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Predicting hepatic steatosis degree in metabolic dysfunction-associated steatotic liver disease using obesity and lipid-related indices

Paniz Forouzesh[1]✉, Sorayya Kheirouri[1] & Mohammad Alizadeh[1,2]

Metabolic dysfunction-associated steatotic liver disease (MASLD), previously known as nonalcoholic fatty liver disease, represents a prevalent condition ranging from simple steatosis to advanced stages associated with liver cancer. Asymptomatic presentation in the majority of cases underscores the need for non-invasive, cost-effective methods to stratify degree of hepatic steatosis. This cross-sectional study aimed to assess the association between obesity and lipid-related indices with the degree of hepatic steatosis in MASLD patients. 150 individuals recently diagnosed with metabolic dysfunction-associated steatotic liver disease were recruited. Anthropometric measurements, including weight, height, and waist circumference (WC), were taken, alongside biochemical parameters such as alanine aminotransferase, aspartate aminotransferase, total cholesterol, triglycerides (TG), high-density lipoprotein, low-density lipoprotein, and fasting plasma glucose, following a 12-h fasting period. Various indicators of obesity and lipid metabolism, including body mass index, waist-to-height ratio (WHtR), a body shape index, lipid accumulation product (LAP), triglyceride-glucose index (TyG), visceral adiposity index, and hepatic steatosis index (HSI), were calculated. The diagnosis of MASLD and degree of hepatic steatosis were established through abdominal ultrasound examination. Data analysis was performed utilizing SPSS version 22. All the investigated indices displayed an area under the curve (AUC) surpassing 0.5, implying a correlation with the degree of hepatic steatosis. Notably, TyG-WC, TyG-WHtR, LAP, and a cardiometabolic obesity index showed the highest AUC values (> 0.7), indicating a relatively strong association with degree of hepatic steatosis. Specifically, in females, TyG-WC (AUC = 0.797, 95% CI 0.712–0.882, threshold = 865.991), while in males, LAP (AUC = 0.746, 95% CI 0.593–0.899, threshold = 74.290), demonstrated the highest AUC values. TyG-WHtR, TyG-WC, and LAP exhibited significant correlations with the degree of hepatic steatosis. Given their non-invasive nature and easy measurement, they hold promise for potential clinical utility, pending validation in additional studies.

Keywords Metabolic dysfunction-associated steatotic liver disease, Non-alcoholic fatty liver disease, Obesity, Lipid-related indices, Hepatic Steatosis

Abbreviations

MASLD	Metabolic dysfunction-associated steatotic liver disease
NAFLD	Nonalcoholic fatty liver disease
BMI	Body mass index
WC	Waist circumference
WHtR	Waist-to-height ratio
TyG index	Triglyceride-glucose index
TyG-BMI	Triglyceride glucose-body mass index
TyG-WC	Triglyceride glucose-waist circumference

[1]Department of Nutrition, Faculty of Nutrition and Food Sciences, Tabriz University of Medical Sciences, Attar Nishabouri St., Tabriz 5166614711, Iran. [2]Nutrition Research Center, Tabriz University of Medical Sciences, Tabriz, Iran. ✉email: paniz75forouzesh@gmail.com

TyG-WHtR	Triglyceride glucose-waist-to-height ratio
ALT	Alanine aminotransferase
AST	Aspartate aminotransferase
HDL-C	High-density lipoprotein cholesterol
TC	Total cholesterol
TG	Triglyceride
FPG	Fasting plasma glucose
HIS	Hepatic steatosis index
VAI	Visceral adiposity index
LAP	Lipid accumulation product
ABSI	Body-shape index
BRI	Body roundness index
COI	Conicity index
IR	Insulin resistance
MASH	Metabolic dysfunction-associated steatohepatitis

Metabolic dysfunction-associated steatotic liver disease (MASLD), previously known as nonalcoholic fatty liver disease (NAFLD), is a type of chronic liver disease[1]. It is typified by hepatic steatosis, affecting over 5% of hepatocytes, in individuals who consume safe levels of alcohol or abstain entirely, and lack other causative factors such as viral hepatitis, steatogenic medications[2,3].

MASLD encompasses a spectrum of histological features, spanning from simple steatosis, marked by fat buildup in the liver, to metabolic dysfunction-associated steatohepatitis (MASH), characterized by hepatocyte swelling, inflammation, and/or fibrosis. Progression of MASH can culminate in liver cirrhosis and hepatocellular carcinoma[4,5].

It is typical for individuals with MASLD to exhibit one or more components of metabolic syndrome, including hypertension, abdominal obesity, hypertriglyceridemia, elevated blood glucose levels, and decreased levels of high-density lipoprotein (HDL) cholesterol[6,7]. Cardiac and vascular diseases emerge as the predominant causes of mortality among individuals with MASLD. The precise pathophysiological mechanisms linking cardiovascular disease and MASLD remain incompletely understood, though it is widely believed that insulin resistance (IR) serves as a common factor in their pathogenesis, connecting both entities[8,9].

It is estimated that 30% of the global population is affected by MASLD, and its prevalence is increasing[10]. Hence, it is crucial to detect the degree of hepatic steatosis and recognize risk factors for MASLD early on. While liver biopsy remains the primary method for diagnosing MASLD, its invasiveness and impracticality for routine health monitoring and comprehensive epidemiological investigations in the general population are notable limitations[11]. Identifying quick, painless, and non-invasive methods to detect individuals with higher degrees of liver steatosis during initial medical visits can facilitate timely intervention and treatment for this disease.

