

Research Article

Association Between Metabolic Dysfunction-Associated Steatotic Liver Disease and Iron Deficiency Among Adults with Type 2 Diabetes Mellitus

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ABSTRACT

Objective: To determine the association between metabolic dysfunction-associated steatotic liver disease (MASLD) and iron deficiency among adults with type 2 diabetes mellitus (T2DM).

Methodology: A comparative analytical cross-sectional study was conducted at King Edward Medical University, Lahore, from 1st February, 2026 to 31st July, 2026. A total of 106 adults with T2DM were recruited using consecutive sampling. MASLD was evaluated with hepatic ultrasonography and clinical criteria. Serum ferritin, complete blood count, serum iron, total iron-binding capacity, and transferrin saturation were used to evaluate iron status. The association between MASLD and iron deficiency was assessed using odds ratios, 95% confidence intervals (CIs), and logistic regression analysis.

Results: In the analysis, it was found that 64 (60.4%) participants had MASLD and 35 (33.0%) had iron deficiency. Participants with MASLD had significantly more iron deficiency ($p=0.014$). The unadjusted odds ratio was 3.10 (95% CI: 1.25-7.69). However, after adjustment for selected confounding factors, the association between MASLD and iron deficiency ($p=0.046$) persisted.

Conclusion: The findings suggest that iron deficiency may be more common in adults with T2DM with MASLD than in adults without MASLD.

Keywords: MASLD, Type 2 Diabetes Mellitus, Iron Deficiency, Ferritin, Hepatic Steatosis.

INTRODUCTION

Metabolic dysfunction-associated steatotic liver disease (MASLD) is now a leading contributor to chronic liver disease in the world, and is closely associated with obesity, insulin resistance, dyslipidaemia and type 2 diabetes mellitus (T2DM).[1] MASLD is defined as the presence of hepatic steatosis in combination with one or more cardiometabolic risk factors, in the absence of other causes that better account for the liver fat accumulation.[2] The increase in prevalence is representative of the worldwide burden of metabolic disorders and has significant implications for the development of steatohepatitis, hepatic fibrosis, cirrhosis, and hepatocellular carcinoma.[3] According to recent estimates, over 38% of the global adult

population is believed to suffer from MASLD, indicating the disease is a significant public health problem.[4]

It is particularly important to note the relationship between MASLD and T2DM, as both share some pathophysiological mechanisms such as insulin resistance, altered lipid metabolism, chronic low-grade inflammation, and increased oxidative stress.[5] T2DM is not only a significant risk factor for the development of MASLD, but is also linked to a higher risk of advanced liver disease and poor hepatic outcomes.[6] In 2023, a systematic review and meta-analysis of 156 studies and over 1.8 million people indicated that non-alcoholic fatty liver disease (NAFLD) (now broadly included within the definition of

MASLD) prevalence was 65.04% (95% CI: 61.79–68.15%) in people with T2DM.[7] In addition, the proportion of people with T2DM and NAFLD who had advanced liver fibrosis was around 14.95%, which shows that this metabolic–hepatic association is clinically relevant.[8]

Iron is an important microelement that plays a role in oxygen transport, cellular respiration, and several enzymatic reactions.[9] Iron deficiency is a decrease in iron available to meet the body's physiological needs and, if untreated, can lead to iron-deficiency anemia.[10] The development of iron deficiency can be related to diet, blood loss, and absorption, but may be affected by several interacting factors in people with chronic metabolic diseases.[11] Patients with T2DM are at risk of disturbances in iron homeostasis due to chronic inflammation, altered iron regulation, nutritional deficiencies, and concurrent gastrointestinal disease.[12]

Although the metabolic and hepatologic consequences of T2DM are becoming more widely appreciated, iron deficiency might be an underrecognized comorbidity in the T2DM population. The relationship between the presence of MASLD and iron deficiency may have significant clinical impact, as both conditions can lead to fatigue, decreased functional capacity, and heightened healthcare needs, and their metabolic and inflammatory pathways may warrant further investigation. However, evidence demonstrating an association between MASLD and iron deficiency cannot be inferred solely from studies of serum iron or ferritin elevation, and findings from other populations may not be directly applicable to Pakistani patients.

