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Magnetic resonance spectroscopy as a diagnostic model for assessment of liver steatosis in metabolic dysfunction-associated steatotic liver disease in non-diabetic patients

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Abstract

Background Metabolic dysfunction-associated steatotic liver (MASLD) disease is the commonest hepatic cause of liver fibrosis and cirrhosis after the introduction of the direct acting antivirals and eradication of hepatitis C. MASLD is usually associated with metabolic syndrome and elevated inflammatory markers. Magnetic resonance spectroscopy (MRS) offers a non-invasive diagnostic, alternative to liver biopsy. This is a case–control diagnostic-accuracy study conducted on 40 patients in the Hepato-gastroenterology Unit in the Internal Medicine Department, Ain Shams University Hospitals, to study the role of MRI spectroscopy as a new diagnostic model for assessment of liver steatosis in non-diabetic MASLD patients compared to the standard ultrasound and clinical criteria. MASLD was diagnosed by a combination of a validated ultrasound hepatic steatosis score grading system and hepatic steatosis index using clinical and laboratory parameters. MRS was performed in all patients and fat peak, water peak, and fat fraction % were measured, and diagnostic accuracy of different MRS is compared to the US scoring and different laboratory and clinical parameters. To our knowledge this is the first study conducted on MRS in our region and Egypt.

Results This study revealed no statistically significant difference between the two groups regarding HbA1C, creatinine, while there was highly statistically significant difference regarding fasting blood sugar, 2 h post-prandial glucose level, urine albumin, and low-density lipoprotein levels. Hepatic steatosis score grading by abdominal ultrasound on the 20 controls showed no fatty changes with grade 0 (50%), and on the 20 MASLD patients showed that 2 cases were grade 1 steatosis (5%), 9 cases were grade 2 steatosis (22.5%), and 9 cases were grade 3 steatosis (22.5%). The diagnostic accuracy of predicting hepatic steatosis using different MRS parameters: fat peak, water peak, and fat fraction had area under the curve of 99.9%, 88.6%, and 100%, respectively. The sensitivity and specificity of fat fraction in detecting hepatic steatosis were 100%. The sensitivity and specificity of the fat peak in detecting hepatic steatosis were 100% and 95%, respectively. Moreover, the sensitivity and specificity of the water peak in detecting the hepatic steatosis were 88.6% and 85%, respectively. There is a statistically significant correlation between the three MRS parameters and the abdominal ultrasound hepatic steatosis score grades.

Conclusion MRS parameters: fat fraction, fat peak, and water peak, have high diagnostic accuracy for predicting the liver steatosis. Moreover, MRS has the added advantage of being a non-invasive and a tool with low radiation risk. MRS also shows the metabolic changes in the liver and could be an eligible outcome in therapeutic clinical trials.

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Keywords Fatty liver disease, MR spectroscopy, MASLD, Fat peak, Water peak, Fat fraction, Hepatic steatosis score, Abdominal ultrasound

Background

Non-alcoholic fatty liver disease (NAFLD) is defined as the presence of fat in the liver tissue exceeding 5% with total abstinence from alcoholic consumption, or consumption of an amount not exceeding 14 drinks/week for men, and 7 drinks/week for women [1]. Most of the patients with NAFLD are asymptomatic and have metabolic syndrome [2, 3]. Metabolic dysfunction-associated steatotic liver disease (MASLD) is the latest term for the fatty liver disease [4]; Eslam et al. [5] were the first to introduce this term in 2020. MASLD is now the official replacement term of NAFLD in medical literature [6].

In MASLD, liver macrosteatosis occurs in the centrilobular zone of liver sinuses. Fatty liver disease is not a benign disorder, as 18% will progress to cirrhosis or fibrosis [7]. The diagnosis of fatty liver in human research is always hindered by the lack of tissue biopsy for accurate diagnosis, due to the invasive nature of the test. Thus, radiological alternatives with a low risk of radiation hazard as CAP-scan, ultrasound, and MRI are more agreeable to the patients [8, 9].

Abdominal ultrasound has the advantage of being low-cost, reliable, reproducible, safe, and accessible [10]. Abdominal ultrasound has a diagnostic accuracy for detecting moderate to severe fatty liver disease when compared to histological liver samples of sensitivity 84.8%, specificity 93.6%, with an area under the curve of 0.93 [10]. However, ultrasound has the disadvantage of being an operator-dependent tool and lower in accuracy than MRS [11]. Moreover, abdominal wall fat or colonic gaseous distension could hinder the visualization of the liver on the B-mode abdominal ultrasound [12].

Hepatic steatosis index was first developed in Korea [6]. Lee et al. [13] found that the sensitivity of HSI with levels of < 30.0 or > 36.0 excluded MASLD, with high sensitivity and specificity of 93.1% and 92.4%, respectively. However, HSI showed a diagnostic accuracy for MASLD with moderate AUC of 0.784 in a recent review [6].

The aim of this study was to evaluate the diagnostic performance of MRI spectroscopy for assessing hepatic steatosis in non diabetic-MASLD patients, and the control group (non-diabetic non-MASLD), as compared to standard known tools of abdominal ultrasound, HSI, and clinical evaluation.

Patients and methods

This is a retrospective case–control diagnostic accuracy study conducted on 40 patients in the Hepato-gastroenterology Unit in the Internal Medicine Department, and the Radiology Department, Ain Shams University Hospitals, to study the role of MRI spectroscopy as a diagnostic model for assessment of liver steatosis in non-diabetic MASLD patients. The study was conducted according to the Declaration of Helsinki guidelines. The study protocol was approved by Ain Shams Faculty of Medicine Ethical Committee, Ethical approval number FMASU MS087/2023. All patients signed an informed consent before participation in the study. The study followed the STRAD 2015 guidelines for diagnostic-accuracy studies.

