

# Impact of Pathological Grades of Metabolic Dysfunction-Associated Steatotic Liver Disease on Weight Loss Following Laparoscopic Sleeve Gastrectomy

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**Purpose:** The impact of hepatic steatosis severity on postoperative weight loss outcomes remains unclear. This study aimed to evaluate the effect of fatty liver severity on percentage of excess weight loss (%EWL) in patients undergoing laparoscopic sleeve gastrectomy (LSG).

**Methods:** This retrospective cohort study included 226 patients with obesity who underwent LSG. Baseline data included liver biopsy grade (mild, moderate, or severe), body mass index (BMI), liver function, and metabolic parameters. Postoperative outcomes were assessed at 1, 3, 6, and 12 months. Statistical methods included the Pearson and Spearman correlations, chi-square test, Kruskal–Wallis test, general linear models, Kaplan–Meier analysis, and multivariate regression to identify the predictors of weight loss and cumulative rates of achieving 50% EWL and to plot the cumulative incidence curve.

**Results:** Baseline BMI, homeostasis model assessment for insulin resistance, free fatty acids, and A1C levels were significantly associated with steatosis severity ( $P < 0.05$ ). Severe metabolic dysfunction-associated steatotic liver disease (MASLD) was associated with a lower %EWL at 1, 3, 6, and 12 months (1 month %EWL: 32.34% vs 38.59% in the mild group;  $P < 0.05$ ). The Kaplan–Meier analysis showed delayed achievement of 50% EWL in the severe group ( $P < 0.05$ ). Multivariate regression analysis identified MASLD severity and preoperative BMI as independent predictors of %EWL. General linear models confirmed the significant dynamic effects of MASLD severity on weight loss over time ( $P < 0.05$ ).

**Conclusion:** MASLD severity significantly affects postoperative weight loss and delays the achievement of optimal outcomes, especially in the early postoperative period. Preoperative evaluation of liver pathology is essential for optimizing surgical outcomes in patients with obese having MASLD.

**Keywords:** obesity, fatty liver, bariatric surgery, insulin resistance

## Introduction

The prevalence of metabolic dysfunction-associated steatotic liver disease (MASLD) has been steadily increasing worldwide,<sup>1,2</sup> particularly in Asia and among Chinese populations,<sup>3,4</sup> where the increase in obesity rates is more pronounced.<sup>4–6</sup> MASLD is a hepatic condition characterized by excessive fat accumulation in hepatocytes without significant alcohol consumption. MASLD is often accompanied by inflammation and fibrosis, which may progress to cirrhosis and hepatocellular carcinoma.<sup>6</sup> In China, the prevalence of MASLD has reached approximately 30%, primarily driven by lifestyle changes and increasing obesity rates, posing a significant public health threat.<sup>7,8</sup> Obesity is regarded as the primary driving factor for MASLD, and its pathogenesis involves intricate interactions among hepatic steatosis,

oxidative stress, and chronic inflammation. Consequently, weight management is recognized as one of the most crucial therapeutic strategies for addressing MASLD.<sup>4,9,10</sup>

Although no specific pharmacological treatment for MASLD has been identified to date, weight loss has been shown through various clinical approaches to effectively improve the pathological characteristics of MASLD.<sup>11–15</sup>

Laparoscopic sleeve gastrectomy (LSG) is among the most commonly performed bariatric procedures globally owing to its simplicity, safety, and efficacy. LSG has been shown to provide significant benefits in body weight reduction and the management of obesity-related comorbidities. LSG induces substantial weight loss by reducing gastric volume, modifying gut hormone secretion, and suppressing appetite, which collectively enhances insulin sensitivity and glycemic control.<sup>16</sup> Additionally, LSG significantly enhances metabolic parameters, including lipid profile, liver enzyme levels, and blood glucose levels. LSG has been demonstrated to ameliorate or resolve type 2 diabetes (T2D), dyslipidemia, and hypertension in many patients.<sup>17</sup> LSG has been shown to improve liver histology in patients with MASLD, including reduction in hepatic steatosis, inflammation, and fibrosis.<sup>18,19</sup>

These findings establish LSG as an effective therapeutic approach, not only for achieving weight loss but also for enhancing metabolic health, with sustained benefits in mitigating obesity-associated complications.<sup>20</sup> LSG reduces gastric volume and modulates gastrointestinal hormone secretion to suppress appetite. Multiple studies have shown that LSG significantly improves hepatic steatosis and fibrosis among patients with MASLD.<sup>21</sup> A study showed that bariatric surgery improves obesity-related metabolic parameters and can partially reverse MASLD progression.<sup>17</sup>

However, MASLD demonstrates significant pathological heterogeneity among patients, with the condition commonly classified as mild, moderate, or severe, based on liver biopsy findings. Varying degrees of MASLD severity may affect postoperative outcomes after LSG,<sup>22</sup> although studies in this area remains limited. Some studies have suggested that the severity of fatty liver in patients with MASLD may affect postoperative weight loss and metabolic improvements; however, specific differences in outcomes among pathological grades remain poorly understood. Furthermore, obesity and MASLD are prevalent chronic conditions, and achieving a favorable postoperative prognosis is critical for these patients. Thus, preoperative evaluation of postoperative outcomes and the development of individualized therapeutic strategies are essential.

Based on these considerations, this study investigated the effect of MASLD severity, determined through pathological grading, on postoperative outcomes following LSG. By examining the differences in postoperative weight loss across various MASLD grades, this study aimed to provide robust evidence to support individualized weight management strategies for patients with MASLD in clinical practice. We hypothesized that MASLD severity significantly affects postoperative outcomes after LSG, with patients exhibiting severe MASLD experiencing more limited weight loss.<sup>20,22,23</sup>

## Materials and Methods

### Data Sources and Recruitment

We retrospectively included 226 patients with obesity who met the criteria for LSG and underwent the procedure at our medical center between December 2020 and August 2024. All the patients received standardized dietary counseling and follow-up protocols postoperatively, ensuring consistency in behavioral interventions across MASLD severity groups. This study was approved by the Ethics Committee of the First Affiliated Hospital of Shandong First Medical University (approval number 2025S035). Requirement for informed patient consent was waived because of the retrospective nature of the study. All patient data were anonymized and handled with strict confidentiality to ensure compliance with the Declaration of Helsinki.

