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MASLD in High-Altitude versus Non-High-Altitude Populations: Prevalence, Risk Factors and Predictive Modeling

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MASLD in High-Altitude versus Non-High-Altitude Populations: Prevalence, Risk Factors and Predictive Modeling

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MASLD in High-Altitude versus Non-High-Altitude Populations: Prevalence, Risk Factors and Predictive Modeling

Abstract

Background: Metabolic Dysfunction-Associated Steatotic Liver Disease (MASLD) is a global health challenge, and high-altitude environments may affect its prevalence via metabolic disruptions. This retrospective cross-sectional study investigated MASLD's prevalence, risk factors, and predictive models in high-altitude versus non-high-altitude populations, exploring geographical impacts.

Methods: A total of 8,460 participants (5,640 high-altitude, 2,820 non-high-altitude) who underwent health exams were enrolled. Data included demographics, physical parameters, imaging parameters and lab tests. Univariate and multivariate logistic regression was adopted to identify risk factors. Nomograms were developed and validated via ROC, calibration, and decision curve analyses.

Results: The overall prevalence of MASLD was 51.52%, significantly higher in the high-altitude group (54.68%) than in the non-high-altitude group (45.21%). Multivariate analysis identified distinct risk profiles: in the high-altitude population, waist circumference (WC), gamma-glutamyl transferase (GGT), and triglycerides (TG) were independent risk factors. In the non-high-altitude population, independent risk factors included fasting plasma glucose (FPG), TG, and WC, while female sex and high-density lipoprotein cholesterol (HDL-C) were protective factors. No significant interaction was found between sex and altitude on MASLD risk. Nomograms incorporating these variables demonstrated good predictive performance, with AUCs of 0.836 (high-altitude, 6 parameters) and 0.885 (non-high-altitude, 8 parameters), and showed favorable clinical utility.

Conclusions: This study confirms geographical disparities in MASLD prevalence and risk factor profiles, providing evidence for altitude-specific prevention. Limitations include its retrospective cross-sectional design, sample imbalance, single-center bias and so on. These findings highlight the need for altitude-specific prevention strategies and warrant further validation in future multi-center studies.

Keywords: Metabolic Dysfunction-Associated Steatotic Liver Disease, High-altitude environments, Nomograms, Risk factors

1. Introduction

In 2020, recognizing the metabolic underpinnings of fatty liver disease, an international consensus first proposed replacing non-alcoholic fatty liver disease (NAFLD) with metabolic-associated fatty liver disease (MAFLD), transitioning from an exclusionary diagnostic framework to an inclusionary approach while eliminating the stigmatizing terminology non-alcoholic(1). The

2023 global multi-society consensus further renamed the condition metabolic dysfunction-associated steatotic liver disease (MASLD) to mitigate pathologizing connotations of fatty liver disease, refining metabolic dysfunction criteria and encompassing cases with concomitant alcohol intake(2). This nomenclature emphasizes MASLD as the hepatic manifestation of systemic metabolic dysregulation, laying the groundwork for precise phenotyping and targeted interventions.

MASLD has emerged as the most prevalent chronic liver disease worldwide. Epidemiological data indicate that 38% of adults and 7-14% of children/adolescents globally are affected by MASLD(3). Meanwhile, with the rising global prevalence of obesity, type 2 diabetes mellitus (T2D), and metabolic syndrome (MetS), this figure continues to rise, with projections suggesting that adult MASLD prevalence will exceed 55% by 2040(4). Notably, MASLD is currently the fastest-growing contributor to disease burden associated with adverse hepatic outcomes, including cirrhosis, hepatic failure, and hepatocellular carcinoma(5). Beyond hepatic consequences, MASLD also correlates with increased risks of developing incident T2D, chronic kidney disease, sarcopenia, extrahepatic malignancies and cardiovascular disease(6). This condition has become a significant global health challenge. However, the insidious onset of MASLD means most patients remain asymptomatic during early stages, with diagnoses typically occurring incidentally through imaging examinations for other conditions or routine health checkups(7). Consequently, early identification of MASLD risk factors combined with timely, targeted preventive interventions holds critical importance for decelerating disease progression and optimizing therapeutic outcomes.

In recent years, growing regional research has highlighted the profound impact of distinct geographical environments on human health. High-altitude environments (≥2,500 meters) present unique metabolic challenges through chronic hypoxia, cold stress, and ultraviolet radiation, altering human energy metabolism through multiple mechanisms that significantly elevate metabolic disorder prevalence compared to non-high-altitude regions(8, 9). Chronic hypoxia suppresses glucose metabolism by reducing glucose oxidation while enhancing glycolysis and lactate production, thereby increasing insulin resistance risk(10). This process induces lipid metabolic reprogramming, promoting free fatty acid release and ectopic fat deposition(11). Concurrent activation of the renin-angiotensin system and sympathetic nervous system exacerbates inflammatory cytokine release, accelerating MetS progression(12). Notably, high-altitude hypoxia may potentiate MASLD progression, leading to exacerbated hepatic fibrosis(13). Emerging clinical evidence indicates that high-altitude populations demonstrate characteristic manifestations including central obesity, dyslipidemia, and heightened MetS prevalence, with MASLD prevalence rates reaching 37.1% in these cohorts(9). Notably, detection rates escalate to 38.4% in regions above 3,000 meters, reflecting a 1.5- to 2-fold increase compared to lowland populations(14).

However, current comparative analyses of MASLD between non-high-altitude and high-altitude populations remain insufficient, particularly regarding the relationship between geographical disparities and MASLD prevalence. Therefore, this study aims to investigate the

prevalence, risk factors of MASLD in high-altitude regions and their differences compared to non-high-altitude areas through a retrospective cross-sectional analysis, thereby revealing the association between environmental factors and metabolic diseases. The findings will provide scientific evidence for optimizing prevention strategies and enhancing health management practices for high-altitude residents.

2. Materials and Methods

2.1 Patients

This retrospective cross-sectional study enrolled individuals undergoing health examinations at our institution's Health Management Center between January 2022 and December 2023, with the following inclusion and exclusion criteria established(15).

2.1.1 Inclusion Criteria

1) Age >18 years; 2) Completion of abdominal ultrasonography, liver elastography imaging evaluations, and metabolic biochemical tests (complete blood count, liver/renal function, glucose, lipid profile); 3) Complete questionnaire data.

2.1.2 Exclusion Criteria

1) Secondary causes of hepatic steatosis including drug-induced liver injury, alcohol-associated liver disease (ethanol intake >60 g/day for males, >50 g/day for females); 2) Other metabolic disorders such as thyroid dysfunction and Cushing syndrome; 3) Severe cardiovascular, pulmonary, renal, endocrine systemic diseases or malignancies; 4) Pregnancy or lactation; 5) Individuals with psychiatric disorders or cognitive impairment affecting study compliance; 6) Missing critical clinical data or laboratory results.

2.2 Data Collection

Demographic data included patient identification number, gender, age, ethnicity, residential address, and past medical history (including hypertension, diabetes mellitus, and alcohol consumption history). Physical examination parameters comprised height, weight, blood pressure (BP), body mass index (BMI), waist circumference (WC) and hip circumference (HC). Imaging parameters included controlled attenuation parameter (CAP) and liver stiffness measurement (LSM). Laboratory investigations encompassed: hepatic function indicators - alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), and gamma-glutamyl transferase (GGT); hematological parameters - white blood cell count (WBC), platelet count (PLT), and lymphocyte count; protein markers - total protein (TP), albumin (ALB), globulin (GLO), and albumin-to-globulin ratio (A/G); bilirubin metabolism indices - total bilirubin (TBIL), direct bilirubin (DBIL), and indirect bilirubin (IBIL); renal function tests - urea, creatinine (CREA), and uric acid (UA); lipid profile components - total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and very low-density lipoprotein cholesterol (VLDL-C); along with fasting plasma glucose (FPG).

2.3 Definition

High-altitude residents were defined as individuals with long-term residence (≥3 years) at altitudes ≥2500 meters and cumulative high-altitude exposure ≥10 months during the 12 months preceding examination. Non-high-altitude residents were characterized by permanent habitation below 2500 meters, historical continuous high-altitude residency <1 year, and cumulative high-altitude exposure <1 month in the preceding 12-month period.

MASLD diagnosis was established per relevant international consensus and guidelines(2, 15) using the following criteria: 1) Hepatic steatosis diagnosed by transient elastography (CAP ≥248 dB/m)(16) and/or liver biopsy demonstrating ≥5% macrovesicular steatosis; 2) Presence of ≥1 cardiometabolic risk factor.

Adult cardiometabolic risk factors were operationally defined as: 1) WC ≥90 cm for males and ≥85 cm for females; 2) FPG ≥6.1 mmol/L, or 2-hour postprandial glucose ≥7.8 mmol/L, or glycated hemoglobin (HbA1) ≥5.7%, or confirmed T2D diagnosis, or active antihyperglycemic treatment; 3) BP ≥130/85 mmHg or current antihypertensive therapy; 4) serum TG ≥1.7 mmol/L or ongoing lipid-lowering treatment; 5) plasma HDL-C ≤1.0 mmol/L (males) and ≤1.3 mmol/L (females), or active lipid-modifying therapy(15).

2.4 Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics 27.0 and R software (version 4.4.1, https://www.r-project.org/). Categorical variables were expressed as frequency (proportion) and compared using the χ^2 test or Fisher's exact test, as appropriate. Data normality was evaluated via the Kolmogorov-Smirnov test. Normally distributed continuous variables were presented as mean ± standard deviation (SD) and analyzed with Student's t-test, whereas non-normally distributed variables were reported as median [interquartile range (IQR)] and assessed using the Mann-Whitney U test. To identify independent risk factors for MASLD, logistic regression analysis was employed. Statistically significant variables ($p < 0.05$) from univariate analyses were included in a multivariate logistic regression model. Variable selection was performed using a forward stepwise method ($p < 0.05$ for entry, $p > 0.10$ for removal), and multicollinearity was assessed by calculating the variance inflation factor (VIF), with a VIF < 5 considered acceptable. The results are presented as odds ratios (ORs) with 95% confidence intervals (CIs). A two-tailed significance threshold was applied, with $p < 0.05$ considered statistically significant. To formally test whether the effect of sex on MASLD risk differs between high-altitude and non-high-altitude populations, we conducted a statistical interaction analysis. Multivariable logistic regression models were constructed including sex, altitude, and their interaction term (sex × altitude). A predictive nomogram was developed based on regression outcomes, and its discriminative performance was validated through receiver operating characteristic (ROC) curve analysis. Calibration curves were generated to evaluate agreement between predicted probabilities and observed outcomes. Clinical utility was further examined using decision curve analysis (DCA) to determine net benefit across varying risk thresholds.