Inclusion criteria Age ranges from 18 to 70 years old; cases were chosen (20 cases) with accidently diagnosed fatty liver disease during routine check-up by abdominal ultrasound and laboratory investigations, with randomly chosen 20 matched healthy controls. We included only patients with diffuse fatty infiltration as detected by abdominal ultrasound before MRS. The 20 matched controls were included with normal ultrasound and negative diagnostic indices. Hepatic steatosis index (HSI) was used in addition to abdominal ultrasound to categorize the patients as cases or controls. HSI was calculated and the < 30.0 or > 36.0 values were used to rule out MASLD [13].

Exclusion criteria Diabetic patients either type I or II DM; alcohol intake above 40 g per day for men and 20 g per day for women; acute illness in the last two weeks before investigation; severe illness unrelated to the liver (e.g., heart failure, kidney failure, malignancy, respiratory failure); pregnancy; hyper- or hypothyroidism that was uncontrolled; or patients with any contraindications to performing magnetic resonance (e.g., permanent pacemaker or metallic joint replacement).

Any patient with a history of liver disease due to any of the following causes was excluded Viral hepatitis, autoimmune hepatitis, drug-induced liver disease, primary biliary cirrhosis, hemochromatosis, Wilson's disease, A1-antithrypsin deficiency, alcoholic liver disease, primary or secondary liver tumors, portal or hepatic veins thrombosis due to any cause, decompensated liver cirrhosis, and ascetic patients due to any cause either hepatic or other. We also excluded patients with a history of bilharziasis or periportal fibrosis.

Both the patient and control groups were subjected to Full history taking, thorough clinical examination, BMI calculation, waist and arm circumference measured in cm, laboratory, and radiological investigations.

Laboratory investigation included Blood urea nitrogen (BUN), creatinine (Cr), and serum albumin level.

Complete blood count includes white cell count (WBC), hemoglobin, mean corpuscular volume (MCV), and platelet count. Lipid profile includes low-density lipoprotein (LDL), high-density lipoprotein (HDL), total cholesterol, and triglycerides. Fasting blood sugar (FBS) and hemoglobin A1C (HbA1C) exclude diabetes in undiagnosed cases, in addition to assessing the metabolic syndrome. Alanine aminotransferase (ALT) and aspartate aminotransferase (AST) were employed to estimate the degree of hepatic inflammation. Gamma glutamyltransferase (GGT), total and direct bilirubin, and different serological markers exclude other causes of chronic liver diseases (HBsAg, HCV antibody, alpha-fetoprotein, and ANA).

Hepatic steatosis index was calculated (HSI): HSI = 8 × ALT/AST + BMI (+2 if type 2 diabetes yes, +2 if female) [13]. The last part of the equation was not applicable, as we did not include diabetic patients in our study.

Study procedures

A) Abdominal Ultrasound:

Pelvi-abdominal ultrasound was performed by an experienced single operator with 12-year experience in abdominal ultrasound in the Hepatology Department (author SN).

We estimated the degree of hepatic steatosis (by assessing the degree of brightness of the liver, liver size, coarseness, homogenous texture, or not. Patients were excluded if they have any primary or secondary liver tumors, decompensated cirrhosis, portal hypertension, ascites due to any cause, portal, or hepatic vein thrombosis). We also measured the spleen size, the portal, and the splenic veins diameters and assessed the presence of any thrombosis or collaterals.

Abdominal ultrasound grading was done according to the "*B-mode ultrasound steatosis score grading*" [14]. This is a commonly used and easily performed ultrasound steatosis scoring, with a high sensitivity and specificity, as compared to the standard histologic steatosis scoring according to a recent meta-analysis performed by Tan et al. 2024. Grade 0—absent steatosis: normal, where the echogenicity of the cortex of the kidney is similar to that of the liver. Grade I—mild steatosis: diffusely increased hepatic echogenicity, but periportal and diaphragmatic echogenicity are still appreciable. Grade II—moderate steatosis: diffusely increased hepatic echogenicity, obscuring periportal echogenicity, but diaphragmatic echogenicity is still appreciable. Grade III—severe steatosis: diffusely increased hepatic echogenicity, obscuring periportal as well as diaphragmatic echogenicity.

B) MRI spectroscopy:

Magnetic resonance spectroscopy (MRS) was done by the author AS with a 10 years' of experience in MRI to all cases using the device Philips Ingenia 1.5 T to assess the hepatic lipid content.

A single-voxel 1 H MRS using a pointer solved selective spectroscopy sequence with following parameters: TR, 2000 ms; TE, 144 ms; NSA, 128; total acquisition time, 4 min 52 s. On the spatially localized three-dimensional T2WI images of liver, a 20*20*20 mm single block was positioned on the right anterior lobe and left interior lobe of the liver, respectively, with care taken to avoid large lumen structures. A Java-based MR user interface spectroscopic analysis package (jMRUI, Barcelona, CA) is to measure the peak height of the water peak at 4.7 ppm and the methylene peak (CH_2) at 1.2 ppm. The intrahepatic content of lipid (IHCL) measured by 1 H MRS, FatMRS, is calculated as follows: FatMRS = CH_2 peak/(water peak + CH_2 peak) * 100%. IHCL is the mean value of FatMRS on the left and right lobe of liver.

Important, the signal fat fraction with MRS has a dynamic range of 0–100%. We used the following grading system (similar to histologic system): Grade 0: < 5% hepatocytes are affected, Grade I: 5–33% hepatocytes are affected, Grade II: 34–66% hepatocytes are affected, Grade III: > 66% hepatocytes are affected [15].

The area under water and fat peaks were quantified, and the water peak was measured at 4.7 ppm and ranged from 0.02 to 0.30 with mean 0.14 and SD 0.08. The fat peak was calculated as the sum of the area of the fat peaks (2.1, 1.3, and 0.9 ppm) or as the area of the main CH_2 peak (1.3 ppm) ranged from 0.01 to 0.24 with mean 0.09 and SD 0.08. Fat fraction was calculated: CH_2 peak/(water peak + CH_2 peak) * 100%, ranged from 4.0 to 84.61% with mean 39.64% and SD 29.47%. Importantly, the signal fat fraction with MRS has a dynamic range of 0–100%.