### Data Collection

#### Inclusion Criteria

(1) Age between 16 and 65 years; (2) body mass index (BMI)  $\geq 32.5$  kg/m<sup>2</sup> without comorbidities, or BMI  $\geq 27.5$  kg/m<sup>2</sup> with diabetes mellitus or other metabolic disorders; (3) those who underwent LSG with liver biopsy; and (4) availability of complete postoperative follow-up data.

## Exclusion Criteria

(1) Alcoholic fatty liver disease; (2) use of obesity-inducing medications post-surgery; (3) pregnancy shortly after surgery; (4) use of weight-affecting medications (eg, metformin, insulin or GLP-1 agonists) following surgery; (5) incomplete follow-up data; and (6) patients with poor compliance were excluded to minimize confounding from postoperative behavioral factors.

## Grouping Method

Liver biopsy specimens were used to assess fatty liver severity based on the following histopathological grading: (1) normal, <5% hepatocellular steatosis; (2) mild, 5–33% hepatic steatosis; (3) moderate, 34–66% hepatic steatosis; and (4) severe, >66% hepatic steatosis.

## Data Collection

Perioperative data for all the patients, including sex, age, BMI, waist circumference, hip circumference, metabolic syndrome (MS), and obesity-related comorbidities (such as hypertension, T2D, and hyperlipidemia), were systematically recorded using an electronic case management system. Processing and pathological diagnosis of liver tissues were performed by experienced pathologists in the Department of Pathology at our hospital, and a final review was conducted by the Department Director. To minimize potential confounding, several strategies were implemented during study design and execution. All patients received standardized preoperative education and postoperative guidance, including structured dietary and medication counseling provided by trained clinical staff. Follow-up visits were conducted at 1, 3, 6, and 12 months postoperatively to ensure adherence and consistency of care. Patients with poor compliance or incomplete follow-up data were excluded. Furthermore, a comprehensive dataset was collected including anthropometric measures, glycemic and lipid profiles, and obesity-related comorbidities, which were incorporated into both univariate and multivariate analyses. These follow-ups included evaluating postoperative weight, conducting blood tests, assessing surgery-related complications, and monitoring the improvements in preoperative obesity-related comorbidities. To assess the effectiveness of weight loss surgery, we used percentage of excess weight loss (%EWL) as the evaluation criterion.

$$\%TWL = (\text{initial body weight} - \text{final body weight}) / \text{initial weight} \times 100\%.$$

$$\%EWL = ([\text{initial body weight} - \text{final body weight}] / [\text{initial weight} - \text{ideal body weight}]) \times 100\%.$$

Ideal BMI (IBMI): 25 kg/m<sup>2</sup>, ideal body weight: IBMI × (height)<sup>2</sup>.

HOMA-IR: (Fasting Glucose\*Fasting Insulin)/22.5

## Statistical Analyses

Continuous variables were assessed for normality using the Shapiro–Wilk test. For variables that were not normally distributed, Spearman’s rank correlation was used to assess the relationship with MASLD severity at baseline, and the Kruskal–Wallis test was used for comparisons between the three MASLD groups at specific time points. For normally distributed continuous variables, the Pearson’s correlation was used at baseline, and one-way analysis of variance (ANOVA) was employed to compare group means at each time point. Where the assumption of homogeneity of variances was violated (the Levene’s test,  $P < 0.05$ ), the Welch’s ANOVA was used. Post-hoc pairwise comparisons following significant ANOVA or the Welch’s ANOVA were performed using the Games–Howell tests (for unequal variances) or least significant difference (LSD) tests (for equal variances). To account for multiple pairwise comparisons performed for %EWL between the MASLD groups at 1, 3, 6, and 12 months, the Bonferroni correction was applied, and statistical significance for the post-hoc tests was set at  $P < 0.05$  divided by the number of comparisons at each time point ( $\alpha/3 = 0.0167$ ). Using univariate analysis to screen for significantly correlated variables and multivariate analysis to adjust for confounders, the process covered, in detail, preoperative blood biochemistry, glucose and lipid metabolism indices, and obesity comorbidities. The Kaplan–Meier curve was used to evaluate the time to achieve 50% EWL, and group differences were assessed using the Log rank test. General linear models were employed to analyze the %EWL changes at different time points across the fatty liver severity groups. All statistical analyses were performed using IBM SPSS Statistics 27.0; Plot using GraphPad Prism 9.5.0.

## Results

### Baseline Characteristics and Group Comparisons

The patients were classified into normal (n=0), mild (n=73), moderate (n=86), and severe (n=67) groups based on the pathological grading of MASLD. As indicated in Table 1, BMI, waist-to-hip ratio (WHR), serum uric acid, triglycerides, total cholesterol, A1C, and homeostasis model assessment for insulin resistance (HOMA-IR) were significantly associated with MASLD severity (P < 0.05). Group differences were denoted by superscript letters (a/b) (P < 0.05). Fatty liver severity was significantly correlated with WHR (r = 0.156, P = 0.020). Significant differences were observed between the mild and moderate groups and between the moderate and severe groups (F = 5.933, P = 0.003; mild vs moderate, P < 0.001; mild vs severe, P = 0.022; moderate vs severe, P = 0.367). Uric acid, total cholesterol, and high-density lipoprotein levels were significantly associated with the severity of fatty liver disease (P < 0.005); however, no significant group differences were found among the mild, moderate, and severe groups (H < 5.991, P > 0.05). Triglyceride was significantly correlated with fatty liver severity (r = 0.188, P = 0.005), with significant differences observed between the mild and severe groups (H = -30.974, P = 0.015). A1C (mild vs severe group, H = -33.116, P = 0.008) and HOMA-IR (mild vs severe group, H = -39.916, P = 0.001) were also significantly different. Aspartate transaminase/alanine transaminase (mild vs severe group, H = 46.988, P < 0.001; mild vs moderate group, H = 45.330, P < 0.001) and low-density lipoprotein (mild vs severe group, H = -32.023, P = 0.01) exhibited similar trends. Metabolic diseases, such as T2D, were notably more prevalent in the severe MASLD group (53.7%) than those in the mild group (28.8%), indicating a significant association between MASLD severity and metabolic diseases (P = 0.011). MASLD