2.5 Quality Control

To ensure data integrity and consistency in this retrospective study, the following quality control measures were implemented:

1) During participant selection, adherence to pre-established inclusion and exclusion criteria was strictly maintained to minimize selection bias; 2) A standardized data extraction form was developed and used, with clear definitions for each variable collected (e.g., laboratory indices, ultrasound parameters, diagnostic conclusions), ensuring uniform criteria across all medical records; 3) All initial clinical data and physical examination findings were derived from records documented by qualified healthcare professionals at our institution. Supplementary test results (e.g., laboratory, ultrasound) were obtained from official reports issued by certified departments, thereby ensuring the professional reliability of the source data; 4) A dual-entry mode was adopted during data extraction. Any inconsistencies identified through systematic comparison—such as discrepancies in values or diagnostic classification—were automatically flagged, reviewed against original medical records, and resolved through consensus discussions; 5) For missing or ambiguously recorded key data, attempts were first made to retrieve supplementary information by reviewing associated test reports or hospitalization records. If the data remained unavailable, they were explicitly documented as missing.

2.6 Ethical Considerations

The study protocol received ethical approval from the Ethics Committee of West China Hospital Tibet Autonomous Region Chengdu Office Hospital, Sichuan University (Approval No.: 2024-1244). The study strictly adhered to the ethical principles of the Declaration of Helsinki. With approval from the ethics committee, the requirement for written informed consent was waived due to the retrospective study design and complete data anonymization.

3. Results

3.1 Patient Characteristics

Participants in this study were consecutively enrolled. During the study period, 77,310 visits were recorded at our Health Management Center. Through rigorous application of inclusion and exclusion criteria, we excluded duplicate registration numbers (n = 34,847), individuals with missing key data (n = 26,238), those with outliers in data (n = 70), individuals younger than 18 years old (n = 89), those with excessive alcohol intake (n = 3,125), and individuals with relevant diseases (as detailed in the exclusion criteria, n = 4,481). Ultimately, 8,460 eligible participants were screened, comprising 5,640 high-altitude residents (66.67%) and 2,820 non-high-altitude residents (33.33%) (Figure 1).

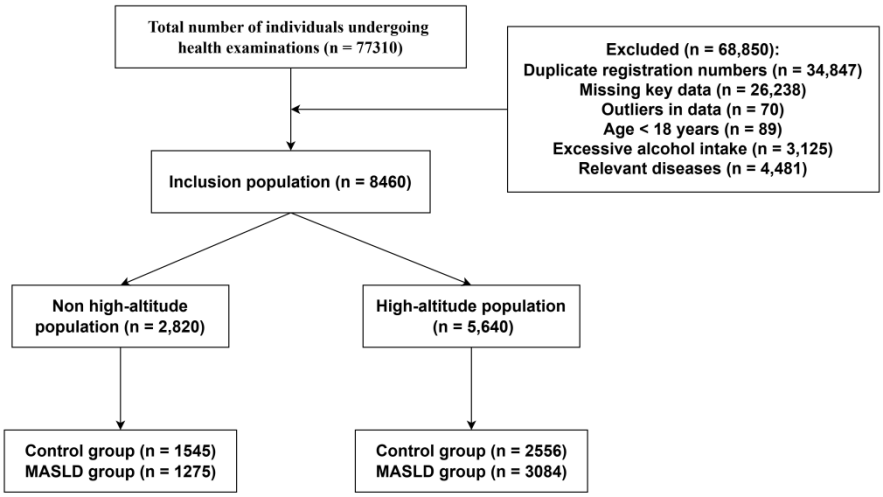


Figure 1. Process diagram for screening research subjects

Baseline comparisons demonstrated significantly higher MASLD prevalence in males versus females across both populations. Compared to non-MASLD subjects, MASLD patients exhibited elevated age, CAP, LSM, blood pressure (SBP/DBP), WC, LDL-C, FPG, and higher proportions of hypertension and diabetes history, with statistical significance. However, PLT, ALB, TBIL, IBIL, UREA, CREA, and eGFR showed no significant differences between MASLD and non-MASLD groups in either population ($p > 0.05$) (Table 1).

Table 1. Clinical characteristics of high-altitude and non-high-altitude population.

	High-altitude			**Non-high-altitude**		
	Non-MASLD (n=2556)	MASLD (n=3084)	***p***	Non-MASLD (n=1545)	MASLD (n=1275)	***p***
Age	44.99 ± 11.47	47.00 ± 10.72	<0.001	43.60 ± 12.43	46.72 ± 12.12	<0.001
CAP	222.70 ± 56.16	299.06 ± 48.91	<0.001	220.45 ± 33.85	299.52 ± 35.96	<0.001
LSM	4.64 ± 2.14	5.24 ± 2.10	<0.001	4.43 ± 1.72	5.14 ± 1.80	<0.001
SBP	114.89 ± 15.02	121.53 ± 16.15	<0.001	116.47 ± 15.06	125.14 ± 16.31	<0.001
DBP	69.94 ± 11.00	75.40 ± 11.99	<0.001	71.61 ± 10.82	78.00 ± 11.98	<0.001
Height	167.38 ± 7.57	169.46 ± 7.34	<0.001	166.83 ± 7.86	169.08 ± 7.37	<0.001
Weight	68.28 ± 9.91	80.24 ± 10.87	<0.001	65.49 ± 10.05	77.55 ± 10.88	<0.001
BMI	24.32 ± 2.85	27.94 ± 3.33	<0.001	23.46 ± 2.68	27.07 ± 3.00	<0.001
WC	85.77 ± 8.40	95.94 ± 8.31	<0.001	80.83 ± 8.93	92.37 ± 8.36	<0.001

HC	95.36 ± 5.54	100.77 ± 6.30	<0.001	93.17 ± 5.79	98.77 ± 6.18	<0.001
WBC	5.89 ± 1.63	6.36 ± 1.60	<0.001	5.81 ± 1.56	6.31 ± 1.55	<0.001
HGB	160.89 ± 20.69	166.36 ± 18.29	<0.001	154.39 ± 17.95	162.37 ± 41.06	<0.001
PLT	210.58 ± 54.92	211.43 ± 54.73	0.565	214.07 ± 57.87	213.66 ± 55.39	0.85
LYMPH	1.88 ± 0.59	2.07 ± 2.92	0.001	1.88 ± 0.58	2.02 ± 0.59	<0.001
NEUT	3.45 ± 1.24	3.74 ± 1.28	<0.001	3.64 ± 9.42	3.71 ± 1.17	0.811
ALT	37.53 ± 37.63	46.49 ± 34.20	<0.001	29.40 ± 27.03	43.59 ± 36.18	<0.001
AST	25.89 ± 19.25	27.28 ± 16.00	0.004	22.78 ± 15.13	27.27 ± 20.82	<0.001
AST/ALT	0.84 ± 0.45	0.69 ± 0.28	<0.001	0.94 ± 0.37	0.74 ± 0.31	<0.001
ALP	87.21 ± 28.48	90.47 ± 25.58	<0.001	75.71 ± 26.04	81.80 ± 21.77	<0.001
GGT	50.24 ± 56.80	72.64 ± 72.97	<0.001	36.49 ± 41.59	62.31 ± 62.36	<0.001
TP	69.84 ± 3.97	70.48 ± 4.17	<0.001	71.72 ± 3.97	72.10 ± 4.17	0.017
ALB	43.98 ± 3.11	44.11 ± 2.91	0.103	45.27 ± 2.85	45.35 ± 2.81	0.473
GLO	25.85 ± 3.83	26.36 ± 3.84	<0.001	26.44 ± 3.61	26.75 ± 3.63	0.028
A.G	1.74 ± 0.31	1.71 ± 0.30	<0.001	1.80 ± 1.92	1.73 ± 0.28	0.206
TBIL	14.14 ± 8.72	13.82 ± 6.41	0.116	13.83 ± 6.57	13.76 ± 6.17	0.781
DBIL	2.66 ± 1.52	2.71 ± 1.20	0.187	2.45 ± 1.05	2.58 ± 1.10	0.003
IBIL	11.54 ± 7.85	11.23 ± 5.60	0.122	11.48 ± 5.88	11.17 ± 5.40	0.185
FPG	4.95 ± 1.43	5.44 ± 1.76	<0.001	5.04 ± 1.20	5.53 ± 1.51	<0.001
UREA	5.07 ± 1.43	5.04 ± 1.21	0.34	5.09 ± 1.59	5.02 ± 1.19	0.197
CREA	74.16 ± 21.14	74.39 ± 13.04	0.626	73.87 ± 28.95	74.89 ± 12.46	0.262
UA	370.95 ± 81.79	414.40 ± 82.92	<0.001	364.91 ± 86.91	415.23 ± 84.86	<0.001

