLD (Table 3; Fig. 2).

Analysis of the interactive effects of influencing factors on the risk of MASLD among adolescents

Analysis of the interactive effects between the independent factors affecting MASLD among adolescents, such as obesity and overweight, having a family history of MASLD, frequently dining out, frequently eating hot dogs/grilled skewers, and frequently eating fresh vegetables and fruits, and other factors showed that frequently dining out \times frequently staying up late ($P = 0.023$, $OR = 1.34$, 95% $CI: 0.114-1.73$), meaning that frequently dining out and frequently staying up late increase the risk; overweight \times exercising < 3 times a week ($P = 0.032$, $OR = 1.01$, 95% $CI: 0.379-2.70$), suggesting a synergistic effect between overweight and exercising < 3 times a week; frequently dine out \times frequently stay up late ($P = 0.023$, $OR = 1.34$, 95% $CI: 0.114-1.73$) suggests a synergistic risk effect on MASLD, but the 95%CI crosses 1, indicating limited statistical stability of this result; overweight \times exercising < 3 times a week ($P = 0.032$, $OR = 1.01$, 95% $CI: 0.379-2.70$) implies a potential synergistic effect, and the result needs to be interpreted with caution due to the 95%CI crossing 1; family history of MASLD \times light diet ($P = 0.050$, $OR = 0.14$, 95% $CI: 0.018-1.00$), with an OR value less than 1 definite protective effect (95%CI does not cross 1), indicating a possible protective effect. (Table 4; Fig. 3)

Univariate analysis of factors affecting the severity of MASLD (mild/moderate and above) among adolescents

Further analysis was conducted on the factors related to the prevalence of MASLD among adolescents, such as overweight and obesity, being Han ethnicity, having parents who are farmers, being male, having a monthly family income of $\leq 5,000$ yuan, having a family history of MASLD, being introverted, frequently eating hot dogs and grilled skewers, having an unbalanced meat and vegetable diet, not frequently eating fresh vegetables and fruits, frequently dining out, and having sleep disorders, to explore their correlations with the severity of MASLD (mild/moderate and above) among adolescents. The results showed that overweight and obesity, having a family history of MASLD, and frequently eating fresh vegetables and fruits were significantly correlated with the severity of MASLD ($P < 0.05$). Further multivariate binary logistic regression analysis showed that having a family history of MASLD was an independent risk factor for MASLD among adolescents ($OR = 2.383$, 95% $CI = 1.010-5.619$, $P = 0.047$), and frequently eating fresh vegetables and fruits ($OR = 0.41$, 95% $CI = 0.17-0.97$, $P = 0.043$) was a protective factor against MASLD among adolescents. These factors had a significant impact on the occurrence of MASLD (Tables 5 and 6; Fig. 4).

Discussion

This study is the first to report that the prevalence rate of metabolic dysfunction-associated steatotic liver disease (MASLD) among adolescents in Hainan Province is 7.64%. Research indicates that the prevalence of MASLD among children and adolescents in China has shown a rapid upward trend, with an estimated prevalence of 2–4% in the general pediatric population and up to 30–40% in obese children²⁸. This finding suggests that the issue of MASLD among adolescents in Hainan Province warrants significant attention. Multivariate analysis reveals that overweight/obesity is the most prominent risk factor, consistent with findings from both domestic and international research. A family history significantly increases the risk of MASLD, indicating that genetic factors play a crucial role in its onset.

The results of the univariate analysis in this study demonstrate that body mass index (BMI), a vital indicator for assessing obesity levels, is closely associated with MASLD²⁹. Obesity stands as one of the primary risk factors for MASLD, with its mechanism potentially lying in the excessive accumulation of body fat that surpasses the liver's metabolic capacity, thereby contributing to the development of fatty liver disease³⁰. Additionally, obesity may further be associated with exacerbate MASLD by affecting insulin sensitivity and promoting inflammatory responses^{31,32}. Multivariate binary logistic regression analysis in this study confirms that BMI is an independent risk factor influencing the development of MASLD in adolescents. Univariate analysis on factors affecting the severity of MASLD in adolescents reveals a significant correlation between BMI and the severity of metabolic-associated fatty liver disease, supporting the central role of obesity in the progression of MASLD.