High IR was identified as the most notable predictor of MASLD in both obese and lean individuals[12]. Moreover, even slight increments in liver fat are associated with IR in both hepatic and skeletal muscles[13]. The detection of IR has been facilitated with the acknowledgment of the triglyceride-glucose index (TyG index), a marker that integrates fasting triglyceride (TG) levels and fasting plasma glucose (FPG). The TyG index has demonstrated high sensitivity and specificity in screening for IR and proves to be a valuable predictor of IR across diverse populations[14].

Leveraging TyG-related parameters, including the combination of TyG with body mass index (TyG-BMI), TyG with waist circumference (TyG-WC), and TyG with waist-to-height ratio (TyG-WHtR), enhances the ability to identify individuals with IR more accurately[15]. Prior studies have supported the notion that incorporating TyG with anthropometric indices aids in the early-stage screening of MASLD[16–18].

Anthropometric indices such as lipid accumulation product (LAP), body roundness index (BRI), visceral adiposity index (VAI), abdominal volume index (AVI), conicity index (COI), and body adiposity index (BAI) act as surrogate markers reflecting both IR and central obesity. These indices possess substantial diagnostic utility in identifying metabolic syndrome and forecasting the likelihood of developing conditions such as diabetes or atherosclerosis[19–21].

Research has investigated the relationship between specific indices and the diagnosis of MASLD[17,22–25], yet there remains a scarcity of studies exploring the effectiveness of obesity and lipid-related indices, such as TyG, TyG-BMI, TyG-WHtR, TyG-WC, hepatic steatosis index (HSI), COI, BRI, body shape index (ABSI), LAP, and VAI, in assessing the degree of hepatic steatosis among individuals with MASLD. This study aims to assess the potential utility of obesity and lipid-related indices in predicting the degree of hepatic steatosis in patients with MASLD.

Hypothesis and Novel Aspect.

This study hypothesizes that obesity and lipid-related indices can reliably predict the degree of hepatic steatosis in patients with MASLD. The novel aspect of this research lies in its comprehensive assessment of multiple indices, including TyG, TyG-BMI, TyG-WHtR, TyG-WC, HSI, COI, BRI, ABSI, LAP, and VAI, for their effectiveness in predicting hepatic steatosis degree. This approach aims to fill the gap in existing knowledge by comparing the diagnostic utility of these indices, potentially offering new non-invasive tools for early detection and management of hepatic steatosis degree in MASLD patients.

Materials and methods

Participants

This cross-sectional study aimed to assess the potential usefulness of obesity and lipid-related indices in predicting the degree of hepatic steatosis among individuals diagnosed with MASLD. A total of 150 MASLD patients were selected through convenient sampling from those referred to the nutrition clinic. all methods were performed in accordance with the Tabriz University of Medical Sciences guidelines and regulations. informed consent was obtained from all subjects and/or their legal guardian(s).

Inclusion criteria

- Willingness to participate: Individuals who expressed willingness to participate in the study.
- Informed consent: Participants who provided informed consent after comprehending the study's objectives and methods.
- Newly diagnosed MASLD patients: Newly diagnosed patients with MASLD grade one and two confirmed by an internal medicine specialist based on liver sonography.
- Age range: Men and women aged between 20 and 65 years.

Exclusion criteria

- Tobacco or alcohol use: Individuals with a history of tobacco or alcohol use.
- Presence of other chronic diseases: Patients with concomitant chronic diseases such as heart disease, diabetes, or mental illness.
- Special diet adherence: Participants adhering to a special diet regimen.
- Medication or dietary supplement intake: Individuals taking medication or dietary supplements at the time of sampling.
- Pregnancy or lactation: Pregnant or lactating women were excluded from the study.
- High body mass index (BMI): Participants with a body mass index equal to or greater than 40 were excluded from the study.

Anthropometric measurements

Anthropometric data including weight, height, and waist circumference (WC) of the enrolled patients were gathered. Weight was measured using an electronic scale with an accuracy of 0.1 kg, while participants wore light clothing and no shoes. Height was measured to the nearest 0.5 cm. Waist circumference was measured without applying pressure on the body surface, using a non-stretch tape measure, at the level between the anterior superior iliac spine and the last rib, after a normal exhalation. Obesity-related indices were computed using the following formulas:

$$\begin{aligned}
&\text{BMI} = \text{weight (kg)}/\text{height}^2\ \text{(m)};\\
&\text{WHtR} = \text{WC (cm)}/\text{height (cm)};\\
&\text{ABSI} = \text{WC (m)}\Big/\left[\text{BMI}^{2/3}\ \left(\text{kg}/\text{m}^2\right) \times \text{Height}^{1/2}\ \text{(m)}\right];\\
&\text{COI} = 0.109^{-1}\ \text{WC (m)}\ [\text{Weight (kg)}/\text{Height (m)}]^{-1/2};\\
&\text{BRI} = 364.2 - 365.5\ [1 - p^{-2}\ \text{WC}^2\ \text{(m)}\ \text{Height}^{-2}\ \text{(m)}]^{1/2}
\end{aligned}$$

Diagnosis of hepatic steatosis degree

MASLD diagnosis and grade of hepatic steatosis were established through abdominal ultrasound conducted with Sonoace X4 Medisio (South Korea), which evaluated hepatic steatosis. The MASLD scoring system, outlined by Hamaguchi, Kojima[26], involved the evaluation of hepatorenal echo contrast, bright liver, deep attenuation, and vessel blurring. Consequently, MASLD was classified into three grades: grade I (mild), grade II (moderate), and grade III (severe).