EGFR	105.23 ± 17.39	104.67 ± 12.46	0.664	101.08 ± 11.65	103.54 ± 14.97	0.244
CHOL	4.68 ± 0.87	4.97 ± 0.92	<0.001	4.81 ± 0.91	5.07 ± 0.92	<0.001
TG	1.28 ± 0.77	1.83 ± 1.27	<0.001	1.38 ± 0.75	2.41 ± 1.79	<0.001
HDL-C	1.31 ± 0.28	1.22 ± 0.24	<0.001	1.41 ± 0.32	1.22 ± 0.25	<0.001
LDL-C	2.90 ± 0.74	3.21 ± 0.76	<0.001	2.92 ± 0.77	3.22 ± 0.75	<0.001
VLDL-C	0.42 ± 0.18	0.48 ± 0.25	<0.001	0.48 ± 0.21	0.61 ± 0.36	<0.001
BFM	19.20 ± 5.55	26.14 ± 6.77	<0.001	18.65 ± 5.83	25.37 ± 6.25	<0.001
SMM	27.19 ± 4.49	30.43 ± 4.68	<0.001	27.05 ± 4.74	30.67 ± 4.54	<0.001
PBF	27.92 ± 6.01	32.33 ± 5.53	<0.001	27.47 ± 6.65	31.68 ± 4.93	<0.001
Sex			<0.001			<0.001
Male	2042 (79.89%)	2736 (88.72%)		1174 (75.99%)	1129 (88.55%)	
Female	514 (20.11%)	348 (11.28%)		371 (24.01%)	146 (11.45%)	
Race			0.002			<0.001
Han ethnic group	536 (20.97%)	548 (17.77%)		1222 (79.09%)	867 (68.00%)	
Tibetan ethnic group	2020 (79.03%)	2536 (82.23%)		323 (20.91%)	408 (32.00%)	
Hypertension			<0.001			<0.001
No	2458 (96.17%)	2789 (90.43%)		1483 (95.99%)	1139 (89.33%)	
Yes	98 (3.83%)	295 (9.57%)		62 (4.01%)	136 (10.67%)	
DM			<0.001			<0.001
No	2497 (97.69%)	2929 (94.97%)		1517 (98.19%)	1205 (94.51%)	
Yes	59 (2.31%)	155 (5.03%)		28 (1.81%)	70 (5.49%)	
Alcohol Consumption			<0.001			<0.001
No	1470 (57.51%)	1591 (51.59%)		1018 (65.89%)	749 (58.75%)	
Yes	1086 (42.49%)	1493 (48.41%)		527 (34.11%)	526 (41.25%)	

DM: Diabetes mellitus; BMI: Body mass index; WC: Waist circumference; HC: Hip circumference; CAP: Controlled attenuation parameter; LSM: Liver stiffness measurement; ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; ALP: Alkaline phosphatase; GGT: Gamma-glutamyl transferase; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; FPG: Fasting plasma glucose; WBC: White blood cell count; PLT: Platelet count; LYMPH: Lymphocyte count; NEUT: Neutrophil count; HGB: Hemoglobin; TP: Total protein; ALB: Albumin; GLO: Globulin; A/G: Albumin-to-globulin ratio; TBIL: Total bilirubin; DBIL: Direct bilirubin; IBIL: Indirect bilirubin; CREA: Creatinine; UA: Uric acid; TC: Total cholesterol; TG: Triglycerides; HDL-C: High-density lipoprotein cholesterol; LDL-C: Low-density lipoprotein cholesterol; VLDL-C: Very low-density lipoprotein cholesterol; BFM: Body fat mass; SMM: Skeletal muscle mass; PBF: Percent body fat.

3.2 Prevalence Disparities

As evidenced in Table 2, the overall MASLD prevalence was observed at 51.52%, with significantly higher rates in high-altitude populations (54.68%) versus non-high-altitude counterparts (45.21%). Among all participants, males exhibited significantly greater prevalence than females (54.58% vs. 35.82%). Stratified by gender, both males (57.26% vs. 49.02%) and females (40.37% vs. 28.23%) in high-altitude regions demonstrated elevated prevalence compared to non-high-altitude populations. Age-stratified analysis revealed significantly higher MASLD rates in high-altitude residents across all age groups except those >70 years. Collectively, these findings suggest high-altitude exposure is a significant independent factor associated with MASLD.

Table 2. Comparison of the prevalence of MASLD between high-altitude and non- high-altitude population.

Group			Total (n)	MASLD (n)	Prevalence (%)	χ^2	*p*
Overall		High-altitude	5640	3084	54.68	67.48	< **0.001**
		Non- high-altitude	2820	1275	45.21		
Overall Sex		Male	7081	3865	54.58	162.63	< **0.001**
		Female	1379	494	35.82		
Overall Age		≤ 30	681	237	34.80	142.69	< **0.001**
		31~40	2450	1146	46.78		
		41~50	2448	1359	55.51		
		51~60	1949	1117	57.31		
		61~70	758	401	52.90		
		>70	174	99	56.90		
Sex	Male	High-altitude	4778	2736	57.26	42.56	< **0.001**
		Non- high-altitude	2303	1129	49.02		
	Female	High-altitude	862	348	40.37	20.69	< **0.001**
		Non- high-altitude	517	146	28.23		
Race	Han ethnic group	High-altitude	1084	548	50.55	23.66	< **0.001**

	Tibetan ethnic group	Non- high-altitude	2089	867	41.50	0.01	0.939
		High-altitude	4556	2536	55.66		
Age Group (Year)	≤ 30	Non- high-altitude	731	408	55.81	6.43	**0.011**
		High-altitude	334	132	39.52		
	31~40	Non- high-altitude	347	105	30.26	15.23	**< 0.001**
		High-altitude	1650	817	49.52		
	41~50	Non- high-altitude	800	329	41.13	18.87	**< 0.001**
		High-altitude	1758	1023	58.19		
	51~60	Non- high-altitude	710	345	48.59	13.13	**< 0.001**
		High-altitude	1269	765	60.28		
	61~70	Non- high-altitude	680	352	51.76	4.25	**0.039**
		High-altitude	541	299	55.26		
	>70	Non- high-altitude	217	102	47.00	1.28	0.257
		High-altitude	88	48	54.55		
		Non- high-altitude	66	42	63.64		

3.3 Risk Factor Analysis

3.3.1 High-Altitude Population Risk Factors

Univariate regression analysis (Table 3) revealed that age, Tibetan ethnicity, alcohol consumption, obesity-related indices (BMI, WC, HC), hepatic parameters (LSM, ALT, AST, ALP, GGT), blood pressure metrics (SBP, DBP), hypertension, diabetes, and multiple blood biomarkers (FPG, WBC, LYMPH, NEUT, HGB, TP, GLO, DBIL, CREA, UA, TC, TG, LDL-C) were significantly associated with increased MASLD risk in high-altitude populations, while female sex and HDL-C correlated with reduced risk.

Multivariate logistic regression incorporating all statistically significant variables identified WC, GGT, and TG as independent risk factors for MASLD in high-altitude populations (Table 3).

Table 3. Univariate and multivariate logistic analysis of high-altitude population.

		Univariate		Multivariate	
		OR (95% CI)	***p***	**OR (95% CI)**	***p***
Age		1.02 (1.01-1.02)	< 0.001		
Sex	Male	1			
	Female	0.51 (0.44-0.59)	< 0.001		
Race	Han ethnic group	1			
	Tibetan ethnic group	1.23 (1.08-1.40)	0.002		
Alcohol Consumption	No	1			
	Yes	1.27 (1.14-1.41)	< 0.001		
Hypertension	No	1			
	Yes	2.65 (2.10-3.36)	< 0.001		
DM	No	1			
	Yes	2.24 (1.65-3.04)	< 0.001		
BMI		1.56 (1.52-1.60)	< 0.001		
WC		1.17 (1.16-1.18)	< 0.001	1.14 (1.11–1.17)	< 0.001
HC		1.18 (1.16-1.19)	< 0.001		
SBP		1.03 (1.03-1.04)	< 0.001		
DBP		1.04 (1.04-1.05)	< 0.001		
ALT		1.03 (1.02-1.03)	< 0.001		
AST		1.04 (1.03-1.04)	< 0.001		
ALP		1.01 (1.00-1.01)	< 0.001		
GGT		1.02 (1.02-1.02)	< 0.001	1.01 (1.00-1.01)	0.004
WBC		1.26 (1.21-1.31)	< 0.001		
PLT		1.00 (1.00-1.00)	0.327		
LYMPH		1.57 (1.42-1.75)	< 0.001		
NEUT		1.30 (1.23-1.37)	< 0.001		
HGB		1.02 (1.01-1.02)	< 0.001		
FPG		2.73 (2.42-3.09)	< 0.001		
TP		1.05 (1.03-1.06)	< 0.001		
ALB		1.01 (0.99-1.03)	0.379		
GLO		1.04 (1.02-1.06)	< 0.001		
A/G		0.72 (0.60-0.87)	0.001		
TBIL		1.00 (0.99-1.01)	0.75		
DBIL		1.14 (1.07-1.22)	< 0.001		
IBIL		1.00 (0.98-1.01)	0.791		
UREA		1.00 (0.95-1.05)	0.882		
CREA		1.01 (1.00-1.01)	0.01		
UA		1.01 (1.01-1.01)	< 0.001		
TC		1.48 (1.38-1.58)	< 0.001		
TG		2.99 (2.69-3.33)	< 0.001	2.23 (1.71-2.91)	< 0.001
HDL-C		0.22 (0.18-0.28)	< 0.001		
LDL-C		1.80 (1.66-1.94)	< 0.001		
LSM		1.58 (1.50-1.67)	< 0.001		

DM: Diabetes mellitus; BMI: Body mass index; WC: Waist circumference; HC: Hip circumference; CAP: Controlled attenuation parameter; LSM: Liver stiffness measurement; ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; ALP: Alkaline phosphatase; GGT: Gamma-glutamyl transferase; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; FPG: Fasting plasma glucose; WBC: White blood cell count; PLT: Platelet count; LYMPH: Lymphocyte count; NEUT: Neutrophil count; HGB: Hemoglobin; TP: Total protein; ALB: Albumin; GLO: Globulin; A/G: Albumin-to-globulin ratio; TBIL: Total bilirubin; DBIL: Direct bilirubin; IBIL: Indirect bilirubin; CREA: Creatinine; UA: Uric acid; TC: Total cholesterol; TG: Triglycerides; HDL-C: High-density lipoprotein cholesterol; LDL-C: Low-density lipoprotein cholesterol.