The role of ethnic differences in the prevalence of MASLD has also gradually garnered academic attention. Factors such as genetic background, dietary habits, and lifestyle among different ethnic groups may collectively influence the pathogenesis of MASLD. For instance, research from the University of Southern California has found that Spanish children carrying the PNPLA3 gene variant (GG) exhibit increased liver fat content, with this variant having the most pronounced effect on the Hispanic population³³. Moreover, this gene variant is relatively common among East Asian populations, potentially explaining the ethnic disparities in MASLD³⁴. Furthermore, studies have shown a significant correlation between ethnicity and the severity of metabolic-associated fatty

Factor	Category	Number	MASLD (-)	MASLD (+)	χ^2	P
Gender	Male	808	732	76	7.209	0.01
	Female	803	756	47		
Age	12–14 years	793	736	57	0.443	0.284
	15–17 years	818	752	66		
BMI	Overweight and obese	218	129	89	393.837	<0.001
	Normal weight	1,393	1,359	34		
Ethnicity	Han	1,069	972	97	9.329	0.01
	Ethnic minority	542	516	26		
Family size	> 3 persons	1,123	1,042	81	4.211	0.755
	≤ 3 persons	488	446	42		
Monthly family income	≤ 5 thousand yuan	482	431	51	8.943	0.013
	> 5 thousand yuan	1,129	1,057	72		
Parental occupation	Farmer	608	585	23	20.548	<0.001
	Non-farmer	1,003	903	100		
Family history of MASLD	Yes	60	27	33	207.182	<0.001
	No	1,551	1,461	90		
Personality	Introverted	448	404	34	4.207	0.028
	Extroverted	1,163	1,084	79		
Factor	Category	Number	MASLD (-)	MASLD (+)	χ^2	P
Frequency of exercise per week	> 3 times	1,078	1,001	77	1.119	0.169
	≤ 3 times	533	487	46		
Often stay up late	Yes	1,209	1,115	94	0.358	0.899
	No	402	373	29		
Often smoke	Yes	83	79	4	1.070	0.528
	No	1,528	1,409	119		
Balanced meat and vegetable diet	Yes	1,306	1,216	90	5.411	0.016
	No	305	272	33		
Often dine out	Yes	347	286	61	62.016	<0.001
	No	1,264	1,202	62		
Often feel stressed	Yes	845	776	69	0.970	0.753
	No	766	714	54		
Often eat hot dogs/grilled skewers	Yes	463	401	62	30.564	<0.001
	No	1,148	1,086	61		
Often eat pork belly/animal organs	Yes	418	381	37	1.481	0.782
	No	1,193	1,107	86		
Often consume cola, milk tea, desserts	Yes	812	734	78	9.244	0.021
	No	799	754	45		
Often eat seafood/beef/lamb	Yes	596	539	57	5.361	0.147
	No	1,015	949	66		
Often eat fresh vegetables and fruits	Yes	1,324	1,246	78	32.144	<0.001
	No	287	242	45		
Dietary taste	Moderate	1,439	1,335	104	3.849	0.121
	Salty	172	153	19		
Factor	Category	Number	MASLD (-)	MASLD (+)	χ^2	P
Type of drinking water	Tap water	1,434	1,325	109	0.021	0.488
	Bottled water/mineral water	177	163	14		
Often have abdominal discomfort/pain	Yes	436	400	36	0.406	0.788
	No	1,175	1,088	87		
Long-term abnormal defecation	Yes	391	361	30	0.415	0.851
Continued						

Factor	Category	Number	MASLD (-)	MASLD (+)	χ^2	P
	No	1,220	1,128	93		
Sleep disorders	Yes	433	383	50	12.853	<0.001
	No	1,178	1,105	73		
HP	Positive	379	352	27	16.633	0.056
	Negative	1,232	1,116	96		

Table 2. Univariate analysis of factors affecting metabolic-associated steatotic liver disease prevalence.