Interpretation of MRS imaging was done by a single radiologist with 12 years of experience in body imaging and 5 years in MRS (Author AS).

Statistical methods

Statistical presentation and analysis of the present study was conducted, using SPSS V20 (Statistical Package for Social Sciences).

We performed descriptive statistics for all the collected parameters data in the two studied groups and presented them in the form of mean, standard deviation (SD), and percentages.

We used Chi-square test for the comparison between groups regarding qualitative data.

We used one-way ANOVA test for the comparison between two groups with quantitative data and parametric distribution. Diagnostic accuracy testing with AUC, sensitivity, and specificity was calculated, and ROC curves were drawn.

The level of significance was calculated according to the following probability (p) values:

- $p > 0.05$ = non significant (NS)
- $p < 0.05$ = significant (S)
- $p < 0.001$ = highly significant (HS).

Results

This was a case–control study conducted on 20 non-diabetic MASLD patients and 20 healthy controls. The demographic presentation of our study was: 13 males (32.5%), 27 females (67.5%), 8 smokers (20%), 32 non-smokers (80%), and 10 with HTN (25%), and 30 without HTN (75%).

In the current study, MASLD was presented more frequently in females (67.5%) than in males (32.5%). The mean age of patients was (49.58) years with SD (9.48), mean weight (kg) 82.88 with SD 8.16, mean waist circumference (cm) 86.78 with SD 6.42, mean arm circumference (cm) 31.88 with SD 3.08, mean BMI (kg/m^2) 30.22 with SD 2.90 (see Table 1).

This study showed no statistically significant difference between the groups regarding sex, age, some co-morbidities as (smoking and hypertension). However, there was a highly statistically significant difference found between the groups regarding weight, waist circumference, arm circumference, and BMI. In addition, this study revealed no statistically significant difference between the groups regarding HbA1C, creatinine, while there was a highly statistically significant difference found between the groups regarding FBG, 2HPPBG, and urine albumin (see Table 2).

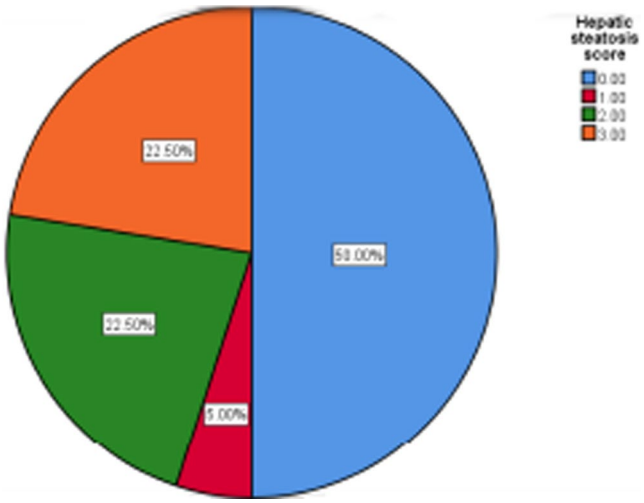
In this study, there was a highly statistically significant difference found between the groups regarding LDL. Hepatic steatosis grading was done using abdominal ultrasound B-mode, and groups were divided into 20 control cases (no fatty changes): grade 0 (50%), and 20 non diabetic MASLD cases: 2 cases were grade 1 steatosis (5%), 9 cases were grade 2 steatosis (22.5%), and 9 cases were grade 3 steatosis (22.5%) (see Fig. 1a). A flow chart of the study process is delineated in Fig. 1b.

Table 1 Relation between abdominal ultrasound hepatic steatosis score and anthropometric measures

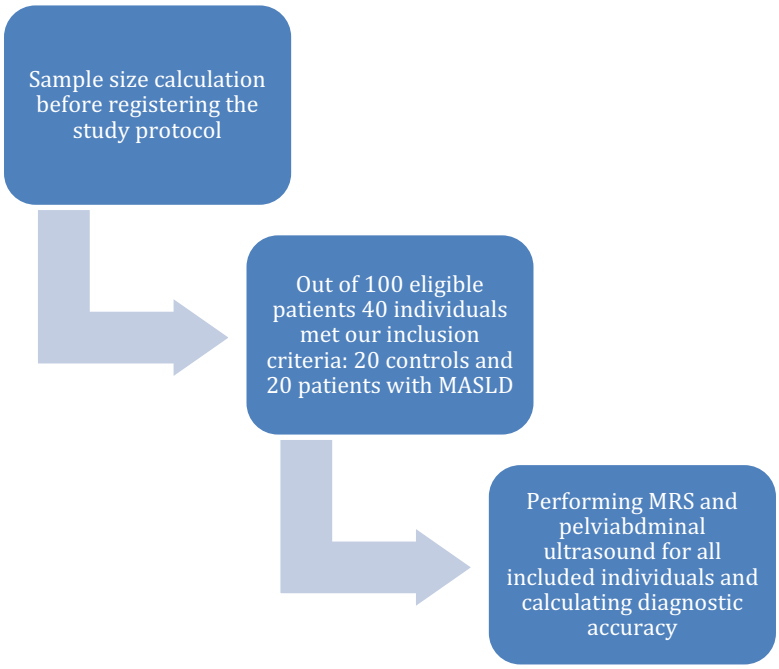
Variable	Hepatic steatosis score								*F*	*p* value
	0.00		1.00		2.00		3.00			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Weight (kg)	78.50	6.89	85.00	8.49	87.89	6.07	87.11	8.27	5.15	0.01 HS
Waist circumference (cm)	84.00	6.05	84.00	5.66	91.67	6.06	88.67	4.61	4.20	0.01 HS
Arm circumference (cm)	29.85	1.96	32.75	4.60	33.03	2.54	35.06	2.19	12.18	< 0.001 HS
BMI (Kg/m^2)	28.63	1.92	31.90	1.56	31.34	1.13	32.26	4.18	5.65	0.003 HS