**Table 1** Preoperative Baseline Information

Factors		Mild Group (n=73)	Moderate Group (n=86)	Severe Group (n=67)	X <sup>2</sup> /t/Z	P
Age(years)		31(25–37.5)	28(25–35)	30(24–34)	-0.101	0.129
Sex (Female, n%)		54(74.0%)	54(62.8%)	47(70.1%)	2.400	0.301
WHR (mean + SD)		0.93 <sup>a, b</sup> (±0.08)	0.97 <sup>b</sup> (±0.07)	0.96 <sup>a</sup> (±0.08)	0.156	0.020
BMI (kg/m <sup>2</sup> )		38.93 <sup>a</sup> (35.95–42.60)	40.57(36.24–48.31)	41.64 <sup>a</sup> (38.90–45.72)	0.207	0.002
UA (umol/L)		361.00(310.5–455)	408.00(341.75–466.25)	415.00(340.00–516.00)	0.160	0.016
TG (mmol/L)		1.33 <sup>a</sup> (0.98–2.15)	1.52(1.19–2.27)	1.72 <sup>a</sup> (1.30–2.68)	0.188	0.005
Total cholesterol (mmol/L)		4.37(3.83–5.01)	4.61(4.06–5.05)	4.71(4.12–5.39)	0.152	0.022
FFA (mmol/L)		0.56 (0.39–0.79)	0.60 (0.48–0.74)	0.63(0.54–0.78)	0.125	0.70
A1C (%)		5.7 <sup>a</sup> (5.5–6.2)	5.9(5.5–6.4)	6.2 <sup>a</sup> (5.7–7.0)	0.198	0.003
HOMA-IR		6.81 <sup>a</sup> (4.54–10.29)	7.94(5.51–13.45)	9.72 <sup>a</sup> (6.48–18.10)	0.240	<0.001
AST/ALT		0.79 <sup>a,b</sup> (0.63–0.94)	0.63 <sup>b</sup> (0.52–0.78)	0.63 <sup>a</sup> (0.54–0.75)	-0.289	<0.001
HDL		1.08(0.95–1.22)	1.05(0.90–1.14)	1.01(0.87–1.24)	-0.135	0.045
LDL		2.69 <sup>a</sup> (2.28–3.23)	2.85(2.41–3.30)	2.95 <sup>a</sup> (2.56–3.68)	0.198	0.003
T2D	With	21 <sup>a</sup> (28.8%)	34(39.5%)	36 <sup>a</sup> (53.7%)	9.083	0.011
	Without	52 <sup>a</sup> (71.2%)	52(60.5%)	31 <sup>a</sup> (46.3%)		
HTN	With	20(27.4%)	30(34.9%)	28(41.8%)	3.211	0.201
	Without	53(72.6%)	56(65.1%)	39(58.2%)		
OSAHS	With	37(50.7%)	57(66.3%)	35(52.2%)	3.211	0.201
	Without	36(49.3)	29(33.7%)	32(47.8%)		
MS	With	23(31.5%)	29(33.7%)	33(49.3%)	4.830	0.089
	Without	50(68.5%)	57(66.3%)	34(50.7%)		
PCOS (n=155)	With	10(18.5%)	15(27.8%)	8(17.0%)	2.115	0.347
	Without	44(81.5%)	39(72.2%)	39(83.0%)		

**Notes:** <sup>a</sup> represents Significant difference between Mild group and Severe group (P<0.05). <sup>b</sup> represents Significant difference between Mild group and Moderate group (P<0.05). The data in the table are n (%) or M(P25-P75).

**Abbreviations:** WHR, Waist hip ratio; BMI, Body mass index; UA, Uric acid; TG, Triglycerides; FFA, Free fatty acids; A1C, Glycated hemoglobin; HOMA-IR, Homeostatic model assessment of insulin resistance; AST, Aspartate transaminase; ALT, Alanine transaminase; HDL, High density lipoprotein; LDL, Low density lipoprotein; T2D, Type 2 diabetes mellitus; HTN, Hypertension; OSAHS, Obstructive sleep apnea-hypopnea syndrome; MS, Metabolic syndrome; PCOS, Poly cystic ovarian syndrome.

severity, as reflected by the degree of hepatic steatosis (DHS), significantly affected weight loss outcomes following LSG. Univariate analysis (Table S1) revealed that higher DHS grades were negatively correlated with percentage of total weight loss (%TWL) at 3 months ( $r = -0.184$ ,  $P = 0.006$ ), indicating that advanced hepatic steatosis impaired early postoperative weight loss.

At 1 month postoperatively, age, sex, and WHR were significantly correlated with %EWL. BMI and the DHS also showed strong associations (Table 2). The DHS and BMI had the most substantial effect on %EWL at all time points, with a consistent negative correlation observed over time ( $P < 0.05$ ). At 3, 6, and 12 months, significant associations were observed between %EWL and several metabolic factors, including free fatty acids (FFAs), A1C, and HOMA-IR. Specifically, fatty liver severity continued to show a significant negative correlation with %EWL across all follow-up periods ( $P < 0.05$ ). Additionally, the effect of metabolic syndrome and obstructive sleep apnea-hypopnea syndrome (OSAHS) on weight loss was less pronounced, showing no significant changes across the time points. Although this association was weakened by 6 months ( $r = -0.059$ ,  $P = 0.451$ ), multivariate regression (Table S2) identified DHS as an independent negative predictor of %TWL both at 1 ( $\beta = -0.159$ ,  $p = 0.036$ ) and 12 ( $\beta = -0.167$ ,  $P = 0.040$ ) months, suggesting persistent detrimental effects in patients with severe MASLD. In contrast, baseline BMI transitioned from an initial inverse correlation (1 month:  $r = -0.134$ ,  $P = 0.044$ ) to a dominant positive predictor of long-term success (12 months:  $\beta = 0.521$ ,  $P < 0.001$ ). These findings underscore that although elevated BMI drives sustained weight loss, MASLD severity, mediated by DHS, imposes early- and late-phase barriers to optimal %TWL, highlighting its clinical relevance in personalized postoperative management.

