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ANATOMICAL VARIATIONS OF THE PORTAL VENOUS SYSTEM AND THEIR ASSOCIATION WITH FIBROSIS SEVERITY IN PATIENTS WITH METABOLIC DYSFUNCTION-ASSOCIATED STEATOTIC LIVER DISEASE

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ABSTRACT

Background: Metabolic dysfunction-associated steatotic liver disease (MASLD) is a leading cause of chronic liver disease, and the level of fibrosis is a significant factor in the liver's outcome. The portal venous system varies in its anatomy, and there is limited understanding of the relationship between portal venous system anatomy and fibrosis in MASLD.

Objective: To determine the frequency of portal venous anatomical variations and assess their association with fibrosis severity in patients with MASLD.

Methods: This was an analytical cross-sectional study of 107 adults who received a diagnosis of MASLD at Prime Teaching Hospital from September 2025 to February 2026. Contrast-enhanced abdominal imaging was used to assess portal venous anatomy, and non-invasive fibrosis assessment was used to determine the severity of fibrosis. Data were examined by appropriate parametric and non-parametric tests, chi-square/Fisher's exact tests, and logistic regression.

Results: In 22 (20.6%) patients, portal vein anatomical variations were found, the most frequent of which was portal vein trifurcation (8.4%). Clinically significant fibrosis (F2-F4) was present in 61 (57.0%) patients. There was a higher prevalence of anatomical variations in F2-F4 compared to F0-F1 fibrosis (26.2% vs. 13.0%), but the difference was not statistically significant (p=0.082). Patients with anatomical variations had higher liver stiffness (p=0.041). Diabetes was an independent predictor of clinically significant fibrosis (p=0.032).

Conclusions: Portal venous variations were present in a significant proportion of subjects with MASLD and were linked to increased liver stiffness, but did not appear to be independently associated with clinically significant fibrosis.

KEYWORDS: MASLD; portal vein; anatomical variation; liver fibrosis; liver stiffness; portal venous system.

INTRODUCTION

Metabolic dysfunction-associated steatotic liver disease (MASLD) has become the leading chronic liver disease globally and is a significant complication of the global obesity pandemic, including type 2 diabetes mellitus, dyslipidemia, and other metabolic disorders.[1] It has been estimated that MASLD affects more than 30% of adults in the world, and is especially prevalent and growing at an alarming rate in the Middle East and other areas with significant metabolic transition.[2, 3] Previously, large pooled analyses with the closely related metabolic-associated fatty liver disease definition found a prevalence of 38.77% (95% CI: 32.94-44.95%), with about 36.31% in Asian populations.[4] Although hepatic steatosis is a central feature of MASLD, the clinical significance of the condition goes beyond this, and a subset of people with MASLD will progress to steatohepatitis, liver fibrosis, cirrhosis, and portal hypertension, leading to a higher risk of liver failure and hepatocellular carcinoma.[5]

Fibrosis is the main determinant of long-term liver outcomes in MASLD, and the more severe the fibrosis, the higher the risks of liver-related morbidity and mortality. Current clinical pathways thus highlight the need to identify clinically significant fibrosis, i-e stage F2 or more, as an important landmark for risk stratification and intervention.[6] The burden of fibrosis is large: a recent systematic review estimated the prevalence of advanced fibrosis (fibrosis stage 4 or higher) at 3.3% (95% CI 2.4-4.2%) and cirrhosis at 1.3% of the general population in 21 countries.[7] It is significantly higher in subgroups of metabolically high-risk individuals, such as an advanced fibrosis prevalence of 19.5 % globally that was 24.4 % in South Asia, in a recent meta-analysis of 244,858 patients

with type 2 diabetes.[8] The results show the need to recognize potential variables that could be predictive or indicative of worsening fibrosis severity prior to the onset of advanced fibrosis.