Table 2 Relation between abdominal ultrasound hepatic steatosis score and lab investigations

Variable	Hepatic steatosis score								*F*	*p* value
	0		1		2		3			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
FBG	93.45	15.77	103.50	4.95	102.89	11.67	111.22	9.76	3.80	0.02 S
2HPPBG	129.50	15.59	158.00	2.83	143.78	19.92	159.22	24.03	6.07	0.002 HS
HbA1c%	6.00	0.36	6.35	0.07	6.11	0.24	6.24	0.30	1.68	0.19 NS
Creat (mg/dl)	1.16	0.24	1.12	0.25	0.95	0.22	1.12	0.19	1.79	0.17 NS
Variable	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	χ^2	***p* value**
Urine albumin										
Nil	20	100	2	100	4	44.4	0	0.0	33.99	< 0.001 HS
1	0	0.0	0	0.0	5	55.6	7	77.8		
2	0	0.0	0	0.0	0	0.0	2	22.2		



(a)



(b)

Fig. 1 **a** Hepatic steatosis score among the whole population (50% were Grade 0: controls). **b** Flow diagram of the study

Regarding the MRS parameters, there was no statistically significant correlation between fat peak and age; however, there was a statistically significant positive correlation between fat peak and BMI, FBG, 2HPP BG, and LDL (mg/dl). There was no statistically significant correlation between water peak and age, but there was a statistically significant negative correlation between water peak and BMI, FBG, 2HPP BG, and LDL (mg/dl). There was no statistically significant positive correlation between fat fraction and age, but there was a statistically significant positive correlation between fat fraction, and BMI, FBG, 2HPP BG, and LDL (mg/dl) (see Table 3).

The AUC of diagnostic accuracy of fat peak, water peak, and fat fraction in predicting hepatic steatosis was 99.9%, 88.6%, and 100%, respectively. Fat fraction predicted hepatic steatosis with the highest sensitivity and

Table 3 Correlation between MRI spectroscopy with age, BMI, FBG, 2HPP BG, and LDL (mg/dl)

Variable	MRI spectroscopy					
	Fat peak		Water peak		Fat fraction %	
	r	*p*-value	*r*	*p*-value	*r*	*p*-value
Age	0.289	0.071	−0.156	0.338	0.230	0.154
BMI (kg/m)	0.597**	0.000	−0.560**	0.000	0.657**	< 0.001
FBG	0.331*	0.037	−0.558**	0.000	0.490**	0.001
2HPP BG	0.400*	0.011	−0.520**	0.001	0.554**	< 0.001
LDL (mg/dl)	0.603**	0.000	−0.344*	0.030	0.560**	< 0.001

*Significant

**Highly significant

specificity (100% in both) of all the three parameters. Moreover, fat peak predicted hepatic steatosis with a sensitivity of 100% and a specificity of 95%; water peak predicted hepatic steatosis with a sensitivity of 88.6% and a specificity of 85% (see Fig. 2a, b, c).

The relation between the MRS fat peak, fat fraction, water peak, and the abdominal ultrasound hepatic steatosis score grades is shown in the figures (see Fig. 3a, b, c).

The relation between abdominal ultrasound hepatic steatosis score and the lipid profile was statistically significant with the LDL, but not with the cholesterol, triglycerides, or the HDL (see Table 4). The relation between ultrasound hepatic steatosis score and MRS parameters is presented in Table 5.

A mean plot presents the graphical relation between BMI (kg/m^2) and the ultrasound hepatic steatosis score (Fig. 4). The relation between the MRS parameters (fat fraction, fat peak, and water peak) and the presence of hepatic steatosis is also shown by mean plots (see Fig. 5a, b, c). Scatter plots show the positive correlation between the HSI with fat the fraction and the HSI with the fat peak. However, there was a negative correlation between HSI and water peak (see Fig. 6a, b, c).