Biochemical tests and measurement of obesity-lipid related indices

Biochemical blood parameters, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), total cholesterol (TC), triglycerides (TG), HDL, low-density lipoprotein cholesterol (LDL-C), and FPG, were evaluated after a minimum 12-h fast in the morning. These assessments were performed using an automatic analyzer, adhering to established standard methodologies.

The following formulas were used to calculate obesity and lipid related indices:

LAP:

$$\begin{aligned}
&\text{Male} = [\text{WC (cm)} - 65) \times \text{TG (mmol/L)}];\\
&\text{Female} = [\text{WC (cm)} - 58) \times \text{TG (mmol/L)};\\
&\text{TyG index} = \text{Ln}\ [\text{TG (mg/dL)} \times \text{FPG (mg/dL)}/2];\\
&\text{TyG-BMI} = \text{TyG} \times \text{BMI};\\
&\text{TyG-WC} = \text{TyG} \times \text{WC};\\
&\text{TyG-WHtR} = \text{TyG} \times \text{WHtR};
\end{aligned}$$

VAI:

$$\text{Male} = [1.31/\text{HDL (mmol/L)}] \times (\text{TG (mmol/L)}/1.03) \times [\text{WC (cm)}/(39.68 + 1.88 \times \text{BMI})];$$
$$\text{Female} = [1.52/\text{HDL (mmol/L)}] \times (\text{TG (mmol/L)}/0.81) \times [\text{WC (cm)}/(36.58 + 1.89 \times \text{BMI})];$$
$$\text{HIS} = 8 \times \text{ALT/AST ratio} + \text{BMI } (+2, \text{ if DM or female});$$

Statistical analysis

The software SPSS model 22 (SPSS Inc.) was utilized for data analysis. The normality of the data was assessed using the Kolmogorov–Smirnov test. Quantitative data were presented as mean ± standard deviation, while qualitative data were represented as frequency (%). Logistic regression analysis was employed to explore the relationship between various parameters, with significance attributed to *P* values below 0.05. Confounding variables such as age, gender, and physical activity were taken into account. Additionally, receiver operating characteristic (ROC) curve analysis was conducted for all parameters to determine the threshold where the sum of sensitivity and specificity was maximized, thereby identifying optimal thresholds for each parameter. This approach enabled researchers to evaluate the predictive efficacy of obesity and lipid-related indices for degree of hepatic steatosis in MASLD. The interpretation of the area under the curve (AUC) was as follows: < 0.5, considered unreliable; 0.5–0.6, deemed useless; 0.6–0.7, categorized as weak; 0.7–0.8, regarded as relatively good; 0.8–0.9, acknowledged as good; and 0.9–1, deemed excellent.

Results

Characteristics of the study participants

The study comprised of 105 females and 45 males diagnosed with MASLD, among whom 47 females (44%) and 21 males (46%) exhibited grade II MASLD. Table 1 presents the demographic, biochemical, and anthropometric profiles, as well as obesity and lipid-related indices, categorized by gender and degree of hepatic steatosis in MASLD patients. Regardless of gender, individuals with Grade II MASLD showed significantly higher levels of BMI, WC, WHtR, AST, ALT, TyG, TyG-BMI, TyG-WHtR, TyG-WC, COI, LAP, VAI, ABSI, and BRI ($P<0.05$). When considering gender, both male and female participants with grade II MASLD had significantly higher levels of TyG-WHtR and TyG-WC. ($P<0.05$), while BMI, WC, ALT, AST, WHtR, TyG-BMI, TyG-WHtR, TyG-WC, HSI, COI, LAP, VAI, BRI, and ABSI were significantly higher among females with grade II MASLD ($P<0.05$).

Associations of obesity and lipid-related indices with degree of hepatic steatosis in MASLD patients

Table 2 depicts the correlation between obesity and lipid-related indices and the degree of hepatic steatosis. Both before and after model adjustment, a positive correlation was evident between the degree of hepatic steatosis and all indices examined in our study (except for HSI). Notably, after considering the confounding factors, the HSI index displayed a positive correlation with degree of hepatic steatosis.

Evaluation of Accuracy of obesity and lipid-related indices in specifying the degree of hepatic steatosis in the study subjects

To evaluate the accuracy of obesity and lipid-related indices in predicting the degree of hepatic steatosis across the entire population, ROC analysis was conducted (Fig. 1; Table 3). The areas under the curve (AUC) for all the indices examined were greater than 0.5, indicating a noticeable association between these indices and the degree of hepatic steatosis.

Among the scrutinized indices, TyG-WC, TyG-WHtR, LAP, and COI demonstrated the highest AUC values, exceeding 0.7 (0.772, 0.735, 0.711, and 0.704, respectively). These results suggest a relatively strong association between these indicators and the degree of hepatic steatosis.

Evaluation of the accuracy of obesity and lipid-related indices in specifying the degree of hepatic steatosis in different genders

Tables 4 and 5, along with Figs. 2 and 3, display the results of ROC analysis and the corresponding AUC values for obesity and lipid-related indices used in diagnosing the degree of hepatic steatosis among females and males, respectively.