The portal venous system plays an important role in hepatic perfusion and is complex in its anatomical structure. The right portal vein is usually split at the hepatic hilum into right anterior and posterior sectoral veins. There is, however, significant variation in the anatomy of this branching. Conventional portal veins are found in about 65 to 80% of people, and variants altogether make up about 20 to 35% of the population.[9] Common variations include portal vein trifurcation, early independent origin of the right posterior portal vein, and atypical origins of right anterior or segmental branches. A systematic review and meta-analysis of 51,244 individuals yielded pooled prevalence estimates of approximately 8% for portal vein trifurcation, 7% for the right posterior portal vein being the dominant branch, and 4% for the right anterior portal vein being the dominant branch.[10] These variations are typically asymptomatic and asymptomatic but clinically significant as portal venous anatomy dictates intrahepatic blood flow and plays a key role in hepatic surgery, transplantation, portal vein embolization, and interventional procedures.[11, 12]

However, the association between the portal venous anatomical configuration and the severity of liver fibrosis in MASLD is still not well understood. Progressive fibrosis results in remodeling of the architecture of the hepatic parenchyma, an increase in intrahepatic vascular resistance, and eventually portal hypertension.[13] Most previous studies on portal veins have been surgical or related to transplantation and interventional radiology, but not to the potential association of the variants with chronic metabolic liver disease or the degree of liver fibrosis.[14] Therefore, it is unclear if certain portal venous branching patterns are more common in patients with advanced fibrosis, or if specific portal venous branching patterns are correlated with more severe fibrosis. An evaluation of this anatomical/ pathological relationship may be a novel approach for the phenotyping of MASLD and potentially uncover portal venous patterns that may be relevant for diagnostic, prognostic, or procedural purposes. Hence, the present study was conducted to elucidate the incidence and distribution of portal venous anatomical variations as well as to evaluate the relationship between the anatomical variations and the severity of fibrosis in patients with metabolic dysfunction-associated steatotic liver disease.

METHODS

This was an analytical cross-sectional study conducted at the Department of Gastroenterology, Prime Teaching Hospital from 1st September 2025 to 28th February 2026.

The sample size was determined by estimating a single proportion using the OpenEpi online sample size calculator. In a previous large study that investigated the radiological anatomy of the portal veins among 967 subjects, the authors found that the portal veins were variably found in about 20% of subjects, with portal vein trifurcation and a short origin of the right posterior portal vein being the most common variants.[15] With an expected prevalence of 20%, a 95% confidence level, and an 8% margin of error, the calculated sample size was 97 participants. For the approximate 10% potential exclusions or incomplete imaging data, the sample size was expanded to 107 individuals. So, the study included a minimum of 107 patients with MASLD.

Non-probability consecutive sampling was used. MASLD patients over 18 years of age, whether male or female, were included. Patients met criteria for inclusion if they had evidence of hepatic steatosis and at least one cardiometabolic risk factor, and had been screened for abdominal imaging that was appropriate for adequate visualization and classification of the portal venous system. Patients with access to fibrosis assessment from an accepted non-invasive technique were included to assess the severity of fibrosis. Patients with significant alcohol consumption, chronic hepatitis B or hepatitis C infection, autoimmune hepatitis, primary biliary cholangitis, primary sclerosing cholangitis, Wilson disease, hemochromatosis, or other known causes of chronic liver disease were excluded. Patients who had a previous liver transplantation, portal vein thrombosis, congenital absence, or complete occlusion of the portal vein, major portal-systemic shunts, or inadequate-quality imaging without a reliable determination of portal venous anatomy were also excluded. Patients who did not have complete clinical, laboratory, or fibrosis assessment data were not included in the final analysis.

Eligible patients were approached and informed about the purpose and procedures of the study after obtaining approval from the institutional ethics committee. Written informed consent was obtained prior to enrolment. A structured data collection proforma was used to record demographic and clinical information, such as age, sex, BMI, diabetes mellitus, hypertension, dyslipidaemia and other relevant metabolic risk factors. The patient's medical record or routine clinical assessment provided the following biochemical investigations: alanine aminotransferase, aspartate aminotransferase, platelet count, fasting glucose/HbA1c and lipid profile. The clinical and laboratory parameters recorded were used to calculate non-invasive fibrosis indices, such as FIB-4 and the NAFLD fibrosis score, where applicable.