Variable	Category	β	SB	Wald	P	OR	95% CI
Gender	Female	0.09	0.28	0.32	0.752	1.09	0.63–1.88
	Male						
BMI	Overweight or obese	0.38	0.03	11.98	<0.001	1.46	1.38–1.56
	Normal weight						
Ethnicity	Han	-0.12	0.36	-0.34	0.732	0.88	0.44–1.78
	Ethnic minority						
Parental occupation	Non-farmer	22.108	20.213	0.015	0.999	0.097	2.010–9.218
	Farmer						
Monthly family income	≤ 5 thousand yuan	-0.096	0.297	0.104	0.748	0.909	0.508–1.626
	> 5 thousand yuan						
Family history of MASLD	No	2.29	0.42	5.48	<0.001	9.92	4.37–22.54
	Yes						
Personality	Extroverted	0.16	0.28	0.56	0.573	1.17	0.68–2.01
	Introverted						
Often eat hot dogs/grilled skewers	No	0.90	0.29	3.08	0.002	2.46	1.39–4.37
	Yes						
Often consume cola, milk tea, desserts	No	-0.32	0.29	-1.12	0.262	0.73	0.41–1.27
	Yes						
Often eat fresh vegetables and fruits	No	-1.46	0.31	-4.77	<0.001	0.23	0.13–0.42
	Yes						
Balanced meat and vegetable diet	No	-0.18	0.33	-0.55	0.584	0.83	0.43–1.60
	Yes						
Often dine out	No	1.55	0.28	5.57	<0.001	4.72	2.73–8.16
	Yes						
Sleep disorders	No	0.02	0.29	0.07	0.943	1.02	0.58–1.79
	Yes						

Table 3. Multivariate analysis of factors influencing metabolic-associated steatotic liver disease prevalence.

liver disease. Genome-wide association studies and large-scale candidate gene studies have identified multiple gene variants associated with the onset of MASLD, such as TM6SF2, GCKR, MBOAT7, and HSD17B13. These gene variants may vary among different ethnic groups, thereby influencing individual susceptibility to fatty liver disease, suggesting the presence of specific physiological or genetic differences among various ethnic groups³⁵.

In terms of familial genetic factors, this study uncovers a significant correlation between a family history of MASLD and the prevalence of MASLD in adolescents. This finding supports the crucial role of genetic factors in the onset of MASLD but also further underscores the critical impact of familial genetic background on individual susceptibility to MASLD. Genetic factors may influence liver fat metabolism and insulin resistance through various mechanisms, thereby potentially increasing the risk of MASLD. As a vital metabolic organ in the human body, the liver's disturbed fat metabolism serves as a core link in the pathogenesis of MASLD. Genetic factors may regulate the expression of genes related to fat metabolism, affecting the liver's processes of fat uptake, synthesis, storage, and decomposition, leading to abnormal fat accumulation in the liver^{36,37}. Meanwhile, insulin resistance is also a significant factor in the onset of MASLD, with genetic factors playing a crucial role in its occurrence and development. Specific gene variants may cause obstacles in the insulin signaling pathway, thereby affecting the liver's sensitivity to insulin and promoting the onset and progression of MASLD^{38,39}. Notably, this study also finds that individuals with a family history of MASLD who adhere to a light diet, avoiding excessive oil and salt, may have a reduced prevalence of MASLD, with the specific mechanism requiring further investigation. Moreover, multivariate binary logistic regression analysis indicates that a family history of metabolic-associated fatty liver disease is an independent risk factor influencing the development of MASLD in adolescents. This finding provides preliminary evidence for the role of familial genetic factors in the