The analysis identified preoperative DHS and BMI as primary independent predictors of %EWL (Table 3). A significant negative association was observed between DHS and %EWL at 1, 3, and 12 months postoperatively, indicating that greater fatty liver severity was linked to poorer weight loss outcomes, as shown in Table 3. At 1 month, the DHS showed a significant effect ( $B = -0.023$ ,  $P = 0.010$ ), with similar trends at 3 ( $B = -0.052$ ,  $P < 0.001$ ) and 12 ( $B = -0.090$ ,  $P = 0.001$ ) months. Although DHS did not reach statistical significance at 6 months ( $P = 0.065$ ), the effect

**Table 2** Factors Affecting %EWL

Factors	1 Month		3 Months		6 Months		12 Months	
	r	P	r	P	r	P	r	P
Age, years	0.153*	0.022	0.098	0.142	0.098	0.211	0.088	0.329
Sex, [Female, n%]	0.175**	0.008	0.199**	0.003	0.350**	<0.001	0.269*	0.002
WHR	-0.160*	0.017	-0.204**	0.002	-0.200*	0.011	-0.032	0.725
BMI (kg/m <sup>2</sup> )	-0.755**	<0.001	-0.749**	<0.001	-0.791**	<0.001	-0.626**	<0.001
DHS	-0.233**	<0.001	-0.311**	<0.001	-0.184*	0.018	-0.322**	<0.001
UA (umol/ L)	-0.155	0.084	-0.157*	0.019	-0.207*	0.008	-0.251**	0.005
TG	0.040	0.546	-0.017	0.797	-0.083	0.292	-0.009	0.919
Total cholesterol (mmol/L)	-0.038	0.567	-0.097	0.149	-0.018	0.815	-0.031	0.734
FFA (mmol/L)	-0.147*	0.034	-0.161*	0.020	-0.186*	0.022	-0.189*	0.047
A1C (%)	-0.059	0.378	-0.133*	0.048	-0.117	0.137	-0.054	0.551
HOMA-IR	-0.185**	0.005	-0.204**	0.002	-0.251**	0.001	-0.198*	0.027
AST/ALT	0.023	0.735	0.105	0.118	0.041	0.608	0.067	0.458
HDL	0.009	0.890	0.018	0.791	0.004	0.960	0.018	0.846
LDL	-0.067	0.326	-0.121	0.075	-0.002	0.806	-0.113	0.219
T2D	0.046	0.489	0.064	0.341	0.101	0.200	0.058	0.523
HTN	0.084	0.209	0.133*	0.046	0.147	0.061	0.167	0.063
MS	0.058	0.383	0.105	0.116	0.116	0.138	0.015	0.870
OSAHS	0.068	0.306	0.081	0.226	0.148	0.069	0.147	0.101

**Notes:** %EWL: the percentage of excess weight loss. \*  $P < 0.05$ , \*\*  $P < 0.01$ .

**Abbreviations:** WHR, Waist hip ratio; BMI, Body mass index; DHS, Degree of hepatic steatosis; UA, Uric acid; TG, Triglycerides; FFA, Free fatty acids; A1C, Glycated hemoglobin; HOMA-IR, Homeostatic model assessment of insulin resistance; AST, Aspartate transaminase; ALT, Alanine transaminase; HDL, High density lipoprotein; LDL, Low density lipoprotein; T2D, Type 2 diabetes mellitus; HTN, Hypertension; MS, Metabolic syndrome; OSAHS, Obstructive sleep apnea-hypopnea syndrome.

**Table 3** Multiple Linear Regression Affecting Postoperative %EWL

Time	Factors	B	SE	β value	t	P value
1 month	SEX	-0.027	0.018	-0.099	-1.476	0.141
	WHR	-0.026	0.100	-0.015	-0.257	0.797
	BMI	-0.012	0.001	-0.635	-10.686	<0.001
	DHS	-0.023	0.009	-0.146	-2.608	0.010
	UA	<0.001	<0.001	0.010	0.175	0.861
	FFA	0.004	0.005	0.041	0.770	0.442
	HOMA-IR	-0.001	0.001	-0.049	-0.905	0.367
	HTN	0.014	0.015	0.052	0.928	0.355
3 month	SEX	-0.047	0.025	-0.120	-1.848	0.066
	WHR	-0.114	0.139	-0.048	-0.821	0.413
	BMI	-0.017	0.002	-0.616	-11.000	<0.001
	DHS	-0.052	0.012	-0.226	-4.173	<0.001
	UA	<0.001	<0.001	-0.039	-0.718	0.473
	FFA	0.006	0.007	0.044	0.858	0.392
	HOMA-IR	<0.001	0.001	-0.017	-0.322	0.748
	HTN	0.035	0.020	0.092	1.695	0.092
6 month	SEX	-0.016	0.034	-0.035	-0.498	0.625
	WHR	-0.138	0.188	-0.047	-0.733	0.465
	BMI	-0.021	0.002	-0.669	-10.326	<0.001
	DHS	-0.032	0.017	-0.113	-1.863	0.065
	UA	<0.001	<0.001	-0.057	-0.938	0.350
	FFA	-0.001	0.013	-0.001	-0.014	0.989
	HOMA-IR	-0.002	0.002	-0.083	-1.375	0.171
	HTN	0.023	0.028	0.048	0.797	0.427
12 month	SEX	-0.003	0.050	-0.005	-0.052	0.959
	WHR	0.458	0.297	0.130	1.542	0.126
	BMI	-0.020	0.003	-0.556	-5.971	<0.001
	DHS	-0.090	0.027	-0.280	-3.365	0.001
	UA	<0.001	<0.001	-0.034	-0.403	0.687
	FFA	-0.042	0.094	-0.035	-0.443	0.659
	HOMA-IR	-0.001	0.003	-0.034	-0.408	0.684
	HTN	-0.010	0.044	-0.019	-0.227	0.821

**Notes:** 1 month  $R^2=0.464$ , adjusted  $R^2=0.442$ ,  $F=21.311$ ,  $P<0.001$ ,  $Y=0.981-0.012*BMI-0.023*DHS$ ; 3 months  $R^2=0.500$ , adjusted  $R^2=0.480$ ,  $F=24.382$ ,  $P<0.001$ ,  $Y=1.595-0.017*BMI-0.052*DHS$ ; 6 months postoperative  $R^2=0.550$ , adjusted  $R^2=0.524$ ,  $F=20.946$ ,  $P<0.001$ ,  $Y=1.973-0.021*BMI$ ; 12 months postoperative  $R^2=0.442$ , adjusted  $R^2=0.396$ ,  $F=9.694$ ,  $P<0.001$ ,  $Y=1.735-0.020*BMI-0.090*DHS$ .

**Abbreviations:** %EWL, the percentage of excess weight loss; SE, standard error; WHR, Waist hip ratio; BMI, Body mass index; DHS, Degree of hepatic steatosis; UA, Uric acid; FFA, Free fatty acids; HOMA-IR, Homeostatic model assessment of insulin resistance; HTN, Hypertension.

reemerged at 12 months, highlighting its long-term effect on weight loss. Preoperative BMI was consistently a significant negative predictor of %EWL across all time points ( $P < 0.05$ ), with a higher BMI correlating with reduced postoperative weight loss outcomes. Other variables, such as sex, WHR, uric acid, FFA, and HOMA-IR, were not significantly associated with %EWL at any time point. The models demonstrated strong explanatory power for %EWL variation, with adjusted  $R^2$  values between 0.396–0.524 across different time points. These findings underscore the critical role of preoperative fatty liver severity and BMI in shaping postoperative weight loss outcomes, and emphasize the importance of preoperative optimization strategies.