3.3.2 Non-High-Altitude Population Risk Factors

Univariate logistic regression analysis (Table 4) demonstrated that age, Tibetan ethnicity, alcohol consumption, obesity-related indices (BMI, WC, HC), hepatic parameters (CAP, LSM, ALT, AST, ALP, GGT), blood pressure metrics (SBP, DBP), hypertension, diabetes, FPG, and multiple blood biomarkers (WBC, LYMPH, NEUT, HGB, TP, DBIL, CREA, UA, TC, TG, LDL-C) were significantly associated with increased MASLD risk in non-high-altitude populations, whereas female sex and HDL-C correlated with reduced risk.

Multivariate logistic regression incorporating all statistically significant variables identified FPG, TG, and WC as independent risk factors for MASLD in non-high-altitude populations, while female sex and HDL-C were independent protective factors (Table 4).

Table 4. Univariate and multivariate logistic analysis of non- high-altitude population.

		Univariate		**Multivariate**	
		OR (95% CI)	***p***	**OR (95% CI)**	***p***
Age		1.02 (1.02-1.03)	< 0.001		
Sex	Male	1			
	Female	0.41 (0.33-0.50)	< 0.001	0.38 (0.19-0.78)	**0.008**
Race	Han ethnic group	1			
	Tibetan ethnic group	1.78 (1.50-2.11)	< 0.001		
Alcohol Consumption	No	1			
	Yes	1.36 (1.16-1.58)	< 0.001		
Hypertension	No	1			
	Yes	2.86 (2.09-3.89)	< 0.001		
DM	No	1			
	Yes	3.15 (2.02-4.91)	< 0.001		
BMI		1.63 (1.56-1.70)	< 0.001		
WC		1.17 (1.16-1.19)	< 0.001	1.11 (1.06-1.16)	**< 0.001**
HC		1.18 (1.16-1.20)	< 0.001		
SBP		1.04 (1.03-1.04)	< 0.001		
DBP		1.05 (1.05-1.06)	< 0.001		

ALT	1.04 (1.03-1.05)	< 0.001		
AST	1.07 (1.05-1.08)	< 0.001		
ALP	1.02 (1.01-1.02)	< 0.001		
GGT	1.03 (1.03-1.03)	< 0.001		
WBC	1.28 (1.21-1.35)	< 0.001		
PLT	1.00 (1.00-1.00)	0.761		
LYMPH	1.60 (1.38-1.84)	< 0.001		
NEUT	1.34 (1.24-1.45)	< 0.001		
HGB	1.03 (1.02-1.03)	< 0.001		
FPG	2.72 (2.29-3.24)	< 0.001	1.83 (1.21-2.79)	**0.004**
TP	1.03 (1.00-1.05)	0.016		
ALB	1.01 (0.98-1.04)	0.51		
GLO	1.02 (1.00-1.05)	0.055		
A/G	0.81 (0.60-1.09)	0.165		
TBIL	1.00 (0.99-1.02)	0.828		
DBIL	1.19 (1.07-1.31)	0.001		
IBIL	0.99 (0.97-1.01)	0.42		
UREA	0.99 (0.92-1.06)	0.685		
CREA	1.01 (1.01-1.02)	< 0.001		
UA	1.01 (1.01-1.01)	< 0.001		
TC	1.38 (1.25-1.51)	< 0.001		
TG	3.65 (3.16-4.23)	< 0.001	2.57 (1.84-3.63)	**< 0.001**
HDL-C	0.08 (0.06-0.11)	< 0.001	0.19 (0.07-0.50)	**0.001**
LDL-C	1.74 (1.56-1.94)	< 0.001		
LSM	1.70 (1.58-1.84)	< 0.001		

DM: Diabetes mellitus; BMI: Body mass index; WC: Waist circumference; HC: Hip circumference; CAP: Controlled attenuation parameter; LSM: Liver stiffness measurement; ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; ALP: Alkaline phosphatase; GGT: Gamma-glutamyl transferase; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; FPG: Fasting plasma glucose; WBC: White blood cell count; PLT: Platelet count; LYMPH: Lymphocyte count; NEUT: Neutrophil count; HGB: Hemoglobin; TP: Total protein; ALB: Albumin; GLO: Globulin; A/G: Albumin-to-globulin ratio; TBIL: Total bilirubin; DBIL: Direct bilirubin; IBIL: Indirect bilirubin; CREA: Creatinine; UA: Uric acid; TC: Total cholesterol; TG: Triglycerides; HDL-C: High-density lipoprotein cholesterol; LDL-C: Low-density lipoprotein cholesterol.

3.3.3 Comparative Analysis of MASLD Risk Factors Between High-Altitude and Non-High-Altitude Populations

Comparative analyses revealed a significantly higher proportion of Tibetan ethnicity in high-altitude populations (82.23% vs. 32.00%) and elevated alcohol consumption rates (48.41% vs. 41.25%) compared to non-high-altitude counterparts. Additionally, high-altitude residents exhibited significantly higher BMI, WC, HC, ALT, ALP, GGT, HGB, and DBIL levels (all $p < 0.05$), whereas non-high-altitude populations showed elevated SBP, DBP, FPG, TP, ALB, GLO, TC, and TG levels (Table 5).

Table 5. Comparative Analysis of MASLD Risk Factors Between High-Altitude and Non-High-Altitude Populations.

		High-altitude (n = 3084)	Non-high-altitude (n = 1275)	p
Age		46.00 (39.00, 54.00)	46.00 (37.00, 55.00)	0.337
Sex	Male	2736 (88.72%)	1129 (88.55%)	0.874
	Female	348 (11.28%)	146 (11.45%)	
Race	Han ethnic group	548 (17.77%)	867 (68.00%)	< 0.001
	Tibetan ethnic group	2536 (82.23%)	408 (32.00%)	
Alcohol Consumption	No	1591 (51.59%)	749 (58.75%)	< 0.001
	Yes	1493 (48.41%)	526 (41.25%)	
Hypertension	No	2789 (90.43%)	1139 (89.33%)	0.268
	Yes	295 (9.57%)	136 (10.67%)	
DM	No	2929 (94.97%)	1205 (94.51%)	0.529
	Yes	155 (5.03%)	70 (5.49%)	
BMI		27.29 (25.75, 29.23)	26.40 (25.08, 28.38)	< 0.001
WC		95.00 (90.00, 100.00)	91.00 (88.00, 97.00)	< 0.001
HC		99.00 (97.00, 103.00)	97.28 (96.00, 101.00)	< 0.001
SBP		119.00 (111.00, 129.00)	123.00 (114.00, 133.00)	< 0.001
DBP		74.00 (67.00, 82.00)	76.00 (70.00, 85.00)	< 0.001
WBC		6.01 (5.26, 7.04)	5.99 (5.23, 7.07)	0.753
PLT		209.65 (175.00, 242.00)	209.65 (177.00, 244.00)	0.372
LYMPH		1.92 (1.63, 2.30)	1.92 (1.62, 2.29)	0.957
NEUT		3.45 (2.90, 4.14)	3.45 (2.91, 4.13)	0.827
HGB		166.00 (156.00, 176.00)	161.79 (152.00, 170.00)	< 0.001
FPG		4.86 (4.63, 5.17)	4.90 (4.80, 5.32)	< 0.001
ALT		34.37 (28.00, 48.00)	34.37 (25.00, 44.00)	< 0.001
AST		23.02 (20.00, 27.00)	23.02 (19.00, 27.00)	0.104
ALP		84.00 (74.00, 100.00)	81.00 (67.00, 92.00)	< 0.001
GGT		44.56 (35.00, 66.00)	44.56 (29.00, 56.00)	< 0.001
TP		70.60 (67.90, 72.80)	71.40 (69.50, 74.40)	< 0.001
ALB		44.50 (42.60, 45.90)	45.00 (43.70, 47.10)	< 0.001
GLO		26.12 (23.80, 28.40)	26.20 (24.40, 28.80)	< 0.001
A/G		1.71 (1.52, 1.89)	1.72 (1.55, 1.87)	0.161
TBIL		12.60 (9.70, 15.40)	12.90 (9.80, 15.10)	0.665
DBIL		2.46 (2.00, 3.00)	2.40 (1.90, 2.80)	0.006

IBIL	10.54 (7.90, 12.10)	10.54 (8.00, 11.90)	0.778
UREA	4.98 (4.22, 5.63)	4.98 (4.25, 5.61)	0.989
CREA	73.53 (67.00, 81.00)	73.53 (67.00, 82.00)	0.078
UA	403.00 (362.00, 460.25)	403.00 (363.00, 457.00)	0.769
TC	4.84 (4.39, 5.46)	4.92 (4.48, 5.53)	0.009
TG	1.46 (1.14, 1.92)	1.54 (1.43, 2.18)	< 0.001
HDL-C	1.20 (1.05, 1.34)	1.21 (1.06, 1.33)	0.979
LDL-C	3.11 (2.73, 3.63)	3.11 (2.75, 3.61)	0.685
CAP	293.00 (270.00, 322.00)	294.00 (269.00, 325.00)	0.474
LSM	4.61 (4.10, 5.60)	4.70 (4.10, 5.45)	0.752

DM: Diabetes mellitus; BMI: Body mass index; WC: Waist circumference; HC: Hip circumference; CAP: Controlled attenuation parameter; LSM: Liver stiffness measurement; ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; ALP: Alkaline phosphatase; GGT: Gamma-glutamyl transferase; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; FPG: Fasting plasma glucose; WBC: White blood cell count; PLT: Platelet count; LYMPH: Lymphocyte count; NEUT: Neutrophil count; HGB: Hemoglobin; TP: Total protein; ALB: Albumin; GLO: Globulin; A/G: Albumin-to-globulin ratio; TBIL: Total bilirubin; DBIL: Direct bilirubin; IBIL: Indirect bilirubin; CREA: Creatinine; UA: Uric acid; TC: Total cholesterol; TG: Triglycerides; HDL-C: High-density lipoprotein cholesterol; LDL-C: Low-density lipoprotein cholesterol; VLDL-C: Very low-density lipoprotein cholesterol; BFM: Body fat mass; SMM: Skeletal muscle mass; PBF: Percent body fat.

