BMC Gastroenterology

RESEARCH

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# The diagnostic value of MRI-PDFF in hepatic steatosis of patients with metabolic dysfunction-associated steatotic liver disease: a systematic review and meta-analysis

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## Abstract

**Objective** To evaluate the diagnostic efficacy of magnetic resonance imaging proton density fat fraction (MRI-PDFF) in assessing hepatic steatosis among patients with metabolic dysfunction-associated steatotic liver disease (MASLD) through systematic review and meta-analysis approaches.

**Methods** Comprehensive searches were conducted across major public electronic databases, including PubMed, Web of Science, Cochrane Library, and Embase, to identify relevant studies that compared MRI-PDFF with liver biopsy in diagnosing steatosis in MASLD patients. Diagnostic accuracy was assessed using sensitivity, specificity, and the area under the curve (AUC) for differentiating various steatosis grades (S0 vs. S1-3; S0-1 vs. S2-3; S0-2 vs. S3).

**Results** A total of 10 studies involving 939 MASLD patients were included in this meta-analysis. MRI-PDFF demonstrated robust diagnostic performance for steatosis grading, with sensitivity values ranging from 0.77 to 0.92 and specificity from 0.87 to 0.94. The AUC values were 0.98 (95% CI: 0.96–0.99) for S0 vs. S1-3, 0.92 (95% CI: 0.89–0.94) for S0-1 vs. S2-3, and 0.90 (95% CI: 0.87–0.93) for S0-2 vs. S3.

**Conclusion** This meta-analysis suggests that MRI-PDFF is highly effective in grading steatosis in MASLD patients. Further validation through additional high-quality studies is warranted to consolidate these findings.

**Clinical trial number** Not applicable.

**Keywords** MRI-PDFF, Nonalcoholic fatty liver disease, Steatosis, Diagnosis, Meta-analysis

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## Introduction

Metabolic dysfunction-associated steatotic liver disease (MASLD) has emerged as the most prevalent chronic liver disease globally, with an estimated prevalence of around 30–40% [1]. Projections indicate that by 2030, the number of MASLD cases in the United States will rise from 83.1 million in 2015 to 100.9 million [2], and the proportion of metabolic dysfunction-associated steatohepatitis (MASH) cases is anticipated to increase from 20 to 27% [3]. The revised terminology MASLD abandons the traditional term "Non-Alcoholic Fatty Liver Disease", instead emphasizing metabolic abnormalities as the central pathogenic driver. This nomenclature shift, endorsed by 2023 international liver society guidelines, enhances precision in identifying patients requiring metabolic-targeted clinical management [1]. Recent statistics highlight a growing prevalence of MASLD in Asian countries, with some regions reporting higher rates than Western countries. In China, the prevalence of MASLD is approximately 29.2%, and the associated complications and mortality rates are notably high in Asian countries [1]. Despite these alarming trends, MASLD has not garnered sufficient attention. The lack of early diagnostic techniques and effective drug treatments has led to many patients remaining undiagnosed and clinically unmanaged.

Hepatic steatosis, characterized by the excessive accumulation of triglycerides in hepatocytes, serves as a key histological marker of MASLD and represents the initial stage of liver disease [4]. Although simple steatosis was once considered benign in the progression of MASLD, it remains a significant risk factor for the development of insulin resistance and inflammation, as well as for accelerating disease progression to fibrosis, cirrhosis, and hepatocellular carcinoma [5, 6]. Liver biopsy, despite being the gold standard for diagnosing MASLD, is limited by its invasiveness, which poses serious risks of complications and may yield inaccurate results due to small sample sizes and biopsy area limitations [7–9]. Consequently, this invasive diagnostic method is not widely used in clinical practice. The development of accurate and noninvasive methods is essential for assessing steatosis and predicting the progression of MASLD. Advances in research have led to the discovery of numerous serum biomarkers and models that can preliminarily diagnose steatosis and fibrosis grading [10, 11]. However, these biomarkers, while highly applicable and reproducible in the laboratory, are not liver-specific and may be influenced by comorbidities, necessitating careful interpretation of results [12].