In females, the highest AUC was observed for TyG-WC (AUC = 0.797, 95% CI 0.712–0.882), followed by TyG-WHtR (AUC = 0.767, 95% CI 0.676–0.857), BRI (AUC = 0.738, 95% CI 0.642–0.834), ABSI (AUC = 0.712, 95% CI 0.612–0.813), COI (AUC = 0.717, 95% CI 0.617–0.816), and TyG-BMI (AUC = 0.704, 95% CI 0.604–0.803). These indices demonstrated a relatively good relationship (AUC > 0.7) with the degree of hepatic steatosis. The optimal thresholds for these indices in our study were: 865.991 for TyG-WC, 6.324 for TyG-WHtR, 160.343 for BRI, 1.270 for ABSI, 283.882 for COI, and 5.558 for TyG-BMI.

Among males, TyG (AUC = 0.718, 95% CI 0.560–0.877) and TyG-related indices such as TyG-WC (AUC = 0.716, 95% CI 0.560–0.872) and TyG-WHtR (AUC = 0.722, 95% CI 0.566–0.878) demonstrated a relatively good relationship (AUC > 0.7) with the degree of hepatic steatosis. Additionally, other indices such as VAI (AUC = 0.702, 95% CI 0.544–0.861) and LAP (AUC = 0.746, 95% CI 0.593–0.899) also exhibited this relationship. The optimal thresholds for these indices were 8.800, 936.532, 5.367, 2.161, and 74.290, respectively.

Discussion

MASLD is a disorder with implications beyond the liver, linked to various extra-hepatic complications like cardiovascular disease (CVD), chronic kidney disease (CKD), and certain cancers. Hence, there's a critical need for simple and non-invasive methods to identify individuals with advanced degree of hepatic steatosis[27,28].

	All			Male			Female		
	Grade I n = 82	Grade II n = 68	*P* value	Grade I n = 24	Grade II n = 21	*P* value	Grade I n = 58	Grade II n = 47	*P* value
Age	41.13 ± 11.94	43.82 ± 11.51	0.160	43.13 ± 13.7	40.24 ± 10.15	0.423	40.31 ± 11.16	45.43 ± 11.81	0.026
Weight (kg)	85.90 ± 12.49	89.84 ± 11.97	0.050	93.83 ± 11.45	91.76 ± 10.94	0.538	82.62 ± 11.46	88.98 ± 12.4	0.008
Height (m)	1.62 ± 0.10	1.62 ± 0.09	0.858	1.74 ± 0.06	1.73 ± 0.05	0.458	1.57 ± 0.06	1.58 ± 0.07	0.634
BMI (kg/m^2)	32.45 ± 3.59	33.96 ± 4.42	0.022	30.72 ± 3.13	30.59 ± 3.69	0.903	33.17 ± 3.55	35.46 ± 3.88	0.002
Waist (cm)	100.01 ± 7.72	107.11 ± 9.90	<0.001	102.50 ± 6.71	104.57 ± 7.09	0.322	98.99 ± 7.92	108.25 ± 10.80	<0.001
WHtR	0.61 ± 0.05	0.66 ± 0.07	<0.001	0.58 ± 0.03	0.60 ± 0.04	0.154	0.62 ± 0.05	0.68 ± 0.07	<0.001
ALT (IU/L)	22.67 ± 10.85	30.45 ± 25.40	0.013	27.66 ± 15.39	42.61 ± 38.12	0.084	20.60 ± 7.54	25.02 ± 14.49	0.047
AST (IU/L)	18.42 ± 6.75	22.27 ± 13.63	0.026	20.25 ± 9.01	26.00 ± 20.51	0.245	17.67 ± 5.48	20.61 ± 8.87	0.051
TC (mg/dL)	182.00 ± 30.06	180.01 ± 42.23	0.767	179.12 ± 32.23	186.09 ± 39.50	0.425	183.18 ± 41.76	177.29 ± 43.53	0.597
TG (mg/dL)	152.76 ± 85.99	180.47 ± 89.15	0.056	176.04 ± 126.40	210.04 ± 87.80	0.296	143.13 ± 61.15	167.25 ± 87.45	0.146
HDL (mg/dL)	41.12 ± 9.59	40.48 ± 9.41	0.683	39.29 ± 8.93	38.23 ± 10.41	0.614	41.87 ± 9.83	41.48 ± 8.87	0.753
LDL (mg/dL)	104.95 ± 28.51	98.17 ± 30.95	0.169	101.71 ± 21.27	100.28 ± 35.40	0.873	106.29 ± 31.09	97.23 ± 29.11	0.127
FPG (mg/dL)	87.54 ± 10.35	91.70 ± 19.35	0.114	89.37 ± 12.90	96.95 ± 27.80	0.411	86.79 ± 9.11	89.36 ± 13.82	0.277
TyG	8.69 ± 0.48	8.90 ± 0.54	0.014	8.82 ± 0.50	9.12 ± 0.53	0.055	8.63 ± 0.47	8.80 ± 0.52	0.102
TyG-BMI	281.92 ± 33.42	301.19 ± 35.28	0.001	271.12 ± 32.25	278.53 ± 31.43	0.441	286.39 ± 33.14	311.32 ± 32.31	<0.001
TyG-wHtR	5.35 ± 0.49	5.86 ± 0.64	<0.001	5.17 ± 0.38	5.50 ± 0.48	0.015	5.42 ± 0.51	6.02 ± 0.65	<0.001
TyG-WC	868.86 ± 78.59	951.67 ± 85.33	<0.001	903.49 ± 70.76	953.45 ± 73.01	0.025	854.54 ± 77.73	950.88 ± 91.02	<0.001
HSI	65.83 ± 17.22	68.99 ± 18.92	0.292	41.50 ± 3.52	43.13 ± 6.71	0.327	75.90 ± 8.01	80.54 ± 7.76	0.003
COI	1.26 ± 0.07	1.32 ± 0.08	<0.001	1.28 ± 0.07	1.32 ± 0.04	0.076	1.25 ± 0.06	1.32 ± 0.10	<0.001
BRI	5.85 ± 1.19	6.97 ± 1.97	<0.001	5.15 ± 0.69	5.56 ± 1.05	0.140	6.14 ± 1.24	7.61 ± 1.97	<0.001
ABSI	146.87 ± 32.46	169.74 ± 46.10	0.001	132.90 ± 23.75	136.62 ± 33.76	0.675	152.66 ± 33.97	184.53 ± 43.31	<0.001
LAP	67.91 ± 36.24	92.00 ± 40.20	<0.001	73.61 ± 50.52	91.93 ± 33.42	0.155	65.55 ± 28.59	92.03 ± 43.22	<0.001
VAI	2.68 ± 1.42	3.37 ± 1.84	0.012	2.55 ± 1.73	3.30 ± 1.60	0.140	2.73 ± 1.28	3.40 ± 1.95	0.037
Education level			0.789			0.475			0.679
Illiterate	2 (2.5%)	3 (4.4%)		0 (0%)	0 (0%)		2 (3.4%)	0 (0%)	
Under diploma	14 (17.1%)	19 (27.9%)		2 (8.3%)	1 (4.8%)		12 (20.7%)	2 (8.3%)	
Diploma	34 (41.5%)	28 (41.2%)		9 (37.5%)	7 (33.3%)		25 (43.1%)	9 (37.5%)	
Educated	32 (39.0%)	18 (26.5%)		13 (54.2%)	13 (61.9%)		19 (32.8%)	13 (54.2%)	
Physical activity			0.104			0.562			0.104
Low	63 (76.8%)	47 (69.1%)		17 (70.8%)	13 (61.9%)		46 (79.3%)	34 (72.3%)	
Moderate	17 (20.7%)	19 (27.9%)		5 (20.8%)	6 (28.6%)		12 (20.7%)	13 (27.7%)	
High	2 (2.4%)	2 (2.9%)		2 (8.3%)	2 (9.5%)		0 (0%)	0 (0%)	