3.4 Development and Validation of MASLD Nomograms

3.4.1 High-Altitude Population

Incorporating forward stepwise regression and relevant literature, sex, FPG, TG, GGT, WC, and HDL-C were selected to construct a nomogram for predicting MASLD in high-altitude populations (Figure 4A). The nomogram demonstrated robust discriminative ability with an AUC of 0.836 (95% CI: 0.825–0.847) (Figure 4B). DCA indicated substantial net benefit across the 0.1–0.8 risk threshold range, demonstrating significant clinical utility (Figure 4C). Calibration curves showed close agreement between predicted probabilities and observed outcomes (Figure 4D).

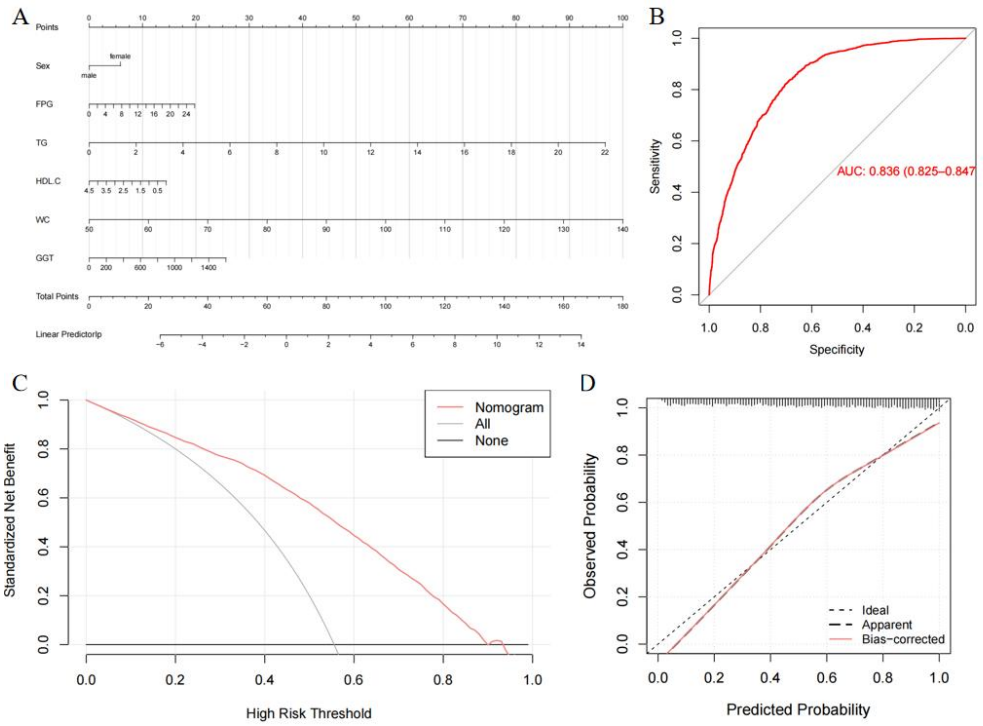


Figure 4. (A) Nomogram of MASLD-predictive risk factors in high-altitude populations. (B) Predictive performance of the nomogram model assessed by receiver operating characteristic (ROC) curve. (C) Decision curve analysis (DCA) of the nomogram model. (D) Calibration of the nomogram model.

3.4.2 Non-High-Altitude Population

Employing forward stepwise regression and evidence-based literature, sex, LSM, SBP, WC, FPG, UA, TG, and HDL-C were selected to develop a nomogram for predicting MASLD in non-high-altitude populations (Figure 5A). The nomogram exhibited strong predictive accuracy with an AUC of 0.885 (95% CI: 0.871–0.898) (Figure 5B). DCA demonstrated substantial net benefit within the 0.1–0.8 risk threshold range, confirming significant clinical utility (Figure 5C). Calibration curves indicated close concordance between predicted probabilities and actual observations (Figure 5D).

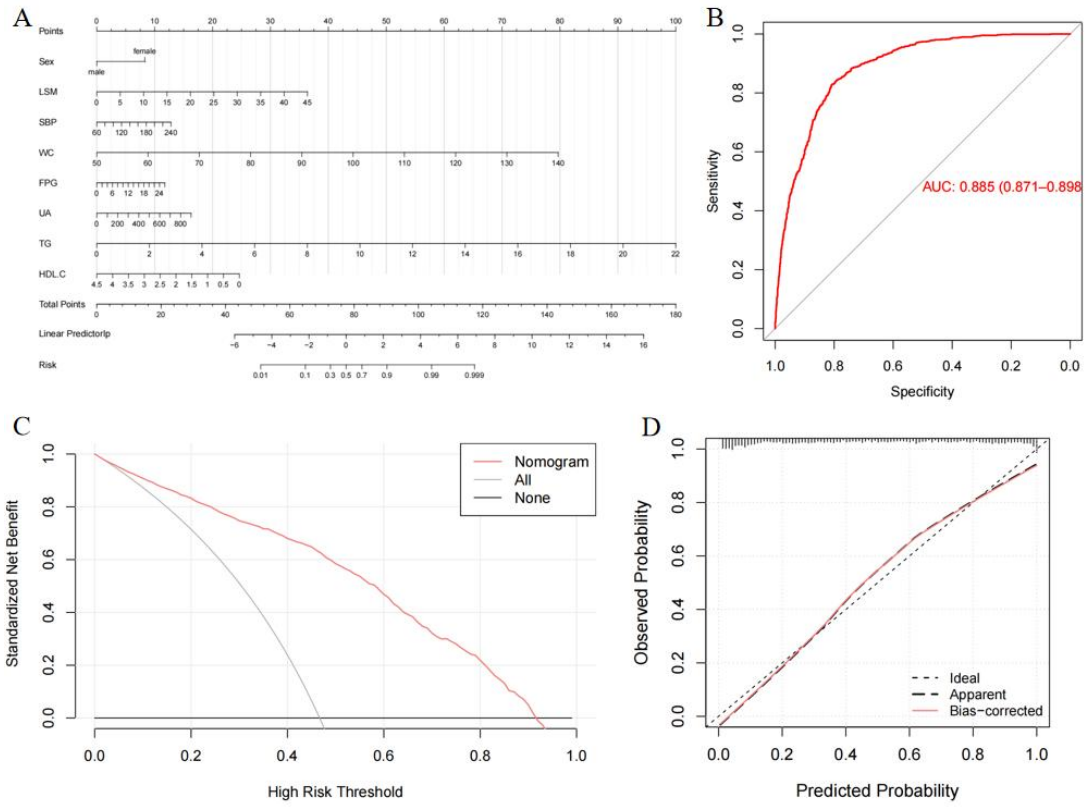


Figure 5. (A) Nomogram of MASLD-predictive risk factors in non-high-altitude populations. (B) Predictive performance of the nomogram model evaluated by receiver operating characteristic (ROC) curve. (C) Decision curve analysis (DCA) of the nomogram model. (D) Calibration of the nomogram model.

3.5 Interaction Analysis between Sex and Altitude

After adjusting for age, LSM, fasting plasma glucose, GGT, triglycerides, HDL-C, systolic and diastolic blood pressure, waist circumference, and uric acid, multivariable logistic regression revealed no statistically significant interaction between sex and altitude (OR=0.82, 95% CI: 0.44-1.52, p=0.524) (Table 6). This indicates that the association between sex and MASLD risk does not differ significantly between high-altitude and non-high-altitude populations.

In the adjusted model, male sex was associated with a lower risk of MASLD (OR=0.42, 95% CI: 0.24-0.74, p=0.002), while altitude itself showed no significant association with MASLD risk (OR=0.98, 95% CI: 0.55-1.75, p=0.943).

Table 6. Interaction Analysis between Sex and Altitude on MASLD Risk

Variable	OR (95% CI)	p-value
Main effects		
Sex (Male vs Female)	0.42 (0.24-0.74)	0.002
Altitude (High vs Low)	0.98 (0.55-1.75)	0.943
Interaction term		
Sex × Altitude	0.82 (0.44-1.52)	0.524

4. Discussion

In this study, the overall prevalence of MASLD was 51.52%, whereas Miao et al.(17) reported a global adult MASLD prevalence of approximately 30%, with 33.1% in Southeast Asia. The substantial variation in prevalence across studies may be attributed to differences in the demographic composition of the study populations. The higher prevalence observed here may be attributed to several factors. First, MASLD emphasizes metabolic-driven pathophysiology. Populations in Sichuan and Tibet, influenced by unique geographical environments and genetic predispositions, may exhibit metabolic disparities contributing to higher incidence. Second, our data were sourced from health examination centers, where individuals are more likely to present with suboptimal health or pre-existing conditions, potentially inflating prevalence estimates. Furthermore, multiple epidemiological studies indicate that MASLD prevalence in high-altitude regions significantly exceeds that in low-altitude areas, with disease risk exhibiting dose-dependent elevation with altitude(18). Our findings align with these observations: chronic hypoxia induces reactive oxygen species (ROS) accumulation and suppresses the PI3K-Akt signaling pathway, enhancing hepatic gluconeogenesis and lipogenesis(10). Hypoxia activates hypoxia-inducible factor-1α (HIF-1α), upregulating fatty acid synthase (FASN) expression, leading to lipid dysregulation and intrahepatic lipid accumulation(10, 11). Hypoxia also activates Kupffer cells via the TLR4/NF-κB pathway, promoting TNF-α and IL-6 release, which exacerbates hepatic inflammation and fibrosis(13).