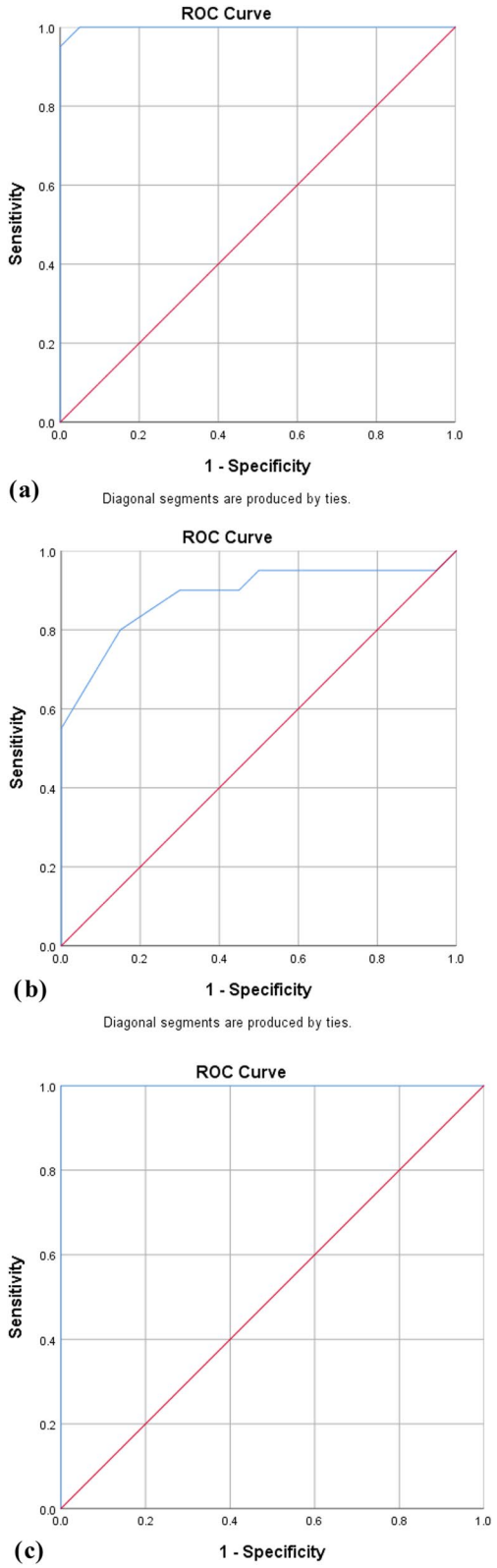
Discussion

MASLD affects about a quarter of the population. MASLD shows an increase in incidence, and its importance is highlighted annually after the recent eradication of hepatitis C globally by the direct acting antivirals. The risk of MASLD lies in the chronic proinflammatory process, and the metabolic disturbances it presents [16]. Moreover, MASLD is one of the leading causes of liver transplantation [17], with no known effective treatment until now. Many drugs have been tried with the hope of avoiding progression to liver fibrosis and cirrhosis [18]. In addition, the standard diagnostic test, i.e., the liver biopsy while offering a clear view of the necro-inflammatory staging of MASLD, carries the risk of liver injury and other complications reaching mortality [17, 19].

While MRI provides an anatomical background to the liver, MRS provides the information on its chemical and metabolic processes. Using parameters as water suppression, field gradient could benefit in quantifying less abundant metabolites [20]. MRI is used in estimating the PDFF, but the biochemical estimation of liver tissue fat content (in boxes of 2 cm^3 areas) is estimated through MRS [21]. Moreover, MRS has the advantage of being performed without any contrast agent and being long used in therapeutic clinical trials [22].

Other MRI techniques that could be of value in liver diseases are MR-Elastography (MRE). Moreover, the diagnostic accuracy of the liver stiffness measurement with a fibrosis score more than or equal F3, fibroscan reaches an AUC of approximately 90%, a value considered more than the other diagnostic laboratory biomarkers: FIB-4, APRI, and BRAD scores. However, in lower fibrosis scores (F1-F2), MRE is a better candidate with AUC reaching 91% [9].

In our study, MRS predicted the metabolic disturbances more than the abdominal ultrasound steatosis score grading, as the latter was correlated only with LDL. MRS parameters were correlated to all lipid profile parameters, HBA1C, fasting, and PPBG. Only age of the patients did not affect the MRS parameters or the steatosis scores. Metabolic syndrome is a known association of MASLD [23]. While HbA1 and blood glucose are commonly used to diagnose and follow-up patients with type II diabetes [24], here in our study this category of patients is excluded. However, we found strong relation between the levels of HbA1C, blood glucose, and presence of hepatic steatosis as compared to the control group. To our knowledge this is the only study that used these strict inclusion and exclusion criteria to uncover the true diagnostic accuracy of MRS in MASLD without any diabetes or overt metabolic disturbance.



◀ **Fig. 2** **a** Best cutoff value ≥ 0.07 ,sensitivity = 100% specificity = 95%. Validity of MRS (fat peak) in diagnosing hepatic steatosis, with AUC 99.9%. **b** Best cutoff value ≤ 0.11 ,sensitivity = 80% , specificity = 85%. Validity of MRS spectroscopy (water peak) in diagnosing hepatic steatosis, with AUC 88.6%. **c** Best cutoff value ≥ 38.5 , sensitivity = 100% , specificity = 100%. Validity of MRS (fat fraction %) in diagnosing hepatic steatosis, with AUC = 100%

A recent cohort on 2094 subjects showed that LDL decrease does not predict the metabolic effects of MASLD; on the contrary, it is associated with a more favorable metabolic profile [25]. In our study, there was a statistically significant positive correlation with increasing LDL and MRS parameters and steatosis score. This is in agreement with a previous study, which showed a positive correlation between small dense LDL (with $r = 0.237$, $p = 0.031$) and sdLDL/LDL ratio (with $r = 0.235$, $p = 0.032$) and CAP-scan diagnosed steatosis [7].

Benefits of MRS include high accuracy in obese individuals with a high BMI, or an increased abdominal fat, which is not the case with ultrasound or CAP-scan, as increased abdominal fat limits the visualization [8, 9]. A recent meta-analysis on the diagnostic accuracy of CAP-scan shows that accuracy is lowered in patients with BMI more than or equal 30 kg/m^2. Moreover, the CAP-scan values increase with BMI increase. CAP-scan is a good diagnostic alternative to tissue biopsy, but lacks specificity in the moderate (S2), or the high level steatosis (S3-4), mostly due to increased abdominal wall fat. Magnetic resonance imaging-based proton density fat fraction (MRIPDFF) may offer a better diagnostic tool than CAP-scan in these cases with AUC > 90% [9]. In patients with high BMI (mean 45 ± 4 kg/m^2), it was found that the MR-hepatic proton density fat fraction (PDFF) measurement using different methods for fat quantification yields comparable results with regression, exceeding 90% and reaching 99% [26].

In a previous study, comparing MRS to liver biopsy, using the same grading system for both techniques (*Grade: Percentage of hepatocyte affected*; grade 0: < 5%; grade I: 5–33%; grade II: 34–66%; grade III: > 66%), they found that the results were similar [15].

In a study performed on 18 older adults, the use of abdominal ultrasound when compared to MRS to quantify hepatic fat content showed had a sensitivity of 96% and specificity of 94% [27]. In comparison, our study showed that the abdominal ultrasound steatosis score had an AUC for fat peak, water peak, and fat fraction of 99.9%, 88.6%, and 100% respectively. Moreover, the hepatic steatosis scores (0–3) had high sensitivity, and specificity in predicting fat fraction, fat peak and water peak.