Contrast-enhanced multiphasic abdominal computed tomography (CT) with multiplanar and, if available, three-dimensional reconstruction (3D) was performed to evaluate portal venous anatomy. The main portal vein and its intrahepatic branches were evaluated for the presence of normal bifurcation and variants. The portal vein anatomy was classified following the radiological classification as normal bifurcation, portal vein trifurcation, and early origin of the right posterior portal vein, etc. The portal vein anatomy was divided into normal bifurcation, portal vein trifurcation, early origin of the right posterior portal vein, etc., which has been established as the radiological classification. Previous imaging studies have proven that portal venous anatomy is reliably defined by CT with multiplanar/3D reconstruction.[9, 16] The available validated non-invasive liver fibrosis assessments, such as

liver stiffness measurement by transient elastography or liver magnetic resonance elastography, were used to assess the severity of fibrosis and were classified by clinically relevant fibrosis stages/severity groups. Imaging findings were documented separately on the study proforma and all of the data were then entered into a computerised database for statistical analysis.

Data collected were entered into and analyzed in the IBM SPSS Statistics v26 software. Continuous variables were tested for normality by the Shapiro-Wilk test, and the results were expressed as mean ± standard deviation if normally distributed, or median if not normally distributed. Frequencies and percentages were used for categorical variables. Portal venous anatomical variants were summarized by number and location overall and by severity of fibrosis.

Independent-samples t-test and Mann-Whitney U test were used for the comparison of continuous variables between two groups, depending on data distribution; for comparison between more than two fibrosis categories, one-way ANOVA was used. Association among categorical variables, such as portal venous anatomical pattern and fibrosis severity category, was evaluated by chi-square test or Fisher's exact test, as appropriate. Binary logistic regression was used to assess the independent association of portal venous anatomical variation with clinically significant/advanced fibrosis after adjustment for potential confounders (age, sex, BMI, diabetes mellitus, and other relevant metabolic factors). Odds ratios with 95% confidence intervals are presented. A p-value less than 0.05 was deemed statistically significant.

RESULTS

The study included a total of 107 patients who had MASLD. The mean age was 48.6 ± 10.7 years, and 62 (57.9%) participants were male. The mean BMI was 28.4 ± 3.9 kg/m². The prevalence of diabetes mellitus, hypertension, and dyslipidemia was 57.0%, 51.4%, and 62.6%, respectively. The median FIB-4 score was 1.46 (IQR: 0.91-2.21). (Table 1)

Normal portal venous anatomy was found in 85 (79.4%) patients, and anatomical variations were noted in 22 (20.6%) patients. The most common variations were portal vein trifurcation (8.4%) and early origin of the right portal posterior vein (7.5%), as well as other less common variations. (Table 2)

Regarding fibrosis severity, 46 (43.0%) patients had F0-F1 fibrosis, while 29 (27.1%), 21 (19.6%), and 11 (10.3%) had F2, F3, and F4 fibrosis, respectively. Overall, clinically significant fibrosis (F2-F4) was present in 61 (57.0%) patients. (Table 3)

Patients with F2-F4 fibrosis were significantly older and had higher BMI, ALT, and AST levels than those with F0-F1 fibrosis. At the same time, diabetes and hypertension were also significantly more common in patients with clinically significant fibrosis. On the other hand, the platelet count was significantly reduced, and the FIB-4 score was significantly increased in the F2-F4 group. (Table 4)

Clinically significant fibrosis was associated with more portal venous anatomical variations compared to F0-F1 fibrosis (26.2% vs. 13.0%), but this was not statistically significant (p=0.082). The variant with portal vein trifurcation was most common in the F2-F4 group. (Table 5)