Furthermore, this study found no significant difference in the prevalence of MASLD between Tibetan populations residing in high-altitude and non-high-altitude regions. This observation may be attributable to the complex synergistic interplay among genetic adaptations, unique metabolic characteristics, traditional dietary habits, and environmental factors within the high-altitude Tibetan population, collectively counteracting the potential adverse hepatic effects of chronic hypoxia. At the genetic level, Tibetans have evolved distinct genetic traits through long-term adaptation to the hypoxic high-altitude environment. For instance, the EPAS1 gene variant rs1868092 enhances hemoglobin production efficiency, prevents excessive erythrocytosis, and optimizes oxygen transport capacity(19). This likely contributes to mitigating potential hypoxic liver injury, resulting in a non-significantly higher MASLD prevalence in high-altitude Tibetans compared to their non-high-altitude counterparts. Metabolically, high-altitude Tibetans exhibit elevated levels of adipokines (e.g., adiponectin and leptin)(20, 21). These promote fatty acid oxidation and suppress hepatic de novo lipogenesis via AMPK pathway activation, while their anti-inflammatory properties attenuate hepatic inflammation, collectively reducing MASLD risk. Dietarily, the traditional yak milk fat consumed by high-altitude Tibetans contains a significantly higher proportion of conjugated linoleic acid (CLA) than conventional dairy products. CLA can activate the PPARα pathway, promoting fatty acid oxidation and inhibiting hepatic lipid accumulation(22). Another staple, high-

fiber highland barley, is rich in β-glucan. This compound improves gut microbiota composition and increases short-chain fatty acid production, potentially activating the AMPK signaling pathway to ameliorate hepatic lipid metabolism disorders and reduce lipid deposition(23). Environmentally, intense high-altitude ultraviolet radiation promotes cutaneous vitamin D synthesis. High-altitude Tibetans exhibit serum 25(OH)D3 levels approximately 20% higher than those in lowland populations, and vitamin D deficiency is positively correlated with hepatic steatosis(24). Furthermore, the cold high-altitude environment enhances brown adipose tissue activity in Tibetans, increasing non-shivering thermogenesis and raising basal metabolic rate by approximately 15%. This promotes systemic lipid consumption, indirectly reducing hepatic fat burden(25). The influence of altitude on MASLD prevalence is complex and potentially modulated by multiple factors. Future research is warranted to elucidate these intricate relationships and develop more targeted strategies for MASLD prevention and treatment.

Concurrently, the study observed no significant difference in MASLD prevalence between individuals over 70 years old residing in high-altitude and non-high-altitude regions. This phenomenon is likely driven by multiple converging factors. Enhanced survivorship bias in the elderly is a key consideration, as the unique high-altitude environment (hypoxia, cold, intense ultraviolet radiation) may selectively favor older individuals with superior metabolic adaptability. Their inherent genetic advantages or optimized mitochondrial function could counteract MASLD risk, while less adapted individuals may have succumbed earlier to metabolic complications, resulting in a convergence of baseline risk with the non-high-altitude elderly population(26). Additionally, age-related metabolic alterations, including decreased basal metabolic rate, sarcopenia, and prevalent IR, diminish the independent impact of the high-altitude environment on fat deposition. Long-term high-altitude exposure may also activate adaptive compensatory mechanisms, leading to metabolic patterns that converge with those of non-high-altitude elderly groups(27). Moreover, the effect of environmental differences is further attenuated by confounding factors such as polypharmacy for comorbidities, potential diagnostic biases, sample size limitations, and behavioral and environmental exposure convergence in the elderly (e.g., lifestyle adjustments, widespread access to healthcare management). These results suggest that the metabolic health of the high-altitude elderly may reflect uniqueness shaped by natural selection and long-term adaptation. However, clinical interventions still necessitate individualized assessment. Future research should expand sample sizes, employ prospective longitudinal designs to clarify age-environment interactions, and further explore the molecular mechanisms underpinning metabolic adaptation in high-altitude elderly populations, alongside the epidemiological impact of survivorship bias.

To establish a predictive model, this study performed risk factor analysis. The results demonstrated that TG and WC are independent risk factors for MASLD common to both populations. Elevated TG is a well-established risk factor for MASLD(28-30), as elevated TG

reflects increased upstream diacylglycerol (DAG) synthesis. DAG activates protein kinase C-ε (PKC-ε) in the liver, contributing to IR and disease progression(31, 32). Furthermore, TG stored in lipid droplets releases free fatty acids (FFAs) into hepatocytes via lipolysis, with excess FFAs promoting lipotoxic metabolite generation, oxidative stress, and inflammation(33), thereby increasing MASLD risk. WC serves as an independent risk factor for MASLD, primarily reflecting visceral adiposity. Excessive visceral adipose tissue secretes elevated FFAs, which contribute to hepatic triglyceride synthesis(34). Concurrently, these FFAs disrupt normal tyrosine phosphorylation, thereby mediating IR development(35), ultimately elevating MASLD incidence.

In addition, our findings indicate that GGT is an independent risk factor for MASLD in the high-altitude population. Multiple studies have established GGT as a biomarker for the development of IR, reflecting early biochemical manifestations of MASLD(36). Consistent with prior studies(37, 38), HDL-C emerged as an independent protective factor. HDL-C exerts antioxidant and anti-inflammatory effects(39), and its major component, apolipoprotein A-I, enhances peroxisome proliferator-activated receptor α (PPARα) expression to mitigate IR and lipid deposition(40).

In constructing the final predictive model, additional variables were included based on established evidence from the literature. LSM is not a strictly risk factor but an indicator of MASLD severity(41, 42), reflecting lipid dysregulation(41) and inflammatory responses(43). While high-altitude populations had higher overall LSM levels, the difference between MASLD patients and non-MASLD individuals was more pronounced in non-high-altitude groups. This suggests that cutoff values for this marker should be adjusted for high-altitude populations. Blood pressure (SBP/DBP) was included in the prediction model for the non-high-altitude population(44). Potential explanations include hypoxia-induced adaptive changes, such as altered endothelial function(45) and elevated hemoglobin levels, which may attenuate hypertension's adverse effects on hepatic microcirculation. UA, confirmed as a risk factor by multiple studies(46, 47), promotes MASLD via endoplasmic reticulum stress, mitochondrial ROS generation, and SREBP-1c activation(48). In summary, our findings demonstrate distinct disparities between high-altitude and non-high-altitude populations in hepatic injury, blood pressure profiles, obesity status and renal function. Compared to non-high-altitude populations, chronic hypoxia-driven oxidative stress and glucolipid metabolic dysregulation in high-altitude residents likely play a more critical role in MASLD pathogenesis. This predominant mechanism may obscure the influence of other conventional risk factors observed in non-high-altitude populations.

The majority of the risk factors identified in this study, such as elevated fasting plasma glucose, elevated triglycerides, reduced high-density lipoprotein cholesterol, central obesity, and hypertension, have also been established as influential factors for cardiovascular disease(49). More importantly, substantial evidence indicates that MASLD itself is an independent risk factor for the incidence and mortality of cardiovascular disease (CVD)(50). The core pathophysiological links lie in chronic low-grade inflammation, insulin resistance, and lipotoxicity(51). These shared

mechanisms form the essence of the multiple parallel hits hypothesis, driving not only intrahepatic fat accumulation, inflammation, and fibrosis but also promoting the development of atherosclerosis, left ventricular dysfunction, and arrhythmias through pathways involving pro-inflammatory cytokines and oxidative stress(52-54). Therefore, research and prediction of MASLD hold clinical significance not only for preventing the liver disease itself but also for managing the risk of cardiovascular events.

A notable observation was that female sex served as a protective factor in non-high-altitude groups. Epidemiological studies consistently report lower MASLD prevalence in females(55), attributed to genetic factors (e.g., PNPLA3 variants(56)), higher gut microbiota diversity(57), sex-specific immune responses(58), and hormonal effects. Estrogen enhances insulin sensitivity via nuclear estrogen receptor-α(59), while androgens promote visceral adiposity through PPAR pathways. However, hypoxia may suppress estrogen levels in high-altitude females more profoundly than androgen changes in males(60), suggesting a potential pivotal role for sex hormones in MASLD sex disparities. Based on this premise, we conducted a dedicated sex-by-altitude interaction analysis. Contrary to the descriptive findings, this analysis did not reveal a statistically significant interaction between sex and altitude on MASLD. This discrepancy may be because the formal interaction analysis controlled for confounders through multivariable adjustment, potentially attenuating the apparent association; alternatively, it might reflect limited statistical power in the present study to detect such a specific interaction effect. Further studies with larger sample sizes, detailed hormonal assessments, and prospective designs are warranted to confirm whether the effect of sex on MASLD risk is significantly modified by geographical environment and to elucidate the underlying biological mechanisms.

Based on logistic regression analysis results, integrated with pathophysiological mechanisms and clinical expertise, we developed nomogram prediction models for MASLD in both populations. ROC curves, calibration curves, and DCA confirmed robust predictive performance. While numerous MASLD prediction models exist(61-63), this represents the first study dedicated to developing a MASLD prediction model tailored for high-altitude populations to our knowledge. MASLD arises from the interplay of genetic predisposition, metabolic profiles, lifestyle factors, and environmental conditions. Significant differences exist between high-altitude and non-high-altitude populations across these dimensions, indicating that existing MASLD prediction models developed solely for non-high-altitude populations are not directly applicable to high-altitude residents. The nomogram we developed, incorporating six parameters (sex, FPG, TG, GGT, WC and HDL-C), enables the calculation of MASLD risk probabilities in high-altitude populations. This tool integrates essential clinical data, hepatic function parameters, and glucolipid metabolic markers—all of which are comprehensive, easily obtainable, and provide robust support for clinical decision-making, demonstrating substantial clinical utility. The non-high-altitude model (including sex, LSM, SBP, WC, FPG, UA, TG and HDL-C) also demonstrates strong clinical applicability.