Postoperative %EWL significantly increased in all MASLD groups over time (1, 3, 6, and 12 months). Correlation analysis demonstrated a significant negative association between MASLD severity and %EWL at each time point: 1

**Table 4** Postoperative Excess Weight Loss Percentage

	Mild Group	Moderate Group	Severe Group	r	P
%EWL					
1 month	38.59% <sup>a</sup> (30.61%-48.78%, n=73)	35.58% (26.05%-42.48%, n=86)	32.34% <sup>a</sup> (24.93%-39.35%, n=67)	-0.233	<0.001
3 months	71.35% <sup>a, b</sup> (±19.93%, n=73)	61.96% <sup>b</sup> (±18.02%, n=83)	56.18% <sup>a</sup> (±12.56%, n=67)	-0.330	<0.001
6 months	90.41% <sup>a</sup> (±25.54%, n=47)	82.60% (±24.00%, n=62)	77.61% <sup>a</sup> (±15.70%, n=44)	-0.218	0.005
12 months	114.82% <sup>a</sup> (±27.55%, n=36)	111.04% <sup>c</sup> (±27.78%, n=49)	95.95% <sup>a, c</sup> (±16.81%, n=39)	-0.287	0.001
%TWL					
1 month	13.27% (11.56%-15.16%, n=73)	13.10% (11.81%-14.69%, n=86)	12.75% (11.11%-14.39%, n=67)	-0.113	0.090
3 months	23.93% <sup>a</sup> (±0.37%, n=73)	23.06% (±0.44%, n=83)	22.25% <sup>a</sup> (±0.50%, n=67)	-0.174	0.009
6 months	31.03% (±0.76%, n=53)	30.77% (±0.65%, n=65)	30.55% (±0.68%, n=46)	-0.036	0.645
12 months	40.58% (±1.37%, n=36)	41.74% (±1.42%, n=49)	37.83% (±1.14%, n=39)	-0.125	0.164

**Notes:** <sup>a</sup>Represents Significant difference between Mild group and Severe group ( $P < 0.05$ ). <sup>b</sup>Represents Significant difference between Mild group and Moderate group ( $P < 0.05$ ). <sup>c</sup>Represents Significant difference between Moderate group and Severe group ( $P < 0.05$ ).

**Abbreviations:** %EWL: the percentage of excess weight loss; %TWL: the percentage of total weight loss.

month ( $r = -0.233$ ,  $P < 0.001$ ), 3 months ( $r = -0.330$ ,  $P < 0.001$ ), 6 months ( $r = -0.218$ ,  $P = 0.005$ ), and 12 months ( $r = -0.287$ ,  $P = 0.001$ ), suggesting that greater steatosis severity was associated with attenuated weight loss (Table 4).

According to the Shapiro–Wilk test, the %EWL and %TWL values at 1 month postoperatively were not normally distributed ( $P < 0.05$ ). Therefore, the Kruskal–Wallis test was used to compare the three MASLD groups. A significant difference in %EWL was found ( $H = 22.861$ ,  $P < 0.001$ ). Bonferroni-corrected post-hoc comparisons showed that the median %EWL in the mild group was significantly higher than both the moderate and severe groups (mild vs severe:  $F = 51.577$ ,  $P < 0.001$ ; mild vs moderate:  $F = 32.341$ ,  $P = 0.020$ ). No significant difference was observed in %TWL among the groups at 1 month ( $H = 3.019$ ,  $P = 0.221$ ).

For follow-up data at 3, 6, and 12 months, both %EWL and %TWL were normally distributed ( $P > 0.05$ ). Levene’s test revealed that the assumption of homogeneity of variances was violated for %EWL at 3 and 6 months (3 months:  $F = 3.592$ ,  $P = 0.029$ ; 6 months:  $F = 4.276$ ,  $P = 0.016$ ). Therefore, Welch’s ANOVA was performed and showed significant group differences (3 months:  $F = 13.998$ ,  $P < 0.001$ ; 6 months:  $F = 3.833$ ,  $P = 0.025$ ). Post-hoc analysis using the Games–Howell test indicated that at 3 months, the mild MASLD group had significantly higher %EWL than both the moderate ( $P = 0.005$ , mean difference =  $7.10\% \pm 2.21\%$ , 95% CI: 1.86–12.33%) and severe groups ( $P < 0.001$ , mean difference =  $11.17\% \pm 2.11\%$ , 95% CI: 6.18–16.17%). At 6 months, only the mild vs severe comparison remained significant ( $P = 0.018$ , mean difference =  $8.91\% \pm 3.21\%$ , 95% CI: 1.27–16.55%).

At 12 months, Levene’s test indicated equal variances ( $F = 2.411$ ,  $P = 0.094$ ), and one-way ANOVA revealed a significant difference in %EWL between the MASLD groups ( $F = 6.247$ ,  $P = 0.003$ ). LSD post-hoc tests showed that the severe group had significantly lower %EWL than the mild ( $P = 0.002$ , mean difference =  $14.07\% \pm 4.33\%$ , 95% CI: 5.49–22.65%) and moderate ( $P = 0.005$ , mean difference =  $11.69\% \pm 4.05\%$ , 95% CI: 3.67–19.72%) groups.

For %TWL at 3 months, both normality and equal variances were confirmed (Levene’s test:  $F = 2.144$ ,  $P = 0.120$ ), allowing for one-way ANOVA. The analysis revealed significant differences among groups ( $F = 3.450$ ,  $P = 0.033$ ). LSD post-hoc comparison showed that the mild group had significantly higher %TWL than the severe group ( $P = 0.009$ , mean difference =  $1.68\% \pm 0.64\%$ , 95% CI: 0.42–2.94%). No significant differences in %TWL were found among the MASLD groups at 6 and 12 months postoperatively.

%EWL values for patients in the three MASLD groups were evaluated across four postoperative time points (1, 3, 6, and 12 months) using a general linear model (GLM) with repeated measures, assessing the main effects of time and group, as well as their interaction.