The incidence of portal venous variation gradually increased with increasing fibrosis (13.0% in F0-F1 disease, 36.4% in cirrhosis). However, the differences between the four fibrosis stages were not statistically significant (p=0.121). (Table 6)

Liver stiffness was significantly higher in patients with portal venous anatomical variations than in those with normal portal venous anatomy (p=0.041). They also had significantly higher FIB-4 scores, but no significant difference in NAFLD fibrosis scores. (Table 7)

There was a statistically significant difference between the fibrosis categories (p<0.001), and liver stiffness increased in a graded fashion, from 6.8 ± 1.7 kPa in F0-F1 fibrosis to 22.6 ± 6.1 kPa in F4 disease. (Table 8)

Diabetes mellitus continued to be independently associated with clinically significant fibrosis on multivariable logistic regression (p=0.032). A positive association was found between PVA and clinically significant fibrosis (aOR=2.16, 95% CI: 0.74-6.30), but this relationship was not statistically significant after adjusting for other potential confounding factors (p=0.159). (Table 9)

Table 1. Demographic, clinical and laboratory characteristics of study participants (n=107)

Variable	n (%)/mean ± SD/median (IQR)
Age (years)	48.6 ± 10.7
Age ≥50 years	54 (50.5)
Male	62 (57.9)
Female	45 (42.1)
BMI (kg/m²)	28.4 ± 3.9
Diabetes mellitus	61 (57.0)
Hypertension	55 (51.4)
Dyslipidemia	67 (62.6)
ALT (U/L)	48.7 ± 24.6
AST (U/L)	40.3 ± 20.1
Platelet count (×10⁹/L)	218 (178-264)

Fasting glucose (mg/dL)	126.8 ± 38.5
HbA1c (%)	6.9 ± 1.3
Total cholesterol (mg/dL)	201.6 ± 42.8
Triglycerides (mg/dL)	168 (125-224)
FIB-4 score	1.46 (0.91-2.21)
NAFLD fibrosis score	−0.71 ± 1.08

Table 2. Distribution of portal venous anatomical patterns on imaging

Portal venous pattern	**n (%)**
Normal bifurcation	85 (79.4)
Portal vein trifurcation	9 (8.4)
Early origin of right posterior portal vein	8 (7.5)
Right anterior portal vein arising from left portal vein	3 (2.8)
Other anatomical variants	2 (1.9)
Any anatomical variation	22 (20.6)

Table 3. Fibrosis severity according to non-invasive fibrosis assessment

Fibrosis category	**n (%)**
No/mild fibrosis (F0-F1)	46 (43.0)
Moderate fibrosis (F2)	29 (27.1)
Advanced fibrosis (F3)	21 (19.6)
Cirrhosis (F4)	11 (10.3)
Clinically significant fibrosis (F2-F4)	61 (57.0)

Table 4. Comparison of demographic and metabolic variables according to fibrosis severity

Variable	**F0-F1 (n=46) n (%)/mean ± SD/median (IQR)**	**F2-F4 (n=61) n (%)/mean ± SD/median (IQR)**	**p-value**
Age (years)	44.8 ± 9.4	51.5 ± 10.9	0.001
Male	24 (52.2)	38 (62.3)	0.291
BMI (kg/m²)	27.4 ± 3.4	29.2 ± 4.1	0.018
Diabetes	19 (41.3)	42 (68.9)	0.005
Hypertension	18 (39.1)	37 (60.7)	0.028
Dyslipidemia	25 (54.3)	42 (68.9)	0.123
ALT (U/L)	42.1 ± 20.3	53.7 ± 26.0	0.014
AST (U/L)	34.7 ± 15.2	44.5 ± 22.3	0.009
Platelets	241 (207-281)	201 (159-243)	0.001
FIB-4	0.98 (0.71-1.41)	1.82 (1.24-2.69)	<0.001

Table 5. Association between portal venous anatomical variation and fibrosis severity