In recent years, magnetic resonance technology, which employs a "physical" method to measure liver stiffness, has emerged as one of the most promising noninvasive diagnostic tools. Magnetic resonance imaging proton density fat fraction (MRI-PDFF) utilizes low-flip-angle gradient echo sequences to minimize T1 bias and acquires multiple echoes, where fat and water signals are approximately in-phase or out-of-phase relative to each other. The data from each echo are then processed through a fitting algorithm that estimates and corrects the T2 effect, simulates the fat signal, and measures the proton density of fat and water, ultimately calculating the fat content [13]. MRI-PDFF has been shown to accurately classify the grade and changes of hepatic steatosis. The larger liver area measured by MRI-based technology may reduce sampling variability caused by the heterogeneity of hepatic steatosis [14, 15]. Although MRI-PDFF has been used in some studies to evaluate hepatic steatosis in MASLD patients, these studies have included relatively small patient cohorts, and the overall performance of MRI-PDFF in the histological grading of MASLD steatosis remains inconsistent. Therefore, we conducted this meta-analysis to synthesize current studies assessing the diagnostic accuracy of MRI-PDFF in the histological grading of steatosis in MASLD patients, aiming to further explore its diagnostic value and provide evidence-based insights for clinical practice.

## Materials and methods

### Search strategy

Following the PRISMA 2020 statement [16], we systematically searched four electronic databases: PubMed, Web of Science, Cochrane Library, and Embase. The search period was from the inception of the databases to January 15, 2025. The English database search strategy included the following keywords: ("MRI-PDFF" OR "MRI-based proton density fatty liver disease") AND ("Non-alcoholic fatty liver disease" OR "MASLD" OR "fatty liver" OR "nonalcoholic" OR "nonalcoholic steatohepatitis"). In addition, target literature was obtained by reviewing the references of the included studies.

### Inclusion and exclusion criteria

Inclusion criteria: (1) Studies published in peer-reviewed journals in Chinese and English; (2) Research subjects were patients with nonalcoholic fatty liver disease; (3) The included studies evaluated the diagnostic value of MRI-PDFF in steatosis of MASLD patients; (4) Pathological examination results were used as the reference standard for the degree of steatosis; (5) Paired data comparing MRI-PDFF and pathological examination results were sufficient to construct a $2 \times 2$ test performance table. Exclusion criteria: (1) Non-population studies; (2) Conference articles, case reports, systematic reviews, etc.; (3) studies involving patients with concurrent significant liver fibrosis (≥ F2 stage by histopathology or non-invasive staging), liver cirrhosis, alcoholic liver disease, viral hepatitis or other metabolic syndrome-related end-organ

damage (e.g., diabetic nephropathy); (4) studies where over 10% of participants had comorbidities potentially affecting hepatic fat metabolism (e.g., hypothyroidism, chronic corticosteroid use); (5) Insufficient outcome information and inability to perform data analysis; (6) Duplicate reporting of research; (7) Studies for which the full text could not be obtained.

#### Literature screening and data extraction

Two researchers independently screened the literature according to the inclusion and exclusion criteria. Initially, the literature was screened by reading the titles and abstracts, and then the full text of the potentially eligible studies was read. When there were disagreements between the two researchers, a third researcher was consulted to reach a consensus through discussion. After the literature screening was completed, two researchers independently extracted data according to the established standard data extraction form. The extracted information included literature information, study time, characteristics of the study subjects, and MRI-PDFF diagnostic results.

#### Quality assessment

The QUADAS-2 scale developed by Whiting of the University of York was used to assess the quality of diagnostic trials in systematic reviews [17]. This scale evaluates the quality from four aspects: selection of study subjects, index test, reference standard, and research process and timing. The risks were assessed in three levels: "high risk," "low risk," and "unknown risk."

#### Statistical analysis methods

Stata 16.0 software was used for statistical analysis. The pooled sensitivity, specificity, positive likelihood ratio (PLR), negative likelihood ratio (NLR), and their 95% confidence intervals (CI) were calculated, and the summary receiver operating characteristic (SROC) curve was drawn to calculate the area under the curve (AUC). Revman 5.3 was used for quality assessment of diagnostic trials. Heterogeneity was assessed using the Q test or I2 test. If $I2 < 50\%$ or $P > 0.1$, the included studies were considered to have homogeneity; if $I2 > 50\%$ or $P \leq 0.1$, the heterogeneity was considered large, and sensitivity analysis was further conducted by excluding each included study one by one to explore the potential sources of heterogeneity. Funnel plots were used to detect publication bias, with $P < 0.05$ indicating statistical significance.