Heatmap of Interactive Effects on MASLD Risk

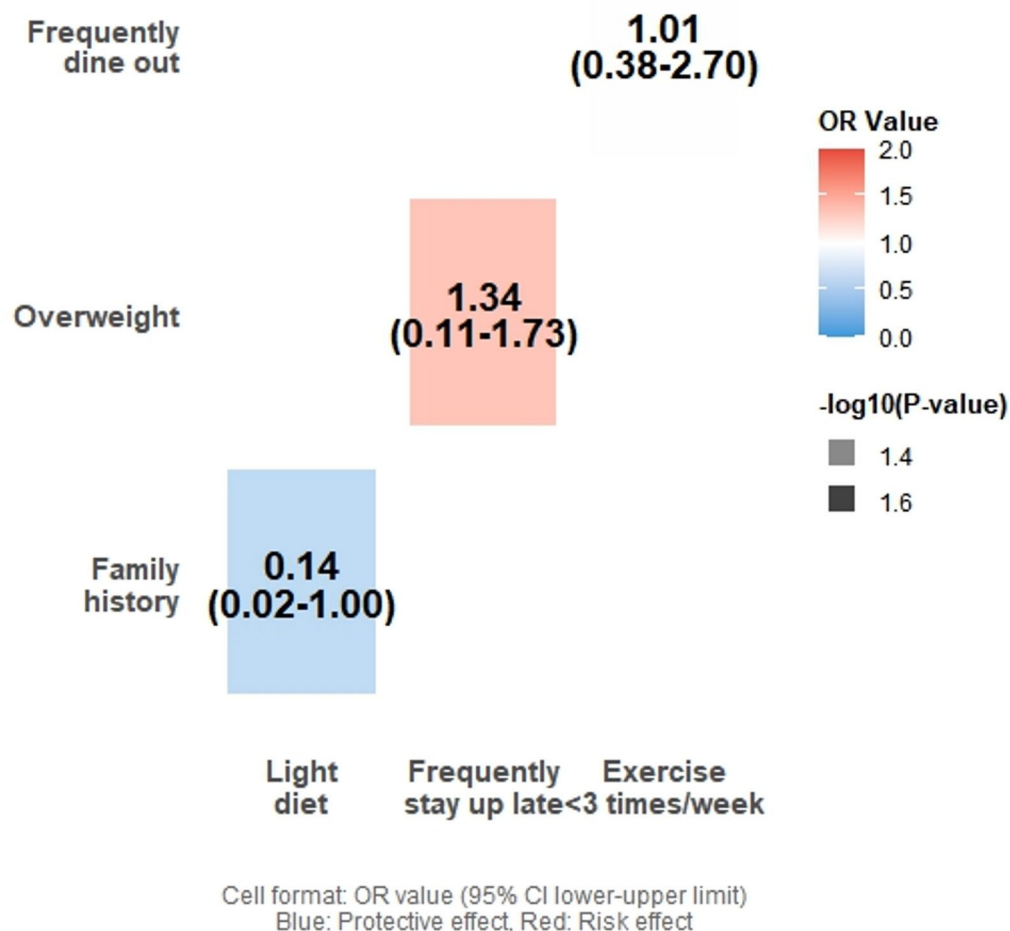


Fig. 2. Analysis of interactive effects of influencing factors on risk.

Interactive Term	P	OR	95% CI
Frequently dine out × Frequently stay up late	0.023	1.34	0.114–1.73
Overweight × Exercise <3 times a week	0.032	1.01	0.379–2.70
Family history of MASLD × Light diet	0.050	0.14	0.018–1.00
Frequently eat grilled food × Frequently eat fresh vegetables	0.721	0.83	0.307–2.25
Family history of MASLD × Balanced meat and vegetable diet	0.981	1.21	0.169–8.54

Table 4. Analysis of interactive effects of influencing factors on risk. Note: An OR value > 1 indicates a risk effect, and an OR value < 1 indicates a protective effect. When the 95% confidence interval (CI) includes 1, No significant interactive effects were observed for other factor combinations.

onset of MASLD in adolescents and may inform future clinical prevention and intervention strategies. However, it is important to note that the odds ratio for family history (OR = 9.92) is notably high with a wide confidence interval (4.37–22.54), which may reflect overestimation due to the relatively small size of the exposed subgroup ($n = 60$). Therefore, this finding should be interpreted with caution, and further studies with larger sample sizes are needed to validate the true effect of family history on MASLD risk.