Portal venous anatomy	**F0-F1 n (%)**	**F2-F4 n (%)**	**p-value**
Normal anatomy	40 (87.0)	45 (73.8)	
Any anatomical variation	6 (13.0)	16 (26.2)	0.082
Portal vein trifurcation	2 (4.3)	7 (11.5)	0.212
Early right posterior branch	3 (6.5)	5 (8.2)	0.731
Other variants	1 (2.2)	4 (6.6)	0.382

Table 6. Comparison of portal venous anatomical variation across individual fibrosis stages

Portal venous anatomy	**F0-F1 (n=46)**	**F2 (n=29)**	**F3 (n=21)**	**F4 (n=11)**	**χ^2**	**p-value**
Normal anatomy	40 (87.0)	23 (79.3)	15 (71.4)	7 (63.6)	5.82	0.121
Any variation	6 (13.0)	6 (20.7)	6 (28.6)	4 (36.4)		
Portal vein trifurcation	2 (4.3)	2 (6.9)	3 (14.3)	2 (18.2)		
Early right posterior branch	3 (6.5)	3 (10.3)	1 (4.8)	1 (9.1)		
Other variants	1 (2.2)	1 (3.4)	2 (9.5)	1 (9.1)		

Table 7. Comparison of liver stiffness and fibrosis scores according to portal venous anatomy

Variable	**Normal anatomy (n=85) mean ± SD/median (IQR)**	**Anatomical variation (n=22) mean ± SD/median (IQR)**	**p-value**
Liver stiffness (kPa)	10.8 ± 6.9	14.1 ± 8.2	0.041

FIB-4,	1.37 (0.87-2.03)	1.79 (1.10-2.65)	0.048
NAFLD fibrosis score	−0.78 ± 1.02	−0.45 ± 1.20	0.180

Table 8. One-way comparison of liver stiffness according to fibrosis stage

Fibrosis stage	Liver stiffness (kPa), mean ± SD
F0-F1	6.8 ± 1.7
F2	9.7 ± 2.1
F3	14.8 ± 3.4
F4	22.6 ± 6.1
ANOVA p-value = <0.001	

Table 9. Binary logistic regression for factors associated with clinically significant fibrosis (F2-F4)

Variable	Unadjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Age ≥50 years	2.47 (1.10-5.54)	0.029	2.13 (0.89-5.08)	0.089
Male sex	1.52 (0.67-3.44)	0.314	1.36 (0.56-3.31)	0.491
BMI ≥30 kg/m²	2.21 (0.91-5.37)	0.080	1.89 (0.73-4.87)	0.190
Diabetes mellitus	3.14 (1.34-7.36)	0.008	2.71 (1.09-6.76)	0.032
Hypertension	2.40 (1.05-5.49)	0.038	1.84 (0.75-4.51)	0.181
Dyslipidemia	1.86 (0.79-4.36)	0.154	1.48 (0.59-3.73)	0.405
Portal venous anatomical variation	2.38 (0.86-6.55)	0.091	2.16 (0.74-6.30)	0.159

DISCUSSION

In the present study, the authors investigated anatomical variations of the portal venous system in patients with MASLD and their association with the severity of fibrosis. In total, 107 patients were analysed, and portal venous anatomical variations were found in 20.6% of patients, while clinically significant fibrosis (F2-F4) was observed in 57.0% of patients. Patients with significant fibrosis had more portal venous variations compared to F0-F1 fibrosis (26.2% versus 13.0%), but this was not statistically significant. However, the liver stiffness and FIB-4 were significantly higher in the patients with portal venous variations, suggesting that there may be a relationship between the portal venous variation and the severity of hepatic fibrosis.