## Results

#### Basic characteristics and quality assessment of included studies

After searching the electronic databases, we identified 2932 articles. After excluding duplicate and irrelevant studies, 1085 articles were included for full-text review. According to the inclusion and exclusion criteria, 10 studies [14, 15, 18–25] were included in the meta-analysis. The literature screening process is shown in Fig. 1A.

The 10 included studies were published between 2013 and 2020, with most studies coming from the United States ($n = 7$), and the remaining three studies from China, Japan, and Italy, respectively. The included studies involved a total of 939 MASLD patients, of which seven studies were adults (mean age range: 48.2–57.5), two studies were children (mean age range: 12.5–13), and one study included both adults and children. More basic characteristics of the included studies are shown in Table 1.

In addition, we used the QUADAS-2 scale to assess the quality of the diagnostic accuracy studies. The assessment results showed that the included studies had high research quality and low potential bias risk, as shown in Figs. 1B-C.

#### Diagnostic accuracy of S0 vs. S1-3

A total of seven studies ($n = 630$) reported the diagnostic results of MRI-PDFF for steatosis S0 vs. S1-3. The meta-analysis results showed that the pooled sensitivity and specificity were 0.92 (95% CI: 0.88–0.95, $I2 = 44.18\%$, Fig. 2A) and 0.94 (95% CI: 0.87–0.97, $I2 = 0\%$, Fig. 2A), respectively; the pooled AUC was 0.93 (95% CI: 0.87–0.96, Fig. 2B). In addition, the pooled PLR and NLR were 14.71 (95% CI: 7.14–30.33) and 0.08 (95% CI: 0.05–0.13), respectively, as shown in Table 2.

#### Diagnostic accuracy of S0-1 vs. S2-3

Nine studies ($n = 859$) reported the diagnostic results of MRI-PDFF for steatosis S0-1 vs. S2-3. The meta-analysis results showed that the pooled sensitivity and specificity were 0.77 (95% CI: 0.65–0.86, $I2 = 58.30$, Fig. 2C) and 0.87 (95% CI: 0.83–0.91, $I2 = 36.02\%$, Fig. 2C), respectively; the pooled AUC was 0.98 (95% CI: 0.96–0.99, Fig. 2D). In addition, the pooled PLR and NLR were 10.43 (95% CI: 6.02–18.05) and 0.24 (95% CI: 0.17–0.32), respectively, as shown in Table 2.

#### Diagnostic accuracy of S0-2 vs. S3

Six studies ($n = 679$) reported the diagnostic results of MRI-PDFF for steatosis S0-2 vs. S3. The meta-analysis results showed that the pooled sensitivity and specificity were 0.78 (95% CI: 0.71–0.84, $I2 = 58.30\%$, Fig. 2E) and 0.93 (95% CI: 0.87–0.96, $I2 = 36.02\%$, Fig. 2E), respectively; the pooled AUC was 0.90 (95% CI: 0.87–0.93, Fig. 2F). In addition, the pooled PLR and NLR were 6.01 (95% CI: 4.54–7.97) and 0.26 (95% CI: 0.16–0.41), respectively, as shown in Table 2.