Table 1. Basic characteristics of the study participants according to gender and grade of MASLD. Values were expressed as mean ± SD or medians (quartile interval) or frequency (percent). *MASLD* metabolic dysfunction-associated steatotic liver disease, *BMI* body mass index, *WC* waist circumference, *WHtR* waist-to-height ratio, *TyG* index triglyceride-glucose index, *TyG-BMI* triglyceride glucose-body mass index, *TyG-WC* triglyceride glucose-waist circumference, *TyG-WHtR* triglyceride glucose-waist-to-height ratio, *ALT* alanine aminotransferase, *AST* aspartate aminotransferase, *HDL-C* high-density lipoprotein cholesterol, *TC* total cholesterol, *TG* triglyceride, *FPG* fasting plasma glucose, *HSI* hepatic steatosis index, *VAI* visceral adiposity index, *LAP* lipid accumulation product, *ABSI* body-shape index, *BRI* body roundness index, *COI* conicity index.

Previous research has highlighted the influence of factors such as obesity, metabolic disorders, and environmental contributors on the occurrence and progression of MASLD[29,30]. Insulin resistance plays a central role in MASLD pathogenesis. One key mechanism involves insulin's reduced ability to inhibit adipose tissue lipolysis, leading to increased delivery of free fatty acids to the liver and heightened de novo lipogenesis, despite IR. Insulin resistance has also been shown to enhance TG synthesis through the Kennedy pathway and potentially impair fatty acid β-oxidation, although this remains debated[13,31,32]. The prevalence of MASLD are escalating due to the obesity epidemic, emphasizing the importance of effective management strategies[33]. Waist circumference may provide a better representation of the risk of obesity-related diseases than BMI[34].

The objective of this investigation was to evaluate the prognostic value of obesity and lipid-related indices in gauging the degree of hepatic steatosis in individuals with MASLD. Our results indicated a direct association between all analyzed measures and the degree of hepatic steatosis. Particularly noteworthy were TyG-WC, TyG-WHtR, and LAP, which exhibited the greatest precision in forecasting the degree of hepatic steatosis among the indices assessed.

The TyG index, comprising FPG and TG levels, is utilized to diagnose IR[35]. Parameters linked to TyG, namely the product of TyG and waist circumference (TyG-WC), TyG and waist-to-height ratio (TyG-WHtR), and TyG

	Univariate model		Multivariate model	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Variables				
TyG	2.25 (1.16, 4.36)	0.017	2.11 (1.05, 4.22)	0.034
TyG-BMI	1.02 (1.01, 1.03)	0.001	1.02 (1.01, 1.03)	0.001
TyG-WHtR	5.02 (2.52, 9.98)	< 0.001	6.25 (2.9, 13.6)	< 0.001
TyG-WC	1.01 (1.01, 1.02)	< 0.001	1.01 (1.01, 1.02)	< 0.001
HSI	1.01 (0.99, 1.03)	0.287	1.1 (1.03, 1.13)	0.001
COI	2.089 (1.186, 2.991)	< 0.001	1.998 (1.059, 2.937)	< 0.001
BRI	1.6 (1.25, 2.01)	< 0.001	1.8 (1.34, 2.4)	< 0.001
ABSI	1.01 (1.01, 1.02)	0.001	1.02 (1.01, 1.03	< 0.001
LAP	1.02 (1.01, 1.03)	0.001	1.02 (1.01, 1.03)	0.001
VAI	1.3 (1.06, 1.062)	0.010	1.3 (1.04, 1.6)	0.02