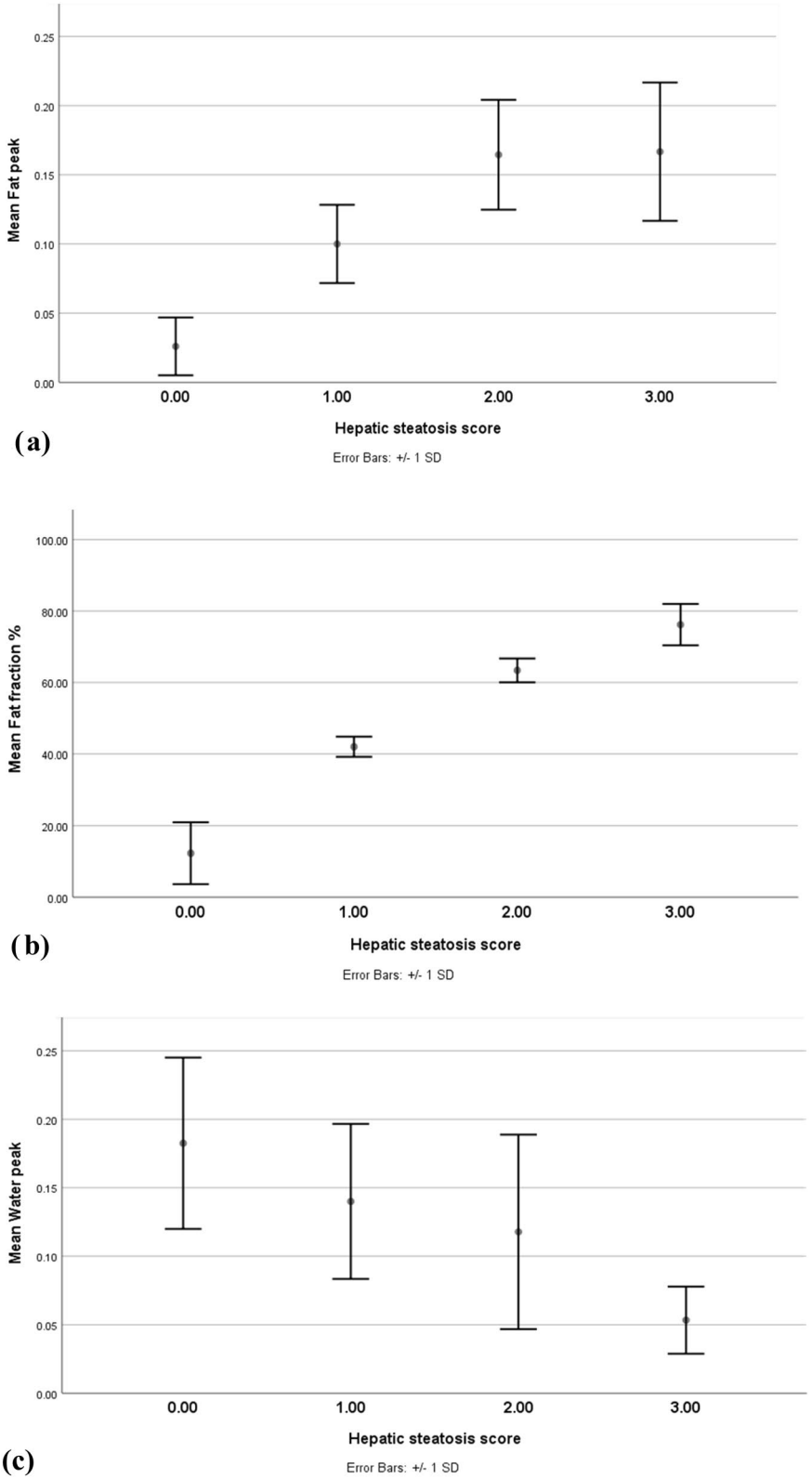


Fig. 3 **a** Mean plot showing the relation between fat peak by MRS and abdominal ultrasound hepatic steatosis score (grades 0–3). **b** Mean plot showing the relation between fat fraction % by MRS and abdominal ultrasound hepatic steatosis score (grades 0–3). **c** Mean plot showing the relation between water peak by MRS and abdominal ultrasound hepatic steatosis score (grades 0–3)

Table 4 Relation between abdominal ultrasound hepatic steatosis score and lipid profile

Variable	Hepatic steatosis score								*F*	*p* value
	0		1		2		3			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
T cholesterol (mg/dl)	184.50	40.34	200.00	14.14	211.44	10.56	212.11	17.32	2.46	0.08 NS
TGs (mg/dl)	145.55	31.03	150.00	14.14	170.22	16.50	166.44	20.03	2.54	0.07 NS
HDL (mg/dl)	56.20	32.54	43.00	4.24	40.78	6.89	40.78	3.11	1.35	0.27 NS
LDL (mg/dl)	91.35	16.77	115.00	7.07	115.44	13.87	108.78	12.81	6.76	0.001 HS

Table 5 Relation between MRI spectroscopy and hepatic steatosis score (yes or no)

	Steatosis				t*	*p* value
	No		Yes			
	Mean	SD	Mean	SD		
Fat peak	0.03	0.02	0.16	0.05	11.66	< 0.001 HS
Water peak	0.18	0.06	0.09	0.06	4.66	< 0.001 HS
Fat fraction %	12.27	8.66	67.00	11.45	17.05	< 0.001 HS