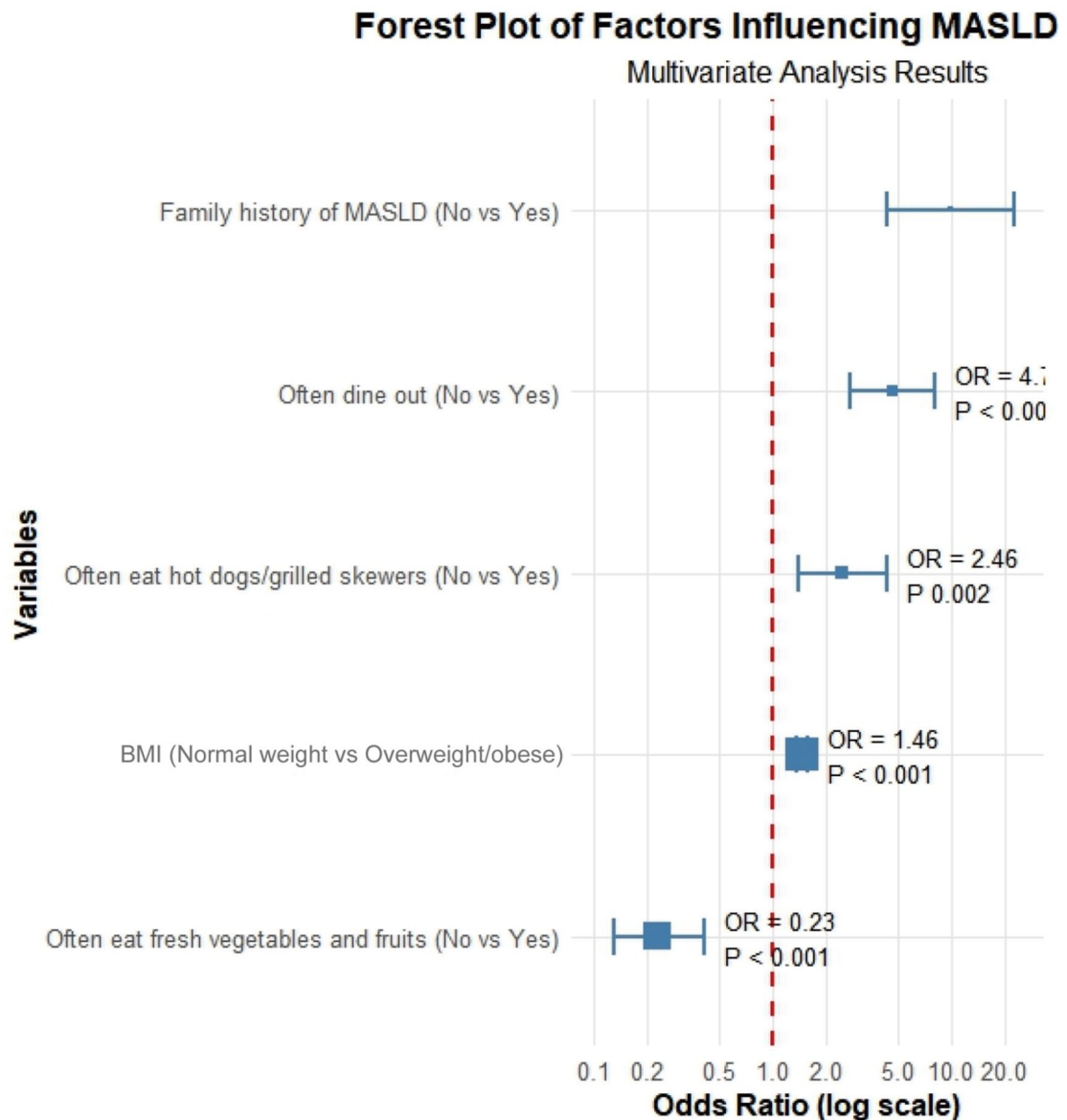


Fig. 3. Forest plot for analyzing influencing factors of MASLD prevalence in adolescents using logistic regression model.