Table 2. Association of MASLD with the amount of obesity and lipid-related indices. Multivariate model adjusted for age, habit of exercise, gender. *CI* confidence interval, *MASLD* metabolic dysfunction-associated steatotic liver disease, *TyG index* triglyceride-glucose index, *TyG-BMI* triglyceride glucose-body mass index, *TyG-WC* triglyceride glucose-waist circumference, *TyG-WHtR* triglyceride glucose-waist-to-height ratio, *HSI* hepatic steatosis index, *VAI* visceral adiposity index, *LAP* lipid accumulation product, *ABSI* body-shape index, *BRI* body roundness index, *COI* conicity index.

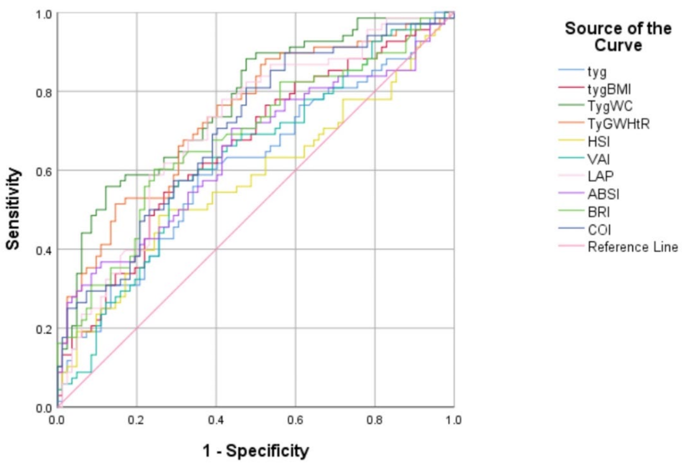

Fig. 1. ROC curve analysis of obesity and lipid-related indices in whole MASLD patients. *TyG index* triglyceride-glucose index, *TyG-BMI* triglyceride glucose-body mass index, *TyG-WC* triglyceride glucose-waist circumference, *TyG-WHtR* triglyceride glucose-waist-to-height ratio, *HSI* hepatic steatosis index, *VAI* visceral adiposity index, *LAP* lipid accumulation product, *ABSI* body-shape index, *BRI* body roundness index, *COI* conicity index.

and body mass index (TyG-BMI), have shown improved efficacy in identifying individuals with IR[35]. Given the role of abdominal obesity and IR as risk and progression factors for MASLD, it is not surprising that indices associated with these factors, such as TyG-WC and TyG-WHtR, displayed the highest predictive accuracy for the degree of hepatic steatosis in our study.

A previous study revealed that TyG-BMI shows a stronger correlation with the degree of hepatic steatosis compared to TyG alone, indicating that higher TyG-BMI values are associated with more severe hepatic steatosis[36]. Our study's results are consistent with this prior research, affirming the heightened predictive capability of TyG-BMI for determining the degree of hepatic steatosis, toward TyG alone. But in general, TyG and TyG-BMI showed less correlations than TyG-WC and TyG-WHtR with degree of hepatic steatosis.

LAP, reflecting surplus lipid accumulation, is calculated based on WC and fasting plasma TG levels[17]. A systematic review and meta-analysis have highlighted LAP as a feasible, cost-effective, and precise tool for diagnosing MASLD in the general population[37]. Another study emphasized the substantial association between LAP and both the presence and severity of MASLD, with LAP exhibiting high diagnostic accuracy, particularly among younger individuals in the general population[38]. Our study's findings underscore LAP's accuracy in indicating the degree of hepatic steatosis in MASLD, particularly among males.

	AUC	95% CI low	95% CI up	Best threshold	Positive-LR	Negative-LR	Specificity	Sensitivity
TyG	0.611	0.517	0.706	8.8009	1.661	0.637	0.646	0.588
TyG-BMI	0.653	0.561	0.744	285.5151	1.498	0.577	0.585	0.662
TyG-WC	0.772	0.694	0.850	924.7758	2.121	0.507	0.695	0.647
TyG-WHtR	0.735	0.652	0.818	5.3459	1.714	0.383	0.537	0.794
HSI	0.577	0.479	0.674	65.1114	1.040	0.933	0.378	0.647
VAI	0.624	0.530	0.717	2.1843	1.285	0.651	0.451	0.706
LAP	0.711	0.624	0.797	65.8279	1.807	0.427	0.585	0.750
ABSI	0.648	0.555	0.742	144.8036	1.608	0.524	0.561	0.706
BRI	0.682	0.592	0.771	6.1208	1.966	0.526	0.671	0.647
COI	0.704	0.618	0.790	1.2805	1.756	0.491	0.598	0.706

Table 3. The best threshold, positive-LR, Negative-LR, sensitivities, specificities and area under the curve of obesity and lipid-related indices for the degree of hepatic steatosis in whole MASLD patients. Multivariate model adjusted for age, habit of exercise, gender. *AUC* area under the curve, *CI* confidence interval, *MASLD* metabolic dysfunction-associated steatotic liver disease, *TyG index* triglyceride-glucose index, *TyG-BMI* triglyceride glucose-body mass index, *TyG-WC* triglyceride glucose-waist circumference, *TyG-WHtR* triglyceride glucose-waist-to-height ratio, *HSI* hepatic steatosis index, *VAI* visceral adiposity index, *LAP* lipid accumulation product, *ABSI* body-shape index, *BRI* body roundness index, *COI* conicity index.