A significant main effect of time was observed ( $F_{[2,148]} = 780.650$ ,  $P < 0.001$ ), indicating substantial changes in %EWL across follow-up. The main effect of MASLD group was also significant ( $F_{[2,149]} = 5.197$ ,  $P = 0.007$ ), suggesting that fatty liver severity influences overall weight loss outcomes. Importantly, a significant time  $\times$  group interaction was

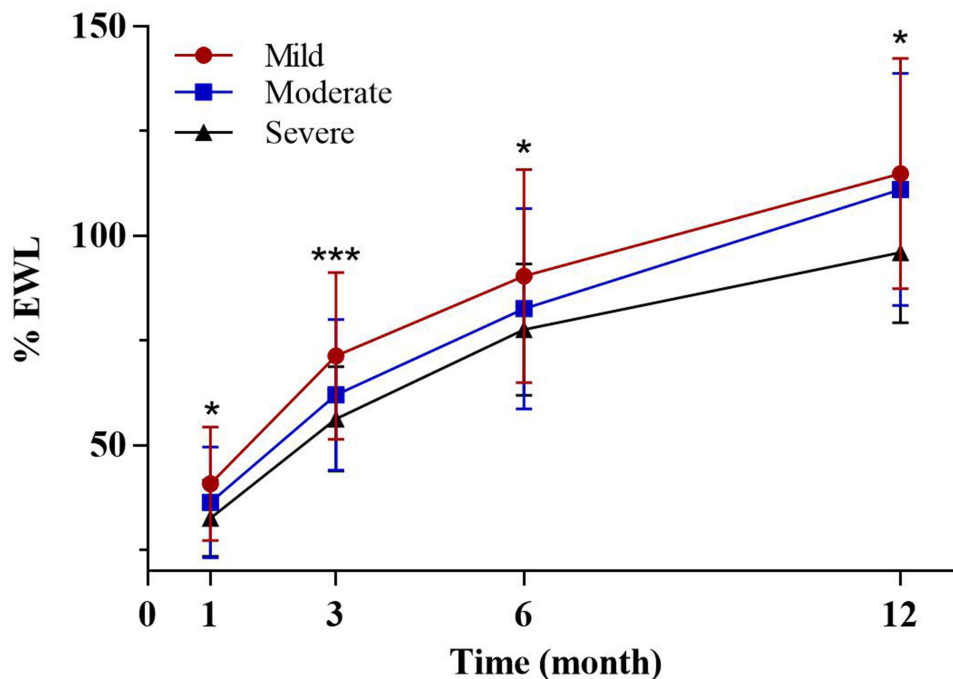
found ( $F_{[2,149]} = 5.926, P = 0.003$ ), indicating that the %EWL trajectory over time differed depending on MASLD severity.

In light of this significant interaction, simple effects analyses were conducted using pairwise comparisons at each time point. Where appropriate, Bonferroni correction was applied to account for multiple comparisons. At 1 month, only the mild vs severe group comparison reached significance ( $P = 0.026$ , mean difference =  $6.8\% \pm 2.5\%$ ). At 3 months, the mild group had significantly higher %EWL than both the moderate ( $P = 0.030$ , mean difference =  $8.6\% \pm 3.3\%$ ) and severe ( $P < 0.001$ , mean difference =  $13.7\% \pm 3.6\%$ ) groups. At 6 months, a significant difference was maintained between mild and severe groups ( $P = 0.016$ , mean difference =  $12.8\% \pm 4.5\%$ ). At 12 months, both the mild vs severe ( $P = 0.004$ , mean difference =  $18.9\% \pm 5.7\%$ ) and moderate vs severe ( $P = 0.016$ , mean difference =  $15.1\% \pm 5.3\%$ ) comparisons were significant.

No significant differences were observed between the moderate and severe groups at 1–6 months, or between the mild and moderate groups at 12 months.

To facilitate interpretation, the results were illustrated in Figure 1, with significance values labeled directly on the graph. All post-hoc p-values are two-tailed, and where not otherwise specified, results are reported with a significance threshold of  $\alpha < 0.05$ .

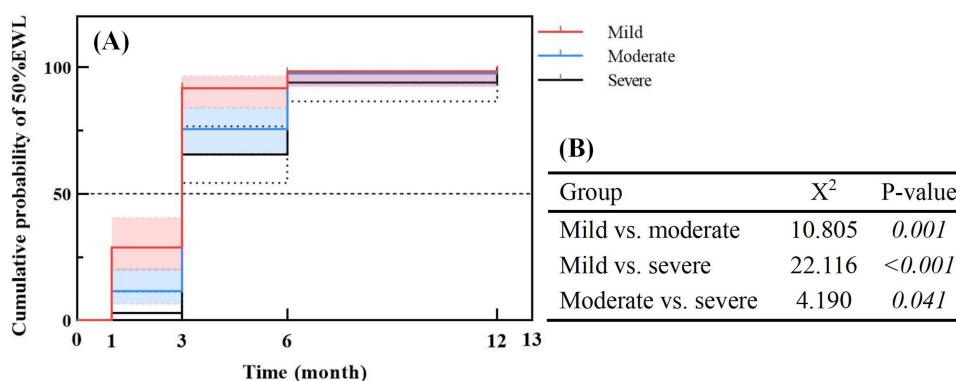
To investigate the differences in the time required to achieve satisfactory weight loss following surgery among patients with varying degrees of fatty liver disease, satisfactory weight loss was defined as reaching 50% EWL, and the cumulative incidence of this event was examined using postoperative follow-up data. A significant difference was observed in the rate of achieving 50% EWL among the MASLD severity groups over the 12 months postoperative follow-up period ( $P < 0.05$ , Figure 2B). Across all time points, the mild MASLD group consistently demonstrated the highest proportion of patients achieving 50% EWL, indicating superior weight-loss outcomes. Conversely, the severe MASLD group exhibited a significantly lower rate of attainment and slower increase in weight loss during the early postoperative period. This was supported by post-operative data showing that at 1 month, 28.8% of patients in the mild group achieved 50% EWL compared with 11.6% in the moderate group, while only 2.6% of patients in the severe group reached this threshold. At 3 months, the mild group maintained a significant advantage, with 91.8% of patients achieving



**Figure 1** General Linear Model Analysis of %EWL Changes Over Time by MASLD Severity.

**Notes:** \* $P < 0.05$ , \*\*\* $P < 0.001$ .

**Abbreviation:** %EWL, the percentage of excess weight loss.



**Figure 2 (A)** Kaplan-Meier Analysis of 50%EWL Achievement Rate by MASLD Severity. **(B)** The Log rank test was employed to undertake a pair-wise comparison of the data. *Italic formatting* in the figure indicates P<0.05, reflecting statistically significant differences.