Our study has several limitations that warrant attention. First, as a retrospective cross-sectional study, the findings are susceptible to selection bias and cannot infer causality; the identified risk factors should therefore be interpreted as potential ones rather than causal determinants. Second, significant sample imbalance exists, which may affect the robustness and estimation precision of both the between-group comparisons and the predictive models. Moreover, the CAP diagnostic cutoff ($\geqslant$248 dB/m) used in this study has not been specifically validated in high-altitude populations; its applicability under special environmental conditions such as plateau hypoxia remains to be confirmed. Finally, the single-center dataset and lack of external validation limit the generalizability of the results. Future studies should involve multi-center collaborations to better reflect the general situation in high-altitude regions and should systematically collect more detailed information on potential confounders or effect modifiers. Analyzing altitude as a continuous variable rather than a categorical one may help more precisely reveal the dose-response relationship between altitude exposure and MASLD risk. By incorporating this richer information, future research is expected to refine and validate the findings of this study.

5. Conclusion

This retrospective cross-sectional study systematically investigated the prevalence, risk factors, and predictive models of MASLD in high-altitude and non-high-altitude populations, yielding critical insights into the association between geographical environment and metabolic liver disease. Both high-altitude and non-high-altitude populations are influenced by multiple factors, including age, sex, obesity, and various biochemical parameters, with glucose and lipid metabolism playing the most prominent roles. Additionally, non-high-altitude populations are significantly affected by hepatic metabolic status, blood pressure, renal function, and lifestyle factors. However, high-altitude regions demonstrated higher rates of alcohol consumption and obesity (BMI, WC, and HC), elevated hepatic metabolic markers (ALT, ALP, GGT), HGB, and DBIL compared to non-high-altitude regions. In contrast, non-high-altitude populations exhibited higher levels of SBP, DBP, FPG, TP, ALB, GLO, TC, and TG. In summary, this study provides the first comprehensive evidence of geographical disparities in MASLD epidemiology and risk factors between high-altitude and non-high-altitude populations, and introduces the first MASLD prediction nomogram tailored for high-altitude residents. These findings have important implications for public health practice and they support the development of altitude-specific MASLD prevention strategies.

Abbreviations

The following abbreviations are used in this manuscript:

MASLD	Metabolic dysfunction-associated steatotic liver disease
NAFLD	Non-alcoholic fatty liver disease
MAFLD	Metabolic-associated fatty liver disease
T2D	Type 2 diabetes mellitus
DM	Diabetes mellitus

MetS	Metabolic syndrome
BP	Blood pressure
BMI	Body mass index
WC	Waist circumference
HC	Hip circumference
CAP	Controlled attenuation parameter
LSM	Liver stiffness measurement
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
ALT	Alanine aminotransferase
AST	aspartate aminotransferase
ALP	Alkaline phosphatase
GGT	Gamma-glutamyl transferase
WBC	White blood cell count
PLT	Platelet count
HGB	Hemoglobin
TP	Total protein
ALB	Albumin
GLO	Globulin
A/G	Albumin-to-globulin ratio
TBIL	Total bilirubin
DBIL	Direct bilirubin
IBIL	Indirect bilirubin
CREA	Creatinine
UA	Uric acid
TC	Total cholesterol
TG	Triglycerides
HDL-C	High-density lipoprotein cholesterol
LDL-C	Low-density lipoprotein cholesterol
VLDL-C	Very low-density lipoprotein cholesterol
FPG	Fasting plasma glucose
LYMPH	Lymphocyte count
NEUT	Neutrophil count
BFM	Body fat mass
SMM	Skeletal muscle mass
PBF	Percent body fat
SD	Standard deviation
IQR	Interquartile range
ORs	Odds ratios
CIs	Confidence intervals
ROC	Receiver operating characteristic
DCA	Decision curve analysis
ROS	Reactive oxygen species
HIF-1α	Hypoxia-inducible factor-1α

FASN	Fatty acid synthase
CLA	Conjugated linoleic acid
G6P	Glucose-6-phosphate
DAG	Diacylglycerol
PKC-ε	Protein kinase C-ε
FFAs	Free fatty acids
PPARα	Peroxisome proliferator-activated receptor α

Declarations

Ethics statement

This study received ethical approval from the Institutional Review Board of West China Hospital, Sichuan University (Approval No.: 2024-1244). The studies were conducted in accordance with the local legislation and institutional requirements.

Consent for publication

Not applicable.

Availability of data and materials

The data supporting the findings of this study are available upon reasonable request from the corresponding author. The data are not publicly available due to patient confidentiality and institutional restrictions.

Conflict of Interest

The authors declare that they have no competing interests.

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Author Contributions

CX and XM designed the research study. XZ and RP extracted and analyzed the data, and drafted the manuscript. JL and RH designed the chart. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

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References

1. Eslam M, Sanyal AJ, George J. MAFLD: A Consensus-Driven Proposed Nomenclature for Metabolic Associated Fatty Liver Disease. Gastroenterology. 2020;158(7):1999-2014.e1.
2. Rinella ME, Lazarus JV, Ratziu V, Francque SM, Sanyal AJ, Kanwal F, et al. A multisociety Delphi consensus statement on new fatty liver disease nomenclature. Hepatology. 2023;78(6):1966-86.
3. Younossi ZM, Kalligeros M, Henry L. Epidemiology of metabolic dysfunction-associated

steatotic liver disease. Clin Mol Hepatol. 2025;31(Suppl):S32-s50.
4. Kendall TJ, Jimenez-Ramos M, Turner F, Ramachandran P, Minnier J, McColgan MD, et al. An integrated gene-to-outcome multimodal database for metabolic dysfunction-associated steatotic liver disease. Nat Med. 2023;29(11):2939-53.
5. Golabi P, Paik JM, AlQahtani S, Younossi Y, Tuncer G, Younossi ZM. Burden of non-alcoholic fatty liver disease in Asia, the Middle East and North Africa: Data from Global Burden of Disease 2009-2019. J Hepatol. 2021;75(4):795-809.
6. Adams LA, Anstee QM, Tilg H, Targher G. Non-alcoholic fatty liver disease and its relationship with cardiovascular disease and other extrahepatic diseases. Gut. 2017;66(6):1138-53.
7. Chan WK, Chuah KH, Rajaram RB, Lim LL, Ratnasingam J, Vethakkan SR. Metabolic Dysfunction-Associated Steatotic Liver Disease (MASLD): A State-of-the-Art Review. J Obes Metab Syndr. 2023;32(3):197-213.
8. Chen R, Yang J, Liu C, Ke J, Gao X, Yang Y, et al. Blood pressure and left ventricular function changes in different ambulatory blood pressure patterns at high altitude. J Clin Hypertens (Greenwich). 2021;23(6):1133-43.
9. Yuan Z, Zou Y, Liu X, Wang L, Chen C. Longitudinal study on blood and biochemical indexes of Tibetan and Han in high altitude area. Front Public Health. 2023;11:1282051.
10. Midha AD, Zhou Y, Queliconi BB, Barrios AM, Haribowo AG, Chew BTL, et al. Organ-specific fuel rewiring in acute and chronic hypoxia redistributes glucose and fatty acid metabolism. Cell Metab. 2023;35(3):504-16.e5.
11. Wu D, Yang Y, Hou Y, Zhao Z, Liang N, Yuan P, et al. Increased mitochondrial fission drives the reprogramming of fatty acid metabolism in hepatocellular carcinoma cells through suppression of Sirtuin 1. Cancer Commun (Lond). 2022;42(1):37-55.
12. Niu M, Chen J, Hou R, Sun Y, Xiao Q, Pan X, et al. Emerging healthy lifestyle factors and all-cause mortality among people with metabolic syndrome and metabolic syndrome-like characteristics in NHANES. J Transl Med. 2023;21(1):239.
13. Ortiz-López N, Fuenzalida C, Dufeu MS, Pinto-León A, Escobar A, Poniachik J, et al. The immune response as a therapeutic target in non-alcoholic fatty liver disease. Front Immunol. 2022;13:954869.
14. Wang X, Wu S, Yuan X, Chen S, Fu Q, Sun Y, et al. Metabolic Dysfunction-associated Fatty Liver Disease and Mortality Among Chinese Adults: a Prospective Cohort Study. J Clin Endocrinol Metab. 2022;107(2):e745-e55.
15. EASL-EASD-EASO Clinical Practice Guidelines on the management of metabolic dysfunction-associated steatotic liver disease (MASLD). J Hepatol. 2024;81(3):492-542.
16. Karlas T, Petroff D, Sasso M, Fan JG, Mi YQ, de Lédinghen V, et al. Individual patient data meta-analysis of controlled attenuation parameter (CAP) technology for assessing steatosis. J Hepatol. 2017;66(5):1022-30.
17. Miao L, Targher G, Byrne CD, Cao YY, Zheng MH. Current status and future trends of the global burden of MASLD. Trends Endocrinol Metab. 2024;35(8):697-707.
18. Wang Y, Meng Q, Zhang J, Guo B, Li N, Deng Q, et al. Altitude and Metabolic Dysfunction-Associated Fatty Liver Disease (MAFLD) in China: A Population-Based Study. High altitude medicine & biology. 2025;26(2):148-55.
19. Li C, Li X, Xiao J, Liu J, Fan X, Fan F, et al. Genetic changes in the EPAS1 gene between Tibetan and Han ethnic groups and adaptation to the plateau hypoxic environment. PeerJ. 2019;7:e7943.