	AUC	95% CI low	95% CI up	Best threshold	Positive-LR	Negative-LR	Specificity	Sensitivity
TyG	0.575	0.465	0.686	8.596	1.314	0.639	0.466	0.702
TyG-BMI	0.704	0.604	0.803	283.882	1.709	0.423	0.552	0.766
TyG-WC	0.797	0.712	0.882	865.991	2.143	0.247	0.603	0.851
TyG-WHtR	0.767	0.676	0.857	5.558	2.021	0.376	0.621	0.766
HSI	0.669	0.565	0.773	76.768	1.821	0.459	0.603	0.723
VAI	0.604	0.495	0.713	2.768	1.490	0.653	0.586	0.617
LAP	0.696	0.596	0.797	63.277	1.900	0.363	0.586	0.787
ABSI	0.712	0.612	0.813	160.343	1.695	0.508	0.586	0.702
BRI	0.738	0.642	0.834	6.324	2.344	0.291	0.655	0.809
COI	0.717	0.617	0.816	1.270	1.768	0.494	0.603	0.702

Table 4. The best threshold, positive-LR, Negative-LR, sensitivities, specificities and area under the curve of obesity and lipid-related indices for the degree of hepatic steatosis in female MASLD patients. Multivariate model adjusted for age, habit of exercise, gender. *AUC* area under the curve, *CI* confidence interval, *MASLD* metabolic dysfunction-associated steatotic liver disease, *TyG index* triglyceride-glucose index, *TyG-BMI* triglyceride glucose-body mass index, *TyG-WC* triglyceride glucose-waist circumference, *TyG-WHtR* triglyceride glucose-waist-to-height ratio, *HSI* hepatic steatosis index, *VAI* visceral adiposity index, *LAP* lipid accumulation product, *ABSI* body-shape index, *BRI* body roundness index, *COI* conicity index.

The Conicity index, comprising waist circumference, height, and weight, serves as a valuable tool for evaluating fat mass distribution[39]. In our study, COI demonstrated a moderately strong association with degree of hepatic steatosis across the overall study population and among females, but it exhibited a negligible correlation with the degree of hepatic steatosis in males. To date, no research has explored the relationship between the degree of hepatic steatosis and this index, highlighting the necessity for further investigations in this area. Other indices examined in our study, such as TyG, TyG-BMI, HIS, BRI, ABSI, and VAI, either displayed weak or insignificant correlations with the degree of hepatic steatosis or demonstrated relatively stronger associations solely in women (BRI and ABSI) or men (TyG and VAI). Additional studies are warranted to draw more conclusive insights in this field.

Conclusion

In summary, this study highlights the strong correlation observed between TyG-related indices, specifically TyG-WHtR and TyG-WC, alongside LAP, and the degree of hepatic steatosis. Their key characteristics, including non-invasiveness and ease of measurement, position them as promising tools for clinical use. These indices present potential for accurately assessing degree of hepatic steatosis and tracking treatment responses in individuals with MASLD.

The findings have significant clinical implications for the management of MASLD. Using non-invasive measures like TyG-WHtR, TyG-WC, and LAP, healthcare providers can more accurately identify patients with advanced degree of hepatic steatosis, enabling earlier detection and timely interventions. This reduces reliance on invasive liver biopsies and allows for more precise monitoring of disease progression. These indices facilitate

	AUC	95% CI low	95% CI up	Best threshold	Positive-LR	Negative-LR	Specificity	Sensitivity
TyG	0.718	0.560	0.877	8.800	2.934	0.201	0.708	0.857
TyG-BMI	0.567	0.397	0.738	278.276	1.484	0.653	0.583	0.619
TyG-WC	0.716	0.560	0.872	936.532	3.206	0.420	0.792	0.667
TyG-WHtR	0.722	0.566	0.878	5.367	2.445	0.403	0.708	0.714
HSI	0.514	0.338	0.689	42.015	1.048	0.952	0.500	0.524
VAI	0.702	0.544	0.861	2.161	2.144	0.428	0.667	0.714
LAP	0.746	0.593	0.899	74.290	3.663	0.300	0.792	0.762
ABSI	0.524	0.350	0.698	132.418	1.369	0.735	0.583	0.571
BRI	0.619	0.451	0.787	5.474	2.119	0.538	0.708	0.619
COI	0.617	0.450	0.784	1.290	1.238	0.762	0.500	0.619

Table 5. The best threshold, positive-LR, Negative-LR, sensitivities, specificities and area under the curve of obesity and lipid-related indices for the degree of hepatic steatosis in male MASLD patients. Multivariate model Adjusted for age, habit of exercise, gender. *AUC* area under the curve, *CI* confidence interval, *MASLD* metabolic dysfunction-associated steatotic liver disease, *TyG index* triglyceride-glucose index, *TyG-BMI* triglyceride glucose-body mass index, *TyG-WC* triglyceride glucose-waist circumference, *TyG-WHtR* triglyceride glucose-waist-to-height ratio, *HSI* hepatic steatosis index, *VAI* visceral adiposity index, *LAP* lipid accumulation product, *ABSI* body-shape index, *BRI* body roundness index, *COI* conicity index.