**Abbreviation:** %EWL, the percentage of excess weight loss.

50% EWL compared with 75.6% and 64.7% in the moderate and severe groups, respectively. At 6 months, the differences between the groups diminished, and all the groups showed significant improvement (98.4%, 97.7%, and 92.6% in the mild, moderate, and severe groups, respectively). At 12 months, nearly similar results were observed in all the groups (98.4%, 98.8%, and 97.5%, respectively), indicating that the cumulative incidence converged over time. Although patients in the severe group had worse weight loss results than those in the moderate and mild groups, 97.5% of patients in this group achieved satisfactory weight loss within 1 year of bariatric surgery.

## Discussion

Although the existing literature suggests that bariatric surgery produces positive outcomes for weight loss and metabolic improvement in patients with MASLD, only a few studies have evaluated the effect of different baseline stages of MASLD on postoperative weight loss,<sup>24,25</sup> and the specific impact of pathology-based hepatic steatosis on postoperative outcomes remains underexplored. Existing literature on MASLD/NAFLD and bariatric outcomes has produced heterogeneous findings. For example, Abdalla et al (2023) and Goh et al (2020) reported no significant associations between histological severity and weight loss, while Rheinwalt et al (2020) and Montoro et al (2022) found that steatosis or fibrosis negatively affected surgical outcomes.<sup>24–26</sup> One major difference lies in the assessment modality: several previous studies relied on imaging-based NAFLD scores or non-standardized pathology reviews. In contrast, our study incorporated intraoperative liver biopsies, enabling a more granular classification of steatosis severity. Furthermore, our use of repeated longitudinal follow-up (%EWL at 1, 3, 6, and 12 months) adds to the literature by tracking dynamic trends in weight loss over time. Moreover, most previous studies were conducted in Western populations with distinct metabolic phenotypes. To our knowledge, this is one of the first biopsy-based MASLD studies in an Asian bariatric cohort, providing important context for populations with different fat distribution, insulin resistance patterns, and MASLD presentation. By integrating steatosis-based pathology, metabolic markers, and prospective weight loss dynamics, this study adds novel evidence to support the role of hepatic steatosis as a risk stratifier in clinical bariatric practice.

Consistent with previous findings, our study further validated that preoperative fatty liver severity is significantly associated with glycolipid metabolism.<sup>27</sup> Additionally, we found that preoperative HOMA-IR and FFA levels were significantly associated with %EWL in a univariate analysis. However, after including BMI, fatty liver severity, HOMA-IR, and FFA in the multifactorial analysis, only BMI and fatty liver severity were significantly associated with %EWL; HOMA-IR and FFA did not show statistical significance. This suggests that the predictive value of glycolipid metabolism indices for postoperative %EWL may be limited when other factors, such as BMI and fatty liver severity, are considered. Therefore, multiple factors should be considered when predicting the effects of weight loss, as well as glycolipid metabolism indices. This study also confirmed that preoperative fatty liver severity and BMI were independent risk factors for predicting %EWL; that is, the effect of fatty liver severity was independent of BMI and vice versa. Therefore,

both factors should be considered when evaluating postoperative weight loss outcomes to develop a more precise treatment plan.

Although indicators of glucose and lipid metabolism (eg, HOMA-IR and FFA) may co-vary with other variables in multifactorial models, their effects might be masked by stronger predictors (eg, DHS and BMI), leading to reduced or non-significant statistical outcomes. The liver serves as the central organ for metabolism, where glucose (eg, insulin resistance, IR) and lipid (eg, FFA) metabolisms play critical roles in the development of hepatic steatosis.<sup>28</sup> The reduced postoperative weight loss cannot be solely attributed to hepatic steatosis because, first, hepatic fat accumulation can impair insulin signaling, increase insulin resistance,<sup>29</sup> and disrupt glucose metabolism. Second, elevated FFA levels associated with hepatic steatosis lead to lipid peroxidation and oxidative stress, further compromising liver function. Finally, the inflammatory response induced by steatosis can impair liver metabolic function and exacerbate metabolic disturbances. These factors may collectively contribute to poorer postoperative weight loss observed in patients with severe hepatic steatosis. The negative association between severe MASLD (reflected by DHS) and early weight loss may reflect its role as a marker of advanced metabolic dysfunction, which could indirectly hinder weight loss through mechanisms such as insulin resistance or altered energy metabolism.

Figure 1 demonstrates that the severity of MASLD significantly affects the trajectory of postoperative weight loss. Patients with severe MASLD exhibited 18.9% greater mean %EWL at 12 months than those with mild MASLD. The Kaplan–Meier analysis (Figure 2) confirmed delayed achievement of higher %EWL levels in the severe MASLD group during the early postoperative period (1–3 months), although the outcomes converged by 12 months. This suggests that although patients with severe MASLD can achieve satisfactory weight loss after sleeve gastrectomy, it occurs more gradually and with less overall %EWL than those with mild or moderate MASLD. Optimizing MASLD severity preoperatively may improve early postoperative weight loss trajectories.

Early impaired weight loss in patients with severe MASLD may be due to systemic metabolic disorders caused by severe steatosis, such as increased lipid toxicity, insulin resistance, and chronic inflammation, all of which compromise energy metabolism postoperatively.<sup>30</sup> Severe hepatic steatosis exacerbates these conditions by impairing mitochondrial function and promoting systemic inflammation, which impedes insulin signaling and oxidative capacity, critical to postoperative metabolic improvement.<sup>28,31,32</sup>

The liver plays a central role in metabolism, and its condition may be a key indicator of weight loss after bariatric surgery. Our findings identified preoperative MASLD severity as an independent predictor of postoperative weight loss. Severe hepatic steatosis, associated with insulin resistance, chronic inflammation, and mitochondrial dysfunction, impairs metabolic flexibility and diminishes the early efficacy of bariatric surgery, aligning with previous studies.<sup>33</sup> Preoperative interventions targeting insulin resistance and hepatic steatosis, such as dietary modification, physical activity,<sup>34</sup> and pharmacological agents like GLP-1 receptor agonists,<sup>35</sup> may improve surgical outcomes.