Regarding socioeconomic and family backgrounds, this study reveals that parental occupation as farmers and lower family monthly income are associated with the prevalence of MASLD in adolescents. Poor family economic conditions often imply limited resources, which may be associated with inadequate or imbalanced nutritional intake among adolescents⁴⁰. Under economic pressure, families may be unable to provide sufficient and balanced diets, resulting in adolescents lacking essential nutrients such as vitamins, minerals, and dietary fiber, which are crucial for maintaining liver health and normal fat metabolism. Simultaneously, to save expenses, families may be more inclined to choose cheaper foods with higher calorie and fat content, such as fast food and processed foods. Long-term consumption of these foods not only increases adolescents' energy intake but may also contribute to abnormal fat accumulation in the liver, which could be associated with an increased risk of MASLD^{41,42}. Furthermore, parental occupation as farmers may imply that adolescents live in an environment distinct from that of families with other occupations. Farmer families often face more physical labor and longer working hours, which may affect their care and supervision of adolescents, including dietary arrangements and the cultivation of healthy lifestyle habits. Moreover, farmer families may have relatively lower educational levels and health awareness, lacking sufficient knowledge about healthy diets and lifestyles. This may also lead to unhealthy tendencies in adolescents' dietary habits and lifestyles, such as irregular eating patterns and lack of exercise, thereby potentially increasing the risk of MASLD^{43,44}. Notably, parental occupation as farmers may also reflect significant differences in the social environment and lifestyle of adolescents compared to those from families with other occupations. For example, adolescents in rural areas may be more exposed to harmful

Factor	Category	Number	Mild Fatty Liver (n = 92)	Moderate and Above Fatty Liver (n = 31)	χ^2	P
Gender	Male	76	56	20	0.131	0.718
	Female	47	36	11		
BMI	Overweight and obese	65	41	24	9.556	0.008
	Normal weight	34	27	7		
Ethnicity	Han	97	72	25	0.079	0.779
	Ethnic minority	26	20	6		
Parental occupation	Non-farmer	100	75	25	0.012	0.914
	Farmer	23	17	6		
Monthly family income	> 5 thousand yuan	51	39	12	0.129	0.719
	≤ 5 thousand yuan	72	53	19		
Family history of MASLD	No	90	72	18	4.818	0.028
	Yes	33	20	13		
Personality	Introverted	77	58	19	0.030	0.861
	Extroverted	46	34	12		
Often eat hot dogs/grilled skewers	No	61	48	13	0.972	0.324
	Yes	62	44	18		
Often consume milk tea, cola, desserts	No	45	38	7	3.504	0.061
	Yes	78	54	24		
Often eat vegetables and fruits	No	45	29	16	4.034	0.045
	Yes	78	63	15		
Often dine out	No	62	45	17	0.326	0.568
	Yes	61	47	14		
Sleep disorders	No	73	53	20	0.459	0.498
	Yes	50	39	11		

Table 5. Univariate analysis of factors affecting the severity of metabolic-associated steatotic liver disease.

Variable	Category	β	SB	Wald	P	OR	95% CI
BMI	Overweight or obese	0.07	0.05	1.30	0.194	1.07	0.97–1.18
	Normal weight						
Family history of MASLD	No	0.868	0.438	3.935	0.047	2.383	1.010–5.619
	Yes						
Often eat fresh vegetables and fruits	No	-0.89	0.44	-2.03	0.043	0.41	0.17–0.97
	Yes						

Table 6. Multivariate analysis of factors influencing metabolic-associated steatotic liver disease prevalence.

substances such as pesticides and fertilizers, which may damage the liver and increase susceptibility to MASLD⁴⁵. Meanwhile, the relative scarcity of cultural and recreational facilities in rural areas may limit adolescents' outdoor activities and social opportunities, potentially affecting their physical and mental health and, consequently, the prevalence of MASLD⁴⁶. This study also finds a significant correlation between personality traits (introversion/extroversion) and metabolic-associated fatty liver disease, suggesting the potential role of psychological factors in its onset. Although personality itself does not directly cause metabolic-associated fatty liver disease, it may influence adolescents' lifestyles and mental health, thereby indirectly being associated with the risk of its onset. Introverted adolescents may be more inclined to engage in solitary and sedentary activities, lacking sufficient exercise. Simultaneously, they may be more susceptible to stress and anxiety, which may affect the endocrine and immune systems, potentially increasing the risk of MASLD^{47,48}. Conversely, extroverted adolescents may be more active and optimistic, which may be associated with a reduced risk of MASLD^{49,50}. This finding suggests that in MASLD prevention strategies, we should pay attention to adolescents' mental health and encourage them to actively participate in social and physical activities to promote their physical and mental well-being.