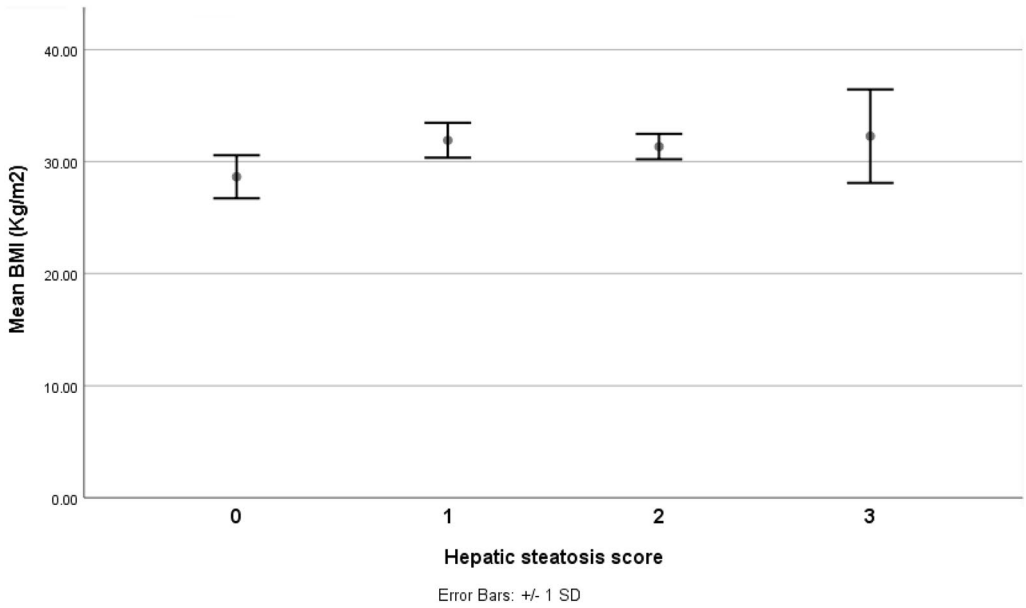


Fig. 4 Mean plot showing the relation between BMI (kg/m^2) and hepatic steatosis score

Finally, MRS offers an innovative tool to understand the pathophysiology of MASLD. We find that free fatty acids in the circulation are found in the liver tissue as part of their final ectopic deposition in the body in case of the metabolic syndrome. The hepatic fat is easily quantified by MRS and offers an eligible outcome in therapeutic clinical trials [20]. Abdominal ultrasound hepatic steatosis scores show comparable results to MRS parameters, as shown in Fig. 3a, b, c.

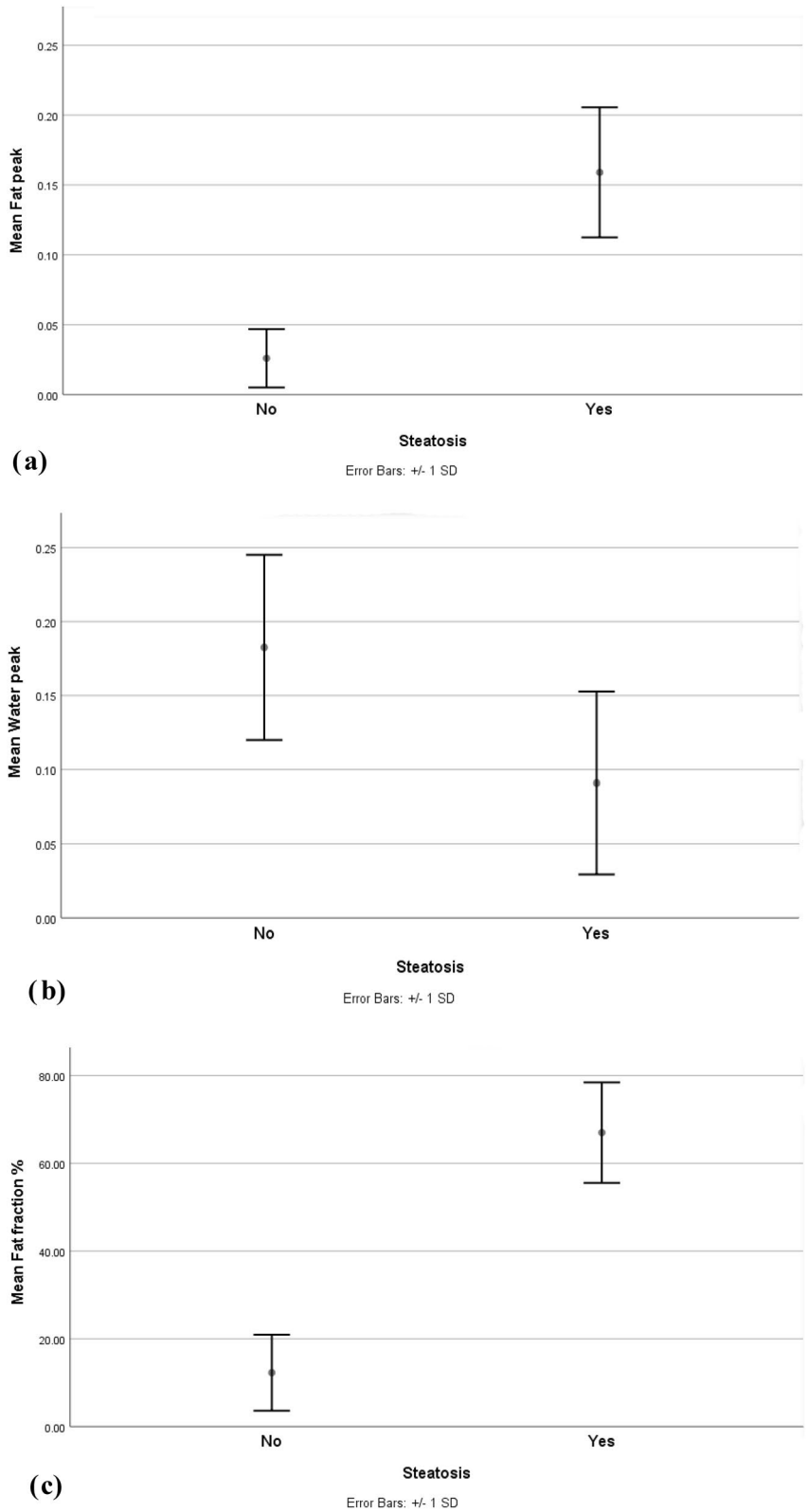
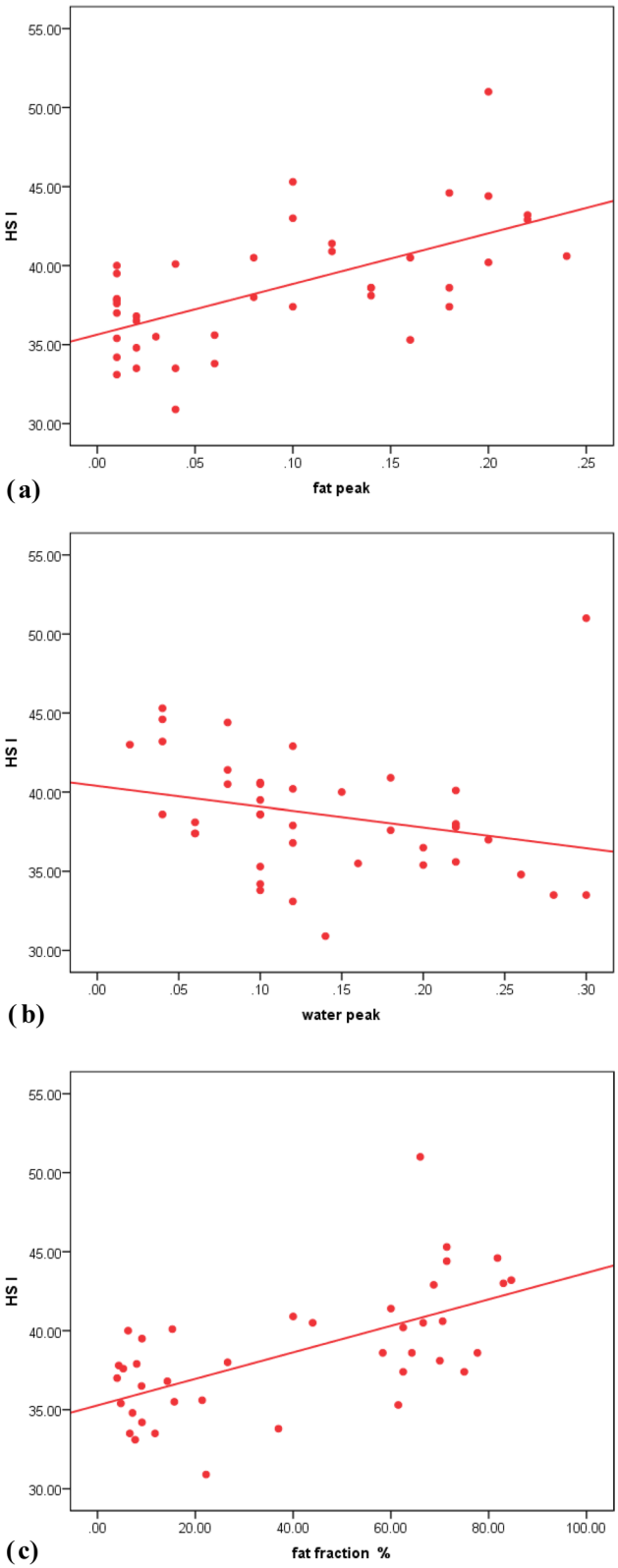