In the present study, the portal venous variation occurred in 20.6% of the patients, which was very similar to that seen by Karki et al. (2021), who evaluated 1000 patients who had undergone a contrast-enhanced computed tomography image and found portal venous variation in 21.4%, while portal venous normal branching was observed in 78.6%. The most common variants were the presence of the portal vein trifurcation (11.3%) and the presence of the right posterior portal vein as the first branch (7.2%). The corresponding frequencies of trifurcation and early right posterior portal vein origin (7.5% and 8.4%, respectively) were then reasonably similar, and good anatomical consistency was maintained across populations.[17]

Likewise, a study of 500 patients who were undergoing multidetector computed tomography (MDCT) in Pakistan in 2021 found normal portal veins in 87.6% of patients, trifurcation in 3.6%, and the right posterior portal vein as the initial branch in 4.4% of the patients. Slightly lower variation rates overall compared to our 20.6% may be due to factors such as imaging protocols, population characteristics and classification criteria. Importantly, that study did not include patients with hepatic pathology, while our population included only patients with MASLD, meaning that there are no direct comparisons that are fully equivalent.[18]

Our results are also similar to the large cross-sectional study of 1003 patients from China, showing that the right posterior portal vein was different with no common trunk, in 21.54% of the cases. These variants were 'not uncommon' and of special interest for hepatic resection, transplantation and interventional procedures, said the investigators. Their overall variation rate (21.54%) is comparable to our rate (20.6%) in spite of differences in the study populations and the indications for imaging.[19]

The current results were also corroborated by the systematic review and meta-analysis of 21 studies with a total of 51,244 participants conducted by Valenzuela-Fuenzalida et al. (2024). The overall prevalence of portal vein trifurcation was 8%; the right posterior PV was the primary branch 7%, and the right anterior PV arising from the left PV was 4%. These pooled estimates of corresponding frequencies were quite close to our own of 8.4%, 7.5%, and 2.8% respectively. This agreement will help to increase the validity of the anatomical distribution seen within our cohort.[10]

A 2024 study by Liu et al. was also able to confirm the relevance of a detailed three-dimensional assessment of the portal venous anatomy. They found that there were 13 subtypes of portal veins in 178 patients, and that the existing classifications were unable to explain all the different types. The researchers' findings help account for the different prevalence rates that have been reported because the three-dimensional reconstruction techniques are more advanced and may reveal subtle branching patterns that could go undetected on traditional two-dimensional computed tomography (CT).[16]

The biological interest of the portal venous variation was that we observed it to increase with the severity of fibrosis, though this was not statistically significant. The proportion increased from 13.0% in F0-F1 disease to 36.4% in cirrhosis. Most studies have focused on portal vein variants as anatomical characteristics in the absence of chronic liver disease; the current study offers a different perspective and investigated portal vein variants in the context of MASLD. Tyagi et al., in their review in 2023 highlighted that PV branching variations are developmental changes in the vitelline venous system and are important to understand the PV architecture, with portal hypertension being a late feature of liver disease rather than a cause of congenital PV branching variation.[20]

The fibrosis results in our study were comparable with current MASLD literature that has shown a strong correlation between metabolic risk factors and liver fibrosis. The MAFLD-only group showed a significant association with fibrosis and elevated liver stiffness even after controlling for demographic and lifestyle factors in the Rotterdam Study of 5445 participants in 2021. Likewise, our patients with clinically significant fibrosis had significantly higher diabetes, hypertension, ALT, AST, and FIB-4 scores, lower platelet counts, and were older. These results validate the well-established contribution of metabolic and biochemical events to the development of fibrosis.[21]

The finding of an independent association between diabetes and clinically significant fibrosis was also consistent with more recent population-level evidence. A large 2024 NHANES study of 13,538 adults documented 25.6% with MASLD, and 11.3% with fibrosis (defined as liver stiffness > 8 kPa), with both being linked to diabetes, BMI, waist-to-hip ratio, and elevated blood pressure. Metabolic disease burden in the form of diabetes was independently associated with CF severity in our cohort, highlighting the importance of metabolic disease burden in fibrosis progression.[22]