Diet and lifestyle have always been focal points of research concerning the impact on MASLD, with multiple studies demonstrating their significant influence^{51–53}. This study finds that regular consumption of fresh vegetables and fruits is considered a protective factor against MASLD⁵⁴. Fresh vegetables and fruits are rich in dietary fiber, vitamins, minerals, and other nutrients that may help improve liver fat metabolism, promote fat breakdown and excretion, and thereby be associated with reduced risk of MASLD^{55,56}. A balanced diet is crucial in preventing MASLD, indicating that we should emphasize dietary diversity and balance and avoid excessive reliance on high-fat, high-calorie foods. Additionally, the study reveals a correlation between frequent dining out and the prevalence of MASLD. This may be related to the fact that takeout foods often contain high levels

MASLD Risk Factors Forest

Multivariate Analysis Results

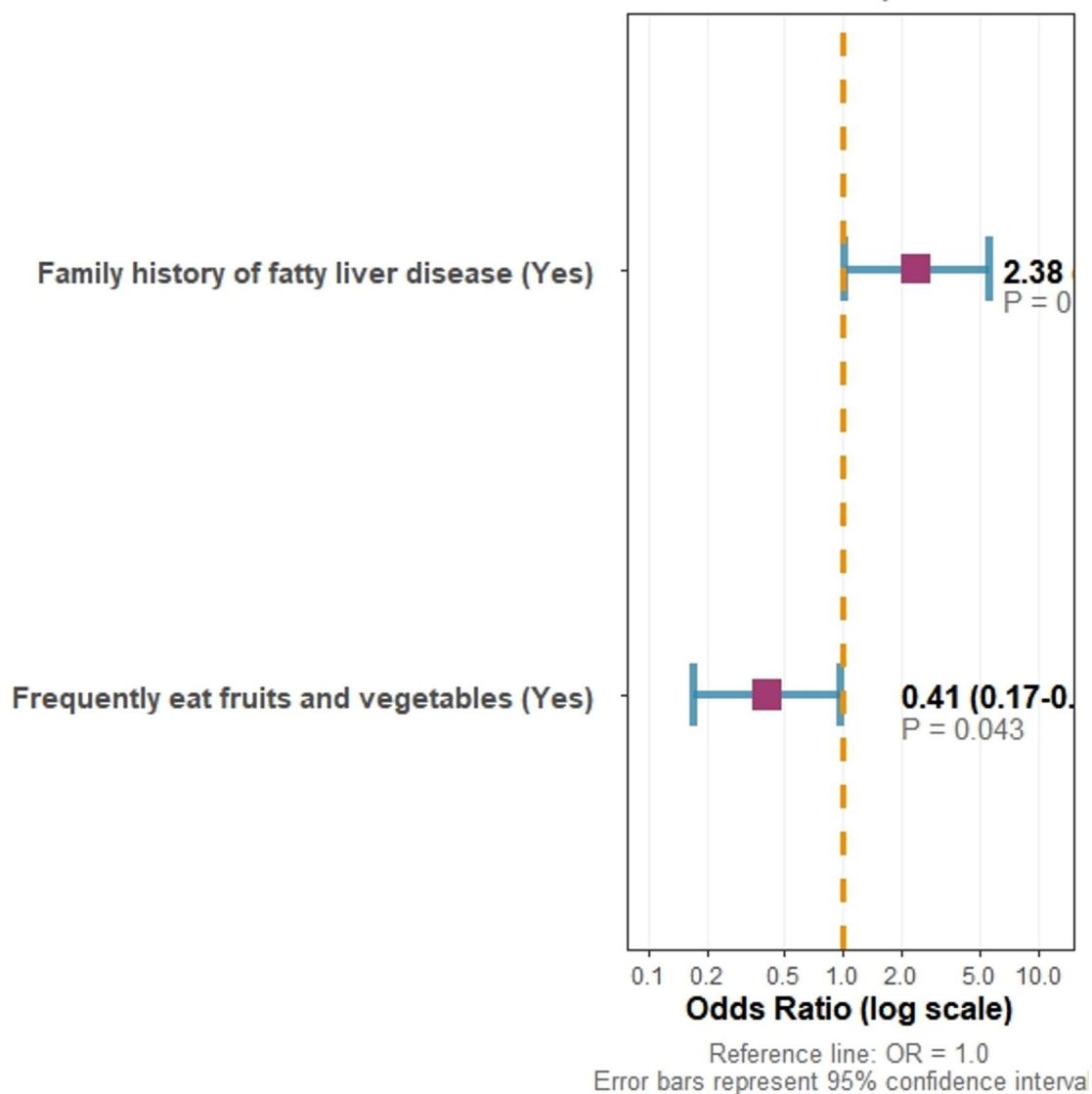


Fig. 4. Forest plot of logistic regression model analyzing factors influencing adolescent MASLD severity.