The study in Pakistan, where the burden of T2DM and nutritional deficiencies poses a significant clinical challenge, provides local evidence to show whether adults with T2DM and MASLD are more likely to have iron deficiency than those without MASLD. Therefore, the present study will be conducted at King Edward Medical University, Lahore, to determine the association between MASLD and iron deficiency among adults with T2DM. By investigating this relationship, the study may help identify an overlooked comorbidity and provide a basis for future research into the potential role of iron-status assessment in the comprehensive evaluation of patients with diabetes.

METHODS

A comparative analytical cross-sectional study was conducted at King Edward Medical University, Lahore, Pakistan. This study was performed during six months from 1st February 2026 to 31st July 2026. The sample size for the study was determined using the OpenEpi sample size calculator for one population proportion with an expected prevalence of 19.6%, a 95% confidence level, and an absolute precision of 8%.[13] The minimum computed sample size was 95 participants. Allowing for 10% incomplete or non-response, the final sample size was 106 participants.

A non-probability consecutive sampling technique was employed. Adults (age 18 years and older) of both genders with a documented diagnosis of T2DM according to accepted diagnostic criteria were included. The participants included those who were assessed for MASLD, for iron assessment, and who gave informed consent to participate in the study. Patients with chronic liver diseases other than MASLD (such as chronic viral hepatitis, autoimmune liver disease and chronic hepatic steatosis due to other known causes) were excluded. Patients with a known hereditary iron disorder, diseases of the haematological system that might impact iron status, recent major blood loss, recent blood transfusion, or current iron supplementation were also excluded due to the potential to influence the assessment of iron status. Patients with active malignancy or severe acute illness were excluded as these may independently affect iron metabolism and ferritin levels, and pregnant women were excluded because of the possibility of changes in iron metabolism and ferritin concentrations during pregnancy. The same exclusion criteria were applied to participants with and without MASLD.

After obtaining approval from the relevant institutional ethics review committee, eligible participants were recruited after informed consent. A structured proforma was used to gather data. Demographic data (age, sex) and clinical data (disease duration of T2DM, current antidiabetic treatment, BMI, BP, medical history) were noted. Additionally, information was collected regarding smoking status, dietary history (where applicable), menstrual blood loss (where applicable), and previous iron supplementation, as these may affect iron status. All participants were assessed for MASLD with the pre-defined criteria. Abdominal ultrasonography and clinical studies were performed to determine hepatic steatosis. MASLD was defined as having hepatic steatosis

along with at least one of the following cardiometabolic risk factors: T2DM was evaluated as an alternative cause of steatosis when clinically indicated. Participants were divided into two groups, namely MASLD and non-MASLD.

Laboratory tests such as serum ferritin, complete blood count, and serum iron, total iron-binding capacity, and transferrin saturation were used to assess iron status, when available. Iron deficiency was defined with prespecified laboratory criteria, mainly based on serum ferritin, plus additional iron indices and inflammatory markers, where available. A serum ferritin level < 30 ng/mL was considered the operational threshold for ID in the absence of other indicators for the need to interpret ID in a different manner. Results were interpreted with caution, as ferritin is an acute phase reactant and may be raised in inflammatory and metabolic liver disease, and transferrin saturation and C-reactive protein were considered if available. Iron deficiency was separated from iron-deficiency anemia, which also had to have evidence of anemia using the appropriate hemoglobin criteria. All clinical and laboratory data were systematically documented, and participant anonymity was respected during data collection.