Interestingly, the liver stiffness of participants with portal venous anatomical variation was significantly higher than that of participants without the variation in our study. Liver stiffness in patients with variants was 14.1±8.2 kPa, whereas in patients with normal liver anatomy, liver stiffness was 10.8±6.9 kPa. Liver stiffness measurement has been evaluated in previous portal vein studies. Although liver stiffness has not been the focus of these studies, the 2024 MRE study by Fan et al. and colleagues showed that liver stiffness measurement is useful for detecting fibrosis associated with MASLD, especially advanced fibrosis and cirrhosis. Likewise, a prospective study from 2024, which included 124 patients with biopsy-proven MASLD, showed that MRE had a high diagnostic accuracy for fibrosis, especially for advanced fibrosis and cirrhosis.[23, 24]

In our study, the independent association of fibrosis severity with clinical outcomes was confirmed by the study of Lee et al. (2024), which included 1,738 patients with MASLD, showing that liver stiffness changes were linked to the development of cirrhosis or HCC. Patients who continued to be in the high liver stiffness group were at the highest risk for liver-related complications. In our study, liver stiffness and FIB-4 were higher in patients with portal venous variations, suggesting a potentially important relationship that warrants further prospective studies in larger cohorts, but this was not the case when the relationship was adjusted for the other factors.[25]

Recently, Paik et al. (2025) reviewed NHANES data between 2017 and 2023 and found the age-standardized prevalence of MASLD was 32.42%, with obesity and type 2 diabetes being the key risk factors for fibrosis and cirrhosis. The findings are similar to our multivariable analysis, where diabetes was still independently associated with clinically significant fibrosis. In our study, however, instead of population-based studies, we studied the portal venous anatomy in a previously diagnosed population with MASLD, with an added and under-explored dimension.[26]

In summary, the present study revealed that around one-fifth of patients with MASLD had a portal venous anatomical variant, which is similar to the prevalence reported in the current radiological literature. The study also indicated a possible correlation between the portal venous variation and the severity of the fibrosis; portal venous variation increased with the severity of fibrosis and was correlated with liver stiffness and FIB-4 scores. An independent association was not observed statistically after adjustment; however, and portal venous anatomy should not be considered an independent marker of fibrosis severity at this time. Instead, these results provide a clinically relevant hypothesis that the architecture of the portal veins at birth could interact with the hemodynamic and structural remodeling that occurs with the development of progressive MASLD. A larger multicenter study with uniform three-dimensional CT/MRI classification and histological and/or validated elastographic fibrosis staging is needed to confirm whether the observed associations are genuine or caused by confounding factors from metabolic and hepatic disease severity.

LIMITATIONS

There were several limitations of the study. The anatomical variations of the portal veins were not well studied, and the single-center nature of the study precluded the ability to investigate the temporal or causal associations of portal venous variability with fibrosis progression. Limited statistical power and generalizability due to relatively small sample size and use of non-probability consecutive sampling. Radiological analysis of portal venous anatomy was undertaken, and small differences may not have been observed due to variability in the quality of radiographs and method of reconstruction. Fibrosis assessment was performed using non-invasive means instead of liver biopsy, which could have led to some misclassification. In addition, the effects of residual confounding due to metabolic, genetic, and hemodynamic factors were not fully ruled out. There is a need for larger multicenter

prospective studies with standardised three-dimensional imaging and histological or advanced elastographic fibrosis assessment.

CONCLUSION

Portal venous anatomical variations were identified in approximately one-fifth of patients with MASLD, with portal vein trifurcation being the most common variant. Anatomical variation was more common with greater fibrosis severity but was not independently associated with clinically significant fibrosis after controlling for metabolic and demographic parameters, though it was associated with higher liver stiffness and FIB-4 scores with increasing fibrosis severity. Diabetes mellitus was still an independent risk factor for clinically significant fibrosis. The results indicate that portal venous anatomy could potentially be of clinical significance in MASLD, but is not yet a stand-alone fibrosis marker. Further multicenter studies are required to clarify this association.

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