Although our study focused on the percentage of hepatic steatosis as the primary marker of MASLD severity, we acknowledge the pathophysiological complexity of MASLD, which includes necroinflammation (MASH) and fibrosis. However, several evidences suggest that steatosis plays a dominant role in metabolic dysregulation and weight loss. Recent studies have shown that baseline hepatic fat content, rather than fibrosis stage, independently predicts postoperative weight loss after bariatric surgery.<sup>25</sup> Furthermore, in a biopsy-based cohort of patients undergoing sleeve gastrectomy, steatosis severity was more strongly associated with attenuated weight loss than with fibrosis or inflammation.<sup>24,26</sup> This aligns with our findings that steatosis severity exhibits time-dependent correlations with %TWL, even after adjusting for metabolic confounders. Although we did not analyze the MASH score or fibrosis owing to sample size constraints, our results emphasize the clinical relevance of quantifying steatosis as a key driver of metabolic dysfunction in MASLD. Nevertheless, it is important to acknowledge that steatosis is only one component of MASLD pathology. The lack of data on inflammatory activity and fibrosis prevents comprehensive staging (eg, using SAF or NAS scores), which could further refine prognostic modeling. This simplification may have led to underestimation of the role of necroinflammation or fibrosis in patients with MASH or advanced disease. While steatosis alone was significantly predictive of postoperative weight loss in our cohort, future studies should incorporate full histological staging or validated non-invasive markers of liver fibrosis (eg, transient elastography, MRI-PDFF) to capture the multidimensional burden of MASLD.

Despite early postoperative challenges, all the groups showed significant improvements in liver function and glycemic control by 6 months, consistent with the benefits of bariatric surgery, such as reduced visceral adiposity and systemic inflammation. These improvements indicate that LSG can reverse metabolic dysfunction, in patients with advanced liver fat disease.<sup>36</sup>

Patients with severe MASLD should be considered for targeted preoperative interventions, including GLP-1 receptor agonists, sodium-glucose linked transporter 2 inhibitors, or structured weight loss programs, to improve liver function and metabolic flexibility.<sup>37</sup> Additionally, enhanced follow-up schedules focused on liver function, glycemic control, and weight loss, which are critical for early identification and management of suboptimal outcomes. Integrating imaging tools, such as magnetic resonance imaging-based proton density fat fraction (PDFF) or ultrasound-derived fat fraction (UDFF), could provide precise longitudinal monitoring of liver fat resolution and inform personalized management strategies.<sup>38</sup>

## Clinical Implications

The observed differences in early postoperative %EWL between MASLD groups—particularly the 13.7% and 18.9% gaps at 3 and 12 months—surpass thresholds often regarded as clinically meaningful in bariatric literature (ie, 10% % EWL difference). These differences may delay the achievement of weight-related targets such as glycemic control, blood pressure reduction, or medication de-escalation. In particular, our Kaplan–Meier analysis revealed that <3% of patients in the severe MASLD group achieved 50% EWL at 1 month, compared to nearly 29% in the mild group. This suggests that MASLD severity can identify patients at risk for early suboptimal response and help guide early intervention. From a clinical perspective, incorporating MASLD grading—through either biopsy or non-invasive surrogates—into preoperative workups could support more personalized postoperative plans. For example, severe MASLD patients may benefit from early introduction of GLP-1 receptor agonists, intensive dietary coaching, or more frequent follow-up visits during the first 3–6 months post-surgery.

## Strengths and Limitations

This study has several notable strengths. First, it provides a detailed histopathological evaluation of MASLD severity through intraoperative liver biopsies, ensuring precise grading of hepatic steatosis (mild, moderate, and severe) rather than relying on non-invasive surrogates. Second, the inclusion of longitudinal follow-up data (up to 12 months post-operatively) and multivariate adjustments for key metabolic confounders (eg, BMI and A1c) strengthened the validity of the observed associations. Third, the use of standardized surgical protocols and postoperative care minimizes the variability in clinical management and enhances internal consistency.

As this was a retrospective, single-center study conducted in a Chinese cohort, its findings may not be generalizable to other ethnic populations with differing metabolic profiles or MASLD pathophysiologies. The 12-month follow-up period precludes conclusions regarding long-term weight maintenance or potential late-phase divergence in the outcomes. Additionally, although histopathology focused on steatosis grading, critical features, such as inflammation (MASH) and fibrosis, were not analyzed because of sample size constraints, limiting insights into their potential roles. Unmeasured behavioral factors (eg, dietary adherence and physical activity) and postoperative medical management (eg, antidiabetic medications) could confound weight loss trajectories, but were not systematically assessed. Finally, the absence of postoperative liver biopsies hindered the exploration of dynamic histological changes after LSG.

Prospective multicenter studies with extended follow-up periods (>5 years) are required to validate these findings in diverse populations. Future studies should integrate comprehensive histological staging (steatosis, inflammation, and fibrosis) and behavioral assessments to disentangle their individual contributions. Additionally, exploring the effect of perioperative metabolic interventions (eg, GLP-1 agonists) in patients with severe MASLD could refine personalized management strategies.

## Conclusion

The severity of MASLD, defined by intraoperative hepatic steatosis, significantly affected both %EWL and %TWL following laparoscopic sleeve gastrectomy. Patients with severe MASLD exhibited a mean of 18.9% lower %EWL at 12

months compared to those with mild disease, particularly during the early postoperative phase. These findings remained robust after adjustment for key metabolic confounders such as BMI and HOMA-IR, suggesting an independent role of MASLD in shaping weight loss trajectories. Given that full histological assessment including inflammation and fibrosis was not feasible, and only steatosis grade was consistently available, our conclusions should be interpreted in light of this limitation. Nevertheless, hepatic steatosis may serve as a readily identifiable marker of metabolic risk and poor postoperative responsiveness. Routine preoperative liver pathology assessment may help identify patients at risk for delayed weight loss, guiding the implementation of intensified follow-up protocols, nutritional support, or pharmacological adjuncts (eg, GLP-1 receptor agonists). However, the invasive nature of liver biopsy limits its widespread use. Future research should therefore explore non-invasive stratification tools (eg, imaging biomarkers) and evaluate the efficacy of preoperative metabolic interventions in patients with suspected or confirmed advanced MASLD. Incorporating MASLD severity into perioperative decision-making may help optimize individualized treatment strategies and improve surgical outcomes.

## Data Sharing Statement

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

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work. San-Yuan Hu and Ming-Wei Zhong should be considered joint senior author.

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## Disclosure

The authors declare that they have no competing interests.

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