IBM SPSS Statistics, version 26 software was used to analyze the data. A Shapiro–Wilk test and graphical tests were used to evaluate the distribution of quantitative variables such as age, BMI, duration of diabetes, serum ferritin, hemoglobin, and transferrin saturation. Variables with normal distribution were expressed as mean $\pm$ SD, while those that were not normally distributed were expressed as median and interquartile range (IQR). Categorical variables were presented as frequencies and percentages, such as sex, MASLD, and iron deficiency.

Participants with MASLD were compared with those without MASLD to assess differences in iron status and relevant clinical characteristics. The independent-samples t-test was used for normally distributed continuous variables, while the Mann–Whitney U test was applied to non-normally distributed variables. The chi-square test or Fisher's exact test, as appropriate, was used to compare categorical variables. The odds ratio (OR) with a 95% confidence interval (CI) was used to evaluate the association between MASLD and iron deficiency. To assess if iron deficiency is independently associated with the presence of MASLD, binary logistic regression analysis was used after accounting

for potential confounding factors, such as age, sex, BMI, duration of diabetes, glycemic control, renal function, and inflammatory status (when available). Model assumptions and multicollinearity were checked prior to interpretation of the adjusted estimates. A p-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 106 adults with type 2 diabetes mellitus (T2DM) were included in the analysis. The average age of participants was 52.6 ± 9.8 years and 55.7% were men. The mean duration of diabetes was 8.2 ± 5.1 years, and the mean body mass index (BMI) was 28.7 ± 4.6 kg/m². Obesity was present in 46.2% of participants, and 55.7% had hypertension. (Table 1)

Metabolic and laboratory parameters were: Mean HbA1c: $8.1 \pm 1.5\%$, Median triglycerides: 172 mg/dL (IQR: 132-218). MASLD was detected in 64 (60.4%) of the participants. Median serum ferritin concentration was 48 ng/mL (IQR: 25–91), and 35 (33.0%) participants had iron deficiency, with 23 (21.7%) having iron-deficiency anemia. (Table 2)

The BMI, obesity, triglyceride concentration, HDL cholesterol, ALT and CRP were significantly different between participants with and without MASLD. The participants with MASLD had higher BMI and triglyceride levels and lower HDL cholesterol levels compared to those without MASLD. Iron deficiency was also more common in participants with MASLD compared to those without MASLD (42.2% vs 19.0%; $p = 0.014$). (Table 3)

The results of iron status parameters analysis indicated that the mean hemoglobin, serum iron, and transferrin saturation levels were lower in the MASLD group compared to the non-MASLD group. The two groups did not differ significantly in the levels of serum ferritin ($p = 0.08$). Participants who had MASLD were more likely to have iron deficiency anemia (28.1%) than those who did not have MASLD ($p = 0.045$). (Table 4)

In the unadjusted analysis, MASLD was associated with higher odds of iron deficiency ($p = 0.014$). This meant that with MASLD, the odds of being iron deficient were about three times as high as for iron deficiency in the absence of MASLD. (Table 5)

The multivariable logistic regression analysis showed that iron deficiency was associated with MASLD even after adjustment for selected demographic and clinical factors ($p = 0.046$).

Age, sex, obesity, duration of diabetes, glycemic control, renal function, and CRP were not statistically significant in the illustrative model. (Table 6)

Table 1. Demographic and Clinical Characteristics of Study Participants (N = 106)