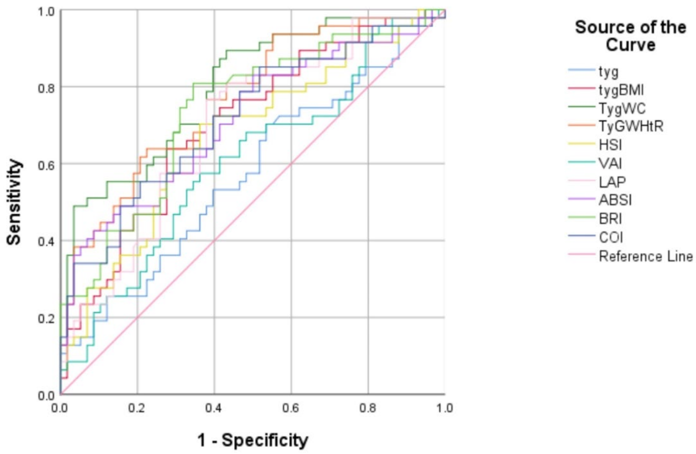

Fig. 2. ROC curve analysis of obesity and lipid-related indices in females with MASLD. *TyG* index triglyceride-glucose index, *TyG-BMI* triglyceride glucose-body mass index, *TyG-WC* triglyceride glucose-waist circumference, *TyG-WHtR* triglyceride glucose-waist-to-height ratio, *HSI* hepatic steatosis index, *VAI* visceral adiposity index, *LAP* lipid accumulation product, *ABSI* body-shape index, *BRI* body roundness index, *COI* conicity index.

personalized treatment plans, enhancing patient care by tailoring interventions based on the degree of hepatic steatosis. They also enable better evaluation of treatment responses in routine clinical practice. Future research should focus on validating these indices in diverse populations and integrating them into clinical guidelines, ultimately improving the management and outcomes of patients with MASLD.

Strengths and limitations

Strengths

- *Comprehensive assessment* This study evaluates a wide range of obesity and lipid-related indices, including TyG, TyG-BMI, TyG-WHtR, TyG-WC, HSI, COI, BRI, ABSI, LAP, and VAI, providing a thorough comparison of their effectiveness in predicting degree of hepatic steatosis in MASLD patients.
- *Clinical relevance* The findings underscore the strong predictive accuracy of indices like TyG-WHtR, TyG-WC, and LAP, which are non-invasive, easily measurable, and highly applicable in clinical settings.
- *Potential for early intervention* By identifying simple and non-invasive methods for predicting degree of hepatic steatosis, the study supports early detection and timely intervention, which are crucial for managing MASLD and its associated risks.

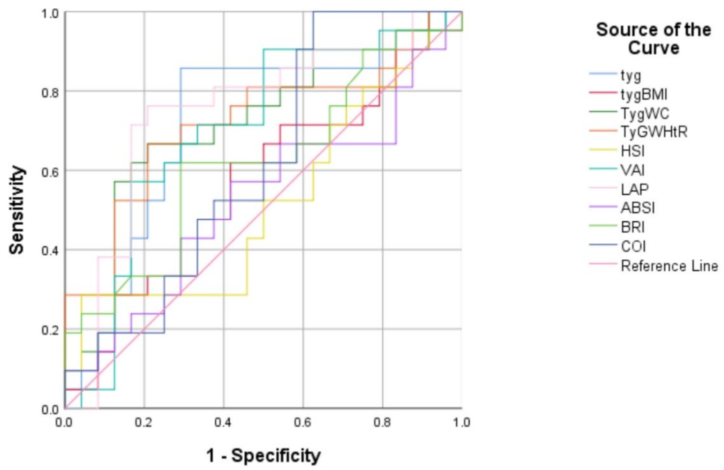

Fig. 3. ROC curve analysis of obesity and lipid-related indices in males with MASLD. *TyG* index triglyceride-glucose index, *TyG-BMI* triglyceride glucose-body mass index, *TyG-WC* triglyceride glucose-waist circumference, *TyG-WHtR* triglyceride glucose-waist-to-height ratio, *HSI* hepatic steatosis index, *VAI* visceral adiposity index, *LAP* lipid accumulation product, *ABSI* body-shape index, *BRI* body roundness index, *COI* conicity index.

Limitations

- *Population specificity* The study findings may be influenced by the specific characteristics of the study population, which could limit the generalizability of the results to other populations with different demographics or risk profiles.
- *Gender differences* The indices demonstrated varying predictive accuracies based on gender, with some indices showing stronger associations in either males or females. This indicates the need for gender-specific analysis and validation in future research.
- *Insufficient data on certain indices* Some indices, such as the COI, showed limited or negligible correlation with degree of hepatic steatosis in specific subgroups, highlighting the necessity for further investigations to establish their clinical utility.
- *Need for validation* While the study presents promising findings, additional research is required to validate these indices in larger and more diverse cohorts, and to confirm their effectiveness in routine clinical practice for assessing and monitoring degree of hepatic steatosis in MASLD patients.

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

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Author contributions

P.F.: Data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); software (equal); writing—original draft (equal); writing—review and editing (equal). S.K.: conceptualization (equal); project administration (equal); supervision (equal); validation (equal); writing—review and editing (equal). M.A.: methodology (equal); project administration (equal); supervision (equal).

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to P.F.

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