of fat, salt, and calories⁵⁷. With the acceleration of life pace, an increasing number of adolescents choose to dine out or order takeout, which often includes excessive amounts of oil, salt, and seasonings for taste. Long-term consumption of such foods can easily lead to energy excess and fat accumulation, thereby increasing the risk of MASLD. Moreover, although interaction analysis suggested a possible synergistic effect between frequent dining out and frequent late nights (OR = 1.34, 95% CI: 0.114–1.73), the confidence interval crossing 1 indicates that this result was not statistically significant and should be interpreted with caution. Further research is needed to confirm this potential interaction. Besides dietary factors, the study also finds a significant correlation between sleep disorders and the prevalence of MASLD. Sleep deprivation may affect liver fat metabolism and insulin resistance, thereby exacerbating MASLD^{58,59}. Sleep is a vital process for the body's recovery and repair, and sleep deprivation can lead to metabolic disorders, affecting the liver's normal function. Especially for adolescents in their critical growth and development period, adequate sleep is of great significance for maintaining physical health and preventing MASLD. Our research findings provide new insights and directions for further exploring the pathogenesis and influencing factors of MASLD.

This study has several limitations. First, although the overall sample size met the statistical requirements, the sample size of certain subgroups (e.g., those with a family history of MASLD) was relatively small, which may have resulted in insufficient statistical power. Second, this study adopted a cross-sectional design, which can only reveal associations between various factors and MASLD but cannot infer causality; further validation through prospective cohort studies is needed in the future. Additionally, information on lifestyle and dietary habits

collected via questionnaires was self-reported by respondents, which may introduce recall bias and affect the accuracy of the results to some extent. Finally, although multivariate analysis adjusted for multiple confounding factors, there may still be unmeasured residual confounders (such as genetic susceptibility loci, environmental exposures, etc.) that could influence the results.

In conclusion, through systematic univariate and multivariate analyses, this study comprehensively reveals multiple key factors associated with the prevalence and severity of MASLD among adolescents in Hainan Province, China. In terms of prevention strategies, weight control should be achieved through a reasonable diet and appropriate exercise. A balanced is encouraged, with increased intake of vegetables and fruits and reduced consumption of high-fat, high-calorie, and high-cholesterol foods. This strategy helps reduce body fat accumulation, improve liver fat metabolism, and lower the risk of MASLD. Meanwhile, good sleep aids in regulating liver fat metabolism and insulin resistance, while reducing the frequency of dining out can lower the intake of high-calorie and high-fat foods. Furthermore, knowledge about MASLD should be disseminated through various channels such as school education, family guidance, and community outreach to enhance adolescents' and their parents' health awareness. Increased health awareness can prompt adolescents to adopt healthier lifestyles. Tailored prevention strategies should also be formulated to comprehensively improve adolescents' liver health. In summary, the prevention and treatment of MASLD in adolescents represent a systematic endeavor that requires the joint efforts of the government, schools, families, and society. This endeavor aims to effectively reduce the prevalence and severity of MASLD in adolescents, improve their quality of life, and provide more scientific evidence for the prevention and treatment of MASLD among adolescents in Hainan Province.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions

S Z, and DY Z contributed equally to this work; SC, DY Z and FH B designed the study and performed statistical analysis. C C, DY Z, DL and FH B drafted the manuscript. SZ, XF H, YT L, FJ M and SM H recruited participants. SZ, XF H, YT L, FJ M, SM H, FZ, SJ C, RY C, YM, YL H, QC Y, YP D, and FZ collected data. All authors read and approved the final manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

The protocol was approved by the institutional ethics committee of the Second Hospital of Hainan Medical University (2024-K57-01) and performed per Helsinki's Declaration. All participants provided written informed consent for data collection and storage.

Consent for publication

Not applicable.

Additional information

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