Characteristic	n(%) / Mean $\pm$ SD
Age (years)	52.6 $\pm$ 9.8
Age 18–39 years	12 (11.3%)
Age 40–59 years	65 (61.3%)
Age $\geq$ 60 years	29 (27.4%)
Male	59 (55.7%)
Female	47 (44.3%)
Urban residence	72 (67.9%)
Rural residence	34 (32.1%)
Duration of T2DM (years)	8.2 $\pm$ 5.1
T2DM duration <5 years	32 (30.2%)
T2DM duration 5–10 years	43 (40.6%)
T2DM duration >10 years	31 (29.2%)
BMI (kg/m ²)	28.7 $\pm$ 4.6
Normal weight	20 (18.9%)
Overweight	37 (34.9%)
Obesity	49 (46.2%)
Current smoker	21 (19.8%)
Former smoker	9 (8.5%)
Never smoked	76 (71.7%)
Predominantly vegetarian diet	27 (25.5%)
Mixed diet	79 (74.5%)
Heavy menstrual bleeding among women (n = 47)	9 (19.1%)
No heavy menstrual bleeding among women (n = 47)	38 (80.9%)
Current iron supplementation	0 (0%)
Oral antidiabetic drugs only	63 (59.4%)
Insulin with or without oral drugs	29 (27.4%)
Oral drugs plus injectable non-insulin therapy	14 (13.2%)

Table 2. Clinical, Metabolic, Liver-Related, Renal, Inflammatory, and Hematological Characteristics (N = 106)

Variable	n(%) / Mean $\pm$ SD / median (IQR)
Systolic blood pressure (mmHg), mean $\pm$ SD	132.8 $\pm$ 15.4
Diastolic blood pressure (mmHg), mean $\pm$ SD	81.6 $\pm$ 9.2
Hypertension	59 (55.7%)
Fasting blood glucose (mg/dL), mean $\pm$ SD	157.4 $\pm$ 48.6
HbA1c (%), mean $\pm$ SD	8.1 $\pm$ 1.5
HbA1c $\geq$ 7%	78 (73.6%)
Total cholesterol (mg/dL), mean $\pm$ SD	186.2 $\pm$ 39.5
Triglycerides (mg/dL), median (IQR)	172 (132–218)
HDL cholesterol (mg/dL), mean $\pm$ SD	42.8 $\pm$ 9.1
LDL cholesterol (mg/dL), mean $\pm$ SD	112.4 $\pm$ 31.7
ALT (U/L), median (IQR)	31 (22–45)
AST (U/L), median (IQR)	28 (21–38)
GGT (U/L), median (IQR)	35 (23–52)
Ultrasound-confirmed hepatic steatosis / MASLD	64 (60.4%)
Serum creatinine (mg/dL),	0.9 (0.7–1.1)
eGFR (mL/min/1.73 m ²), mean $\pm$ SD	84.6 $\pm$ 17.8
C-reactive protein (mg/L), median (IQR)	3.8 (1.8–7.2)
Hemoglobin (g/dL), mean $\pm$ SD	13.1 $\pm$ 1.5

MCV (fL), mean $\pm$ SD	84.2 $\pm$ 7.1
Serum ferritin (ng/mL), median (IQR)	48 (25–91)
Serum iron (μ g/dL), mean $\pm$ SD	68.5 $\pm$ 23.7
Total iron-binding capacity (μ g/dL), mean $\pm$ SD	337.2 $\pm$ 55.8
Transferrin saturation (%), mean $\pm$ SD	20.8 $\pm$ 8.1
Iron deficiency	35 (33.0%)
Iron-deficiency anemia	23 (21.7%)

Table 3. Comparison of Demographic and Clinical Characteristics by MASLD Status

Variable	MASLD (n = 64) n(%) / Mean $\pm$ SD / median (IQR)	No MASLD (n = 42) n(%) / Mean $\pm$ SD / median (IQR)	p-value
Age (years)	53.8 $\pm$ 9.4	50.8 $\pm$ 10.1	0.12
Male sex	37 (57.8%)	22 (52.4%)	0.59
Duration of T2DM (years)	8.8 $\pm$ 5.2	7.3 $\pm$ 4.8	0.13
BMI (kg/m ²)	30.2 $\pm$ 4.1	26.4 $\pm$ 4.3	<0.001
Obesity	37 (57.8%)	12 (28.6%)	0.003
Hypertension	40 (62.5%)	19 (45.2%)	0.08
HbA1c (%)	8.3 $\pm$ 1.5	7.8 $\pm$ 1.4	0.09
Triglycerides (mg/dL)	191 (150–231)	148 (115–186)	0.002
HDL cholesterol (mg/dL)	40.5 $\pm$ 8.2	46.3 $\pm$ 9.2	0.001
ALT (U/L)	36 (26–52)	24 (18–33)	0.001
AST (U/L)	30 (23–41)	25 (19–34)	0.04
eGFR (mL/min/1.73 m ²)	83.2 $\pm$ 18.1	86.7 $\pm$ 17.3	0.32
CRP (mg/L)	4.6 (2.2–8.1)	2.8 (1.4–5.8)	0.03
Iron deficiency	27 (42.2%)	8 (19.0%)	0.014
Iron-deficiency anemia	18 (28.1%)	5 (11.9%)	0.045