20. Shi J, Jia Z, Sun J, Wang X, Zhao X, Zhao C, et al. Structural variants involved in high-altitude adaptation detected using single-molecule long-read sequencing. Nat Commun. 2023;14(1):8282.
21. Zhang LX, Sun Y, Liang Y, Li K, Chen Y, Gusanglamu, et al. Relationship between dyslipidemia and gene polymorphism in Tibetan population. Biomed Environ Sci. 2012;25(3):305-10.
22. Cai D, Li Y, Zhang K, Zhou B, Guo F, Holm L, et al. Co-option of PPARα in the regulation of lipogenesis and fatty acid oxidation in CLA-induced hepatic steatosis. Journal of cellular physiology. 2021;236(6):4387-402.
23. Liu H, Nie C, Hu X, Li J. Highland barley β-glucan supplementation attenuated hepatic lipid accumulation in Western diet-induced non-alcoholic fatty liver disease mice by modulating gut microbiota. Food & function. 2024;15(3):1250-64.
24. Barchetta I, Cimini FA, Cavallo MG. Vitamin D and Metabolic Dysfunction-Associated Fatty Liver Disease (MAFLD): An Update. Nutrients. 2020;12(11).
25. Mihaylov SR, Castelli LM, Lin YH, Gül A, Soni N, Hastings C, et al. The master energy homeostasis regulator PGC-1 α exhibits an mRNA nuclear export function. Nature communications. 2023;14(1):5496.
26. Zhou T, Xie C. Association between Triglyceride-Glucose index and onset of type 2 diabetes in metabolic Dysfunction-Associated steatotic liver disease population. Sci Rep. 2025;15(1):18044.
27. Wu W, Chen G, Zhang X, Wu H, Wang YE, Li X, et al. The effect of long-term exposure to moderate high altitude on adipokines and insulin sensitivity. Cytokine. 2025;185:156823.
28. Kahl S, Straßburger K, Pacini G, Trinks N, Pafili K, Mastrototaro L, et al. Dysglycemia and liver lipid content determine the relationship of insulin resistance with hepatic OXPHOS capacity in obesity. Journal of hepatology. 2025;82(3):417-26.
29. Qi X, Li J, Caussy C, Teng GJ, Loomba R. Epidemiology, screening, and co-management of type 2 diabetes mellitus and metabolic dysfunction-associated steatotic liver disease. Hepatology (Baltimore, Md). 2024.
30. Feng X, Zhang R, Yang Z, Zhang K, Xing J. Mechanism of Metabolic Dysfunction-associated Steatotic Liver Disease: Important role of lipid metabolism. Journal of clinical and translational hepatology. 2024;12(9):815-26.
31. Scoditti E, Sabatini S, Carli F, Gastaldelli A. Hepatic glucose metabolism in the steatotic liver. Nature reviews Gastroenterology & hepatology. 2024;21(5):319-34.
32. Lyu K, Zhang Y, Zhang D, Kahn M, Ter Horst KW, Rodrigues MRS, et al. A Membrane-Bound Diacylglycerol Species Induces PKCε-Mediated Hepatic Insulin Resistance. Cell metabolism. 2020;32(4):654-64.e5.
33. Friedman SL, Neuschwander-Tetri BA, Rinella M, Sanyal AJ. Mechanisms of NAFLD development and therapeutic strategies. Nature medicine. 2018;24(7):908-22.
34. Li Y, Yang P, Ye J, Xu Q, Wu J, Wang Y. Updated mechanisms of MASLD pathogenesis. Lipids in health and disease. 2024;23(1):117.
35. Den Hartogh DJ, Vlavcheski F, Tsiani E. Muscle Cell Insulin Resistance Is Attenuated by Rosmarinic Acid: Elucidating the Mechanisms Involved. International journal of molecular sciences. 2023;24(6).
36. Adams LA, Lindor KD. Nonalcoholic fatty liver disease. Annals of epidemiology. 2007;17(11):863-9.
37. Ye L, Yan K, Tian Z, Xiao ZH, Xie RY, Xie ZY, et al. Helicobacter pylori infection is linked to metabolic dysfunction and associated steatotic liver disease: A large cross-sectional study. World

journal of gastroenterology. 2025;31(13):102563.
38. Martínez-Montoro JI, Martínez-Sánchez MA, Balaguer-Román A, Fernández-Ruiz VE, Hernández-Barceló JE, Ferrer-Gómez M, et al. Triglyceride to HDL Cholesterol Ratio for the Identification of MASLD in Obesity: A Liver Biopsy-Based Case-Control Study. Nutrients. 2024;16(9).
39. Durrington PN, Bashir B, Soran H. How Does HDL Participate in Atherogenesis? Antioxidant Activity Versus Role in Reverse Cholesterol Transport. Antioxidants (Basel, Switzerland). 2025;14(4).
40. Wang Y, Zhang Y, Wang Y. Overexpression of Apolipoprotein A-I Alleviates Insulin Resistance in MASLD Mice Through the PPARα Pathway. International journal of molecular sciences. 2025;26(3).
41. Kobayashi T, Iwaki M, Nogami A, Kawamura N, Honda Y, Ogawa Y, et al. Prediction of outcomes in patients with metabolic dysfunction-associated steatotic liver disease based on initial measurements and subsequent changes in magnetic resonance elastography. Journal of gastroenterology. 2024;59(1):56-65.
42. Muñoz Rossi FA, Salazar Agudelo J, Quinapanta Castro NI, Mosquera SZ, Mejia Fajardo MC, Mosquera López ED, et al. Relationship Between Metabolic Dysfunction-Associated Steatotic Liver Disease and Lipoprotein (a) and Other Biomarkers. Cureus. 2024;16(6):e63019.
43. Chen J, Zhou H, Jin H, Liu K. Role of Inflammatory Factors in Mediating the Effect of Lipids on Nonalcoholic Fatty Liver Disease: A Two-Step, Multivariable Mendelian Randomization Study. Nutrients. 2022;14(20).
44. Cao W, Jiang T, Deng W, Wang S, Li X, Zhang Z, et al. Insulin resistance has closer correlation with the occurrence of metabolic dysfunction associated steatotic liver disease diagnosed by liver biopsy. Frontiers in medicine. 2024;11:1384927.
45. Duo D, Duan Y, Zhu J, Bai X, Yang J, Liu G, et al. New strategy for rational use of antihypertensive drugs in clinical practice in high-altitude hypoxic environments. Drug metabolism reviews. 2023;55(4):388-404.
46. Shi D, Tan Q, Zhang Y, Qi X, Xu X, Xu G, et al. Serum uric acid trajectories and risk of metabolic dysfunction-associated steatotic liver disease in China: a 2019-2021 cohort health survey. BMC public health. 2025;25(1):653.
47. Chen W, Deng Y, Li M, Li J, Cao Y, Xie W. Serum uric acid and mortality in metabolic dysfunction-associated steatotic liver disease: Subgroup differences. Nutrition, metabolism, and cardiovascular diseases : NMCD. 2024;34(12):2771-8.
48. Choi YJ, Shin HS, Choi HS, Park JW, Jo I, Oh ES, et al. Uric acid induces fat accumulation via generation of endoplasmic reticulum stress and SREBP-1c activation in hepatocytes. Laboratory investigation; a journal of technical methods and pathology. 2014;94(10):1114-25.
49. Hajar R. Framingham Contribution to Cardiovascular Disease. Heart views : the official journal of the Gulf Heart Association. 2016;17(2):78-81.
50. Duell PB, Welty FK, Miller M, Chait A, Hammond G, Ahmad Z, et al. Nonalcoholic Fatty Liver Disease and Cardiovascular Risk: A Scientific Statement From the American Heart Association. Arteriosclerosis, thrombosis, and vascular biology. 2022;42(6):e168-e85.
51. Targher G, Byrne CD, Tilg H. MASLD: a systemic metabolic disorder with cardiovascular and malignant complications. Gut. 2024;73(4):691-702.
52. Anstee QM, Mantovani A, Tilg H, Targher G. Risk of cardiomyopathy and cardiac arrhythmias in patients with nonalcoholic fatty liver disease. Nature reviews Gastroenterology & hepatology.

2018;15(7):425-39.
53. Yong JN, Ng CH, Lee CW, Chan YY, Tang ASP, Teng M, et al. Non-alcoholic fatty liver disease association with structural heart, systolic and diastolic dysfunction: a meta-analysis. Hepatology international. 2022;16(2):269-81.
54. Di Minno MN, Di Minno A, Ambrosino P, Songia P, Tremoli E, Poggio P. Aortic valve sclerosis as a marker of atherosclerosis: Novel insights from hepatic steatosis. International journal of cardiology. 2016;217:1-6.
55. Kan C, Zhang K, Wang Y, Zhang X, Liu C, Ma Y, et al. Global burden and future trends of metabolic dysfunction-associated Steatotic liver disease: 1990-2021 to 2045. Annals of hepatology. 2025;30(2):101898.
56. Sookoian S, Pirola CJ. Meta-analysis of the influence of I148M variant of patatin-like phospholipase domain containing 3 gene (PNPLA3) on the susceptibility and histological severity of nonalcoholic fatty liver disease. Hepatology (Baltimore, Md). 2011;53(6):1883-94.
57. Shi J, Yang Y, Xu W, Cai H, Wu J, Long J, et al. Sex-Specific Associations between Gut Microbiome and Non-Alcoholic Fatty Liver Disease among Urban Chinese Adults. Microorganisms. 2021;9(10).
58. Sutti S, Albano E. Adaptive immunity: an emerging player in the progression of NAFLD. Nature reviews Gastroenterology & hepatology. 2020;17(2):81-92.
59. Dakin RS, Walker BR, Seckl JR, Hadoke PW, Drake AJ. Estrogens protect male mice from obesity complications and influence glucocorticoid metabolism. International journal of obesity (2005). 2015;39(10):1539-47.
60. Chen J, Chen J, Fu H, Li Y, Wang L, Luo S, et al. Hypoxia exacerbates nonalcoholic fatty liver disease via the HIF-2α/PPARα pathway. American journal of physiology Endocrinology and metabolism. 2019;317(4):E710-e22.
61. Liu Y, Wang Y, Xing Y, Wolters M, Shi D, Zhang P, et al. Establish a noninvasive model to screen metabolic dysfunction-associated steatotic liver disease in children aged 6-14 years in China and its applications in high-obesity-risk countries and regions. The Lancet regional health Western Pacific. 2024;49:101150.
62. Chen H, Zhang J, Chen X, Luo L, Dong W, Wang Y, et al. Development and validation of machine learning models for MASLD: based on multiple potential screening indicators. Frontiers in endocrinology. 2024;15:1449064.
63. Duran-Bertran J, Rusu EC, Barrientos-Riosalido A, Bertran L, Mahmoudian R, Aguilar C, et al. Platelet-associated biomarkers in nonalcoholic steatohepatitis: Insights from a female cohort with obesity. European journal of clinical investigation. 2024;54(3):e14123.