Fig. 5 **a** Mean plot showing the relation between the fat peak by MRS and presence of hepatic steatosis. **b** Mean plot showing the relation between water peak by MRS and presence of hepatic steatosis. **c** Mean plot showing the relation between the fat fraction % by MRS and presence of hepatic steatosis



◀ **Fig. 6** **a** Scatter plot showing a positive correlation between HSI and fat peak. **b** Scatter plot showing a negative correlation between HS I and water peak. **c** Scatter plot showing a positive correlation between HS I and fat fraction %

The small number of cases and the lack of liver histology limited our study; as these cases were accidently discovered during routine check-ups, there were no indications for an invasive procedure as liver biopsy.

We recommend future study on a large-scale population with broad range of metabolic dysfunction ranging from diabetes to different grades of MASLD, with using different diagnostic tools: as non-invasive laboratory tests, MR-elastography, and CAP-scan in comparison with MRS and ultrasound.

Conclusions

MRS parameters, fat fraction, fat peak, and water peak, have a high diagnostic accuracy for predicting liver steatosis. MRS has the added advantage of being non-invasive, with a low risk of radiation. MRS also shows the metabolic changes in the liver and could be an eligible surrogate outcome in the therapeutic clinical trials.

Abbreviations

APRI	Aspartate aminotransferase to platelet ratio index
AUC	Area under the curve
BMI	Body mass index
BARD	The BARD score is composed of 3 variables: an AST/ALT ratio P0.8 sums 2 points; a BMI P28 sums 1 point; presence of diabetes sums 1 point.
CAP-scan	Controlled attenuation parameter scan.
FIB-4	Fibrosis index based on 4 factors
MASLD	Metabolic dysfunction-associated steatotic liver disease
MRE	MR-elastography
MRIPDFF	Magnetic resonance imaging-based proton density fat fraction
MRS	MR spectroscopy
NAFLD	Non-alcoholic fatty liver disease
PDFF	Proton density fat fraction

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Author contributions

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Availability of data and materials
All data can be provided upon reasonable request from the authors.

Declarations

Ethics approval and consent to participate
The protocol of the study has the Ethical approval number FMASU MS087/2023 from Ethical Committee of Ain Shams Faculty of Medicine. All patients signed an informed consent before participation in the study.

Consent for publication
Not applicable.

Competing interests
All authors declare that there are no competing interests.

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