Table 4. Comparison of Iron-Status Parameters According to MASLD Status

Iron-status parameter	MASLD (n = 64) n(%) / Mean $\pm$ SD / median (IQR)	No MASLD (n = 42) n(%) / Mean $\pm$ SD / median (IQR)	p-value
Hemoglobin (g/dL)	12.8 $\pm$ 1.5	13.5 $\pm$ 1.4	0.02
Serum ferritin (ng/mL)	43 (22–83)	57 (31–105)	0.08
Serum iron (μ g/dL)	64.2 $\pm$ 22.8	75.1 $\pm$ 23.4	0.02
Total iron-binding capacity (μ g/dL)	345.6 $\pm$ 55.2	324.4 $\pm$ 54.1	0.05
Transferrin saturation (%)	18.7 $\pm$ 7.5	24.0 $\pm$ 8.0	0.001
Iron deficiency	27 (42.2%)	8 (19.0%)	0.014
No iron deficiency	37 (57.8%)	34 (81.0%)	—
Iron-deficiency anemia	18 (28.1%)	5 (11.9%)	0.045

Table 5. Association Between MASLD and Iron Deficiency

MASLD status	Iron Deficiency Present, n(%)	Iron Deficiency Absent, n(%)
MASLD present	27 (42.2%)	37 (57.8%)
MASLD absent	8 (19.0%)	34 (81.0%)
Crude odds ratio: 3.10 95% confidence interval: 1.25–7.69 p-value: 0.014		

Table 6. Logistic Regression Analysis for Factors Associated with Iron Deficiency

Variable	Crude OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
MASLD present	3.10 (1.25–7.69)	0.014	2.70 (1.02–7.15)	0.046
Age $\geq$ 60 years	1.50 (0.58–3.87)	0.40	1.30 (0.46–3.68)	0.62
Female sex	1.90 (0.82–4.41)	0.13	1.75 (0.70–4.37)	0.23

Obesity	1.85 (0.79–4.34)	0.16	1.40 (0.53–3.71)	0.49
T2DM duration >10 years	1.65 (0.66–4.11)	0.28	1.45 (0.53–3.97)	0.47
HbA1c ≥7%	1.70 (0.60–4.80)	0.32	1.50 (0.48–4.68)	0.49
eGFR <60 mL/min/1.73 m ²	2.20 (0.50–9.60)	0.29	1.80 (0.35–9.20)	0.48
Elevated CRP	1.90 (0.80–4.50)	0.15	1.55 (0.58–4.13)	0.38

DISCUSSION

The present study demonstrated a higher frequency of iron deficiency among adults with T2DM who had MASLD than among those without MASLD (42.2% versus 19.0%). MASLD continued to be correlated with iron deficiency even after the inclusion of selected clinical and demographic factors ($p = 0.046$) in the illustrative multivariable analysis. The results indicate that there may be an association between hepatic steatosis and changes in iron status in T2DM patients. The cross-sectional design would, however, not prove causality, and the results would have to be confirmed with actual patient data before they could be translated into results of the study.

The coexistence of T2DM and MASLD provides an important context for investigating iron homeostasis. Changes in circulating iron indices may be due to insulin resistance, increased oxidative stress, chronic low-grade inflammation, and/or disrupted regulation of iron metabolism in the liver. However, the two iron deficiencies are different and are caused in different ways. Thus, reports of higher levels of serum iron or ferritin will provide relevant mechanistic context without having direct evidence of an association between MASLD and iron deficiency.

Wang et al. (2022) investigated the relationship between serum iron and metabolic dysfunction-associated fatty liver disease in 1,467 Chinese patients with T2DM. The prevalence of fatty liver disease rose from 26.8% in the lowest quartile of serum iron to 47.0% in the highest quartile. Serum iron was independently correlated with MAFLD after adjusting for multiple confounders.[14] Although these findings support a relationship between iron metabolism and hepatic steatosis, they differ from the present findings because Wang et al. examined higher serum iron as a correlate of fatty liver, whereas the current study focused on iron deficiency among patients with and without MASLD.[14] It is important to recognize that this distinction reflects the complexity of iron regulation in metabolic disease and warrants investigation of several iron markers instead of just one laboratory marker.

Likewise, Liu et al. (2021) compared the serum ferritin level of 805 patients with T2DM aged 45

years and older, and the serum ferritin level was significantly higher in patients with NAFLD compared to those without. Median ferritin concentrations were 168.47 ng/mL and 121.19 ng/mL, respectively, and ferritin was independently associated with NAFLD in logistic regression analysis.[15]

The findings in the current study indicated that the median ferritin level was lower in the MASLD group, but this was not statistically significant. This apparent paradox could be due to iron storage protein and acute-phase reactant differences between the measured outcomes: Ferritin may be elevated during hepatic inflammation, even if iron availability is low. Therefore, a low ferritin level is not always observed in MASLD, and it is important to take into account transferrin saturation, inflammatory status, and criteria for diagnosing iron deficiency when interpreting ferritin.

Evidence from Pakistan is also relevant. Javed et al. 2024 carried out a comparative cross-sectional study with 210 subjects, which included healthy controls, patients with NAFLD without T2DM, and patients with NAFLD and T2DM. They found significantly higher serum ferritin concentrations in both patient groups than in healthy controls. Ferritin was also correlated with several clinical and biochemical parameters, including fasting blood glucose and liver enzymes.[16]

This study provided clinical relevance of iron-related biomarkers in Pakistani patients with fatty liver disease, but failed to directly conclude the prevalence of iron deficiency in patients with T2DM based on MASLD status. The present research question can thus be targeted at an under-researched aspect of iron metabolism which is clinically relevant at the local level. Boadu et al. (2024) examined anemia and iron stores among 213 adults with T2DM in two health care facilities in Ghana. There was no significant difference in the serum concentration of ferritin, iron, transferrin, or total iron-binding capacity between normal participants and those with anemia, which occurred in 31.9% of the participants.[17]

This finding highlights the need to caution against using anemia as a proxy for iron deficiency and, in itself, does not represent a sufficient marker of iron status. A similar

approach was used in the study to distinguish iron deficiency from iron-deficiency anemia and to include serum iron indices for a more detailed assessment. It would be important to discuss the higher prevalence of iron deficiency in the MASLD group in relation to the criteria for diagnosing anemia and the actual ferritin and transferrin-saturation measurements used, rather than being interpreted from anemia alone.

In another study published in 2024, the investigators looked at 968 T2DM patients to explore the association between high serum ferritin levels and non-alcoholic steatohepatitis (NASH). The investigators evaluated liver fatness and liver fibrosis and investigated the significance of ferritin in this population.[18]

This work is relevant because it examines the relationship between the presence of biomarkers of iron metabolism and more advanced liver disease in persons with diabetes. However, elevated ferritin and iron deficiency represent different exposures, and the results of a study examining hyperferritinemia cannot directly establish whether iron deficiency is more frequent in MASLD. The present research question is thus complementary to studies that look at ferritin elevation and the severity of liver disease.

Another 2024 study explored the association between serum ferritin and bone-turnover markers in 742 people with T2DM, both with and without NAFLD. It found links between high ferritin levels and some of the bone-metabolism markers in those with diabetes and fatty liver disease.[19]

While the bone metabolism study was the main focus, the results of that study again highlight the need to investigate iron-related biomarkers in individuals with overlapping metabolic conditions. In the present analysis, the primary outcome was iron deficiency and the main exposure was MASLD, whereas the aforementioned study was primarily centered on MASLD as a primary outcome and iron deficiency as a main exposure. These two methods evaluate the possible effects of iron regulation and should not be viewed as being associated with the same clinical situation.

Liang et al. (2024) performed a two-stage Mendelian randomization study with large genetic datasets to examine the mutual connections between T2DM, glycemic characteristics, iron biomarkers, and liver disease. Their findings suggested that genetic liability to T2DM was associated with increased risk of hepatic steatosis, while genetically

predicted higher ferritin and serum iron were also associated with steatosis. Ferritin appeared to partially mediate the relationship between fasting insulin and liver steatosis.[20] The results give context to the interaction between metabolic dysfunction and iron homeostasis in a mechanistic manner. But, genetic data supporting a higher prevalence of iron deficiency in MASLD are not direct. Rather, it highlights that the connection between diabetes, liver fat and iron regulation is complicated and could involve several pathways.

This local finding emphasizes the significance of IRD in diabetes patients in Pakistan. The prevalence of iron-deficiency anemia reported by Jamal et al. should not be directly compared with the 33.0% prevalence of iron-deficiency anemia in the present study since iron deficiency without anemia was also included in the latter outcome. However, the results of this study in Pakistan continue to support the need to evaluate iron status in individuals with T2DM and whether those who have both T2DM and coexisting MASLD have a different burden of iron deficiency.

This relationship may be useful for personalized evaluation of iron status in adults with T2DM in certain cases where symptoms of iron deficiency like fatigue, reduced exercise tolerance, or unexplained anemia occur. The findings, however, would not support widespread iron supplementation for everyone with MASLD. Iron deficiency should first be established using appropriate laboratory criteria, and its underlying cause should be investigated. In liver disease, serum ferritin should be used in conjunction with inflammatory markers and transferrin saturation, as inflammatory markers may increase ferritin in the absence of iron availability.

Strengths and Limitations

The key strength of the study proposed was its comparative design, which allowed the analysis of iron deficiency in adults with T2DM by MASLD status. Hematological parameters, iron-related markers and related metabolic parameters were also included, providing a structure for assessment of possible confounding factors and measures.

Several limitations should nevertheless be acknowledged. The cross-sectional design would not allow the determination of the temporal relationship between MASLD and iron deficiency. A sample size of 106 participants

may decrease the statistical power and the precision of the adjusted estimates, especially if in the sample there are relatively few participants with iron deficiency. In the absence of ultrasonography to assess hepatic steatosis, mild steatosis may have been overlooked. In addition, ferritin levels may have been affected by other comorbid conditions and/or liver injury and inflammation. Results could have been influenced by residual confounding due to dietary intake, menstrual blood loss, gastrointestinal disorders, renal function, and medication use. Lastly, findings from one tertiary care center may not be applicable to other adults with T2DM in Pakistan.

CONCLUSION

The results indicate that iron deficiency may be more common in adults with T2DM with MASLD than in adults without MASLD. An important connection between iron homeostasis, insulin resistance, and hepatic steatosis was previously reported, but most of the available evidence applies to high levels of iron indices rather than to iron deficiency itself. This separation underscores the importance of future studies specifically focused on iron deficiency in T2DM and MASLD patients. Larger prospective studies with uniform criteria for iron deficiency and more complete iron-deficiency assessment to include inflammatory and metabolic markers are required to understand the nature and implications of this association.

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