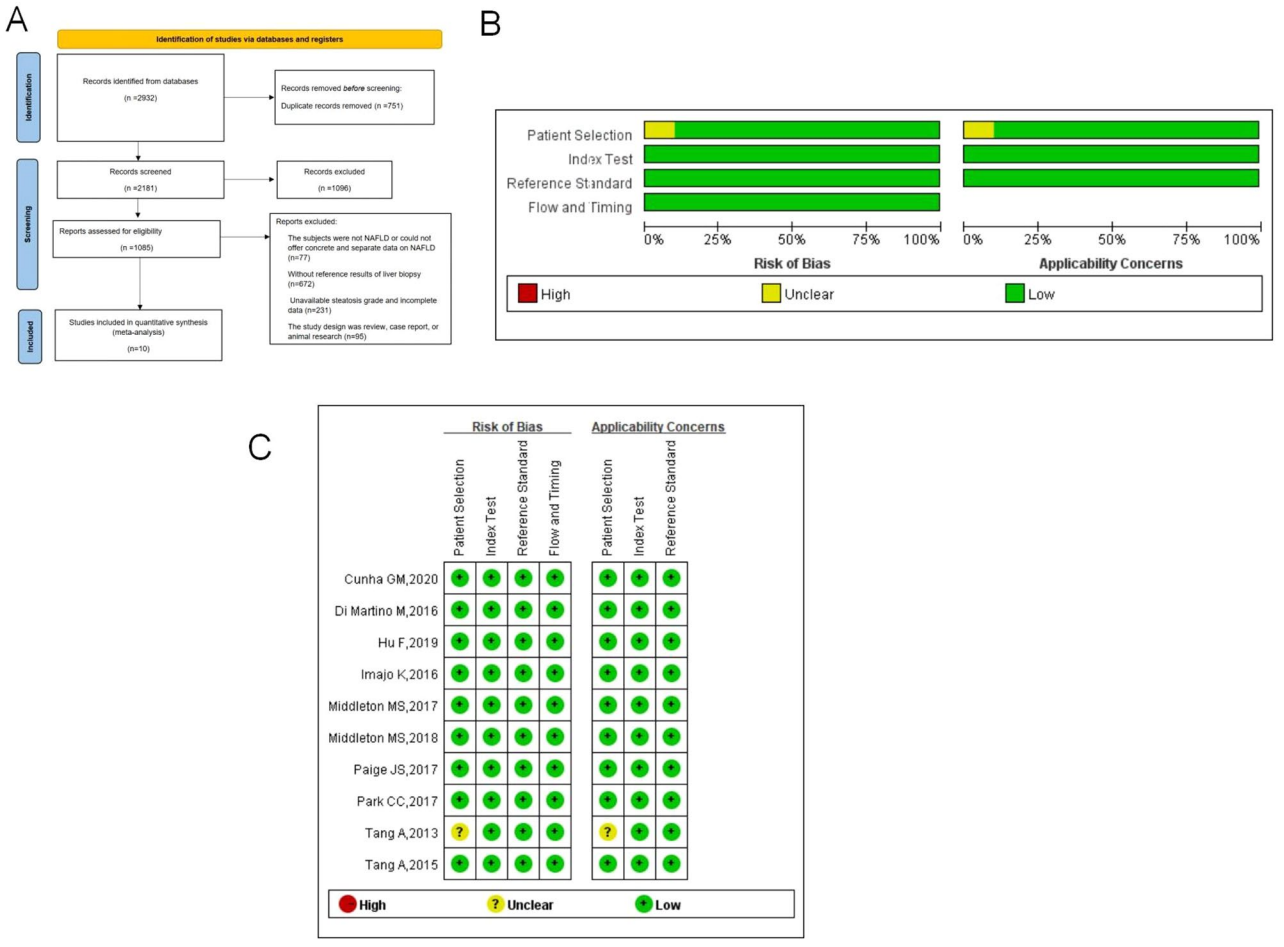


**Fig. 1** **A**: Flowchart of literature screening; **B**: Methodological quality graph of included studies; **C**: Methodological quality summary of included studies

### Sensitivity analysis and publication Bias

Since two studies involved children and one study included both children and adults, we excluded these three studies for sensitivity analysis. The results showed that MRI-PDFF still had good diagnostic value for steatosis grading in adult MASLD patients. The sensitivity of MRI-PDFF for diagnosing steatosis S0 vs. S1-3 in adult MASLD was 0.91 (95% CI: 0.87–0.94), specificity was 0.94 (95% CI: 0.88–0.98), and the pooled AUC was 0.98 (95% CI: 0.96–0.99), as shown in Supplementary Figure 1A. The sensitivity of MRI-PDFF for diagnosing steatosis S0-1 vs. S2-3 in adult MASLD was 0.81 (95% CI: 0.73–0.87), specificity was 0.93 (95% CI: 0.87–0.97), and the pooled AUC was 0.91 (95% CI: 0.89–0.94), as shown in Supplementary Figure 1B. The sensitivity of MRI-PDFF for diagnosing steatosis S0-2 vs. S3 in adult MASLD was 0.83 (95% CI: 0.72–0.90), specificity was 0.86 (95% CI: 0.81–0.90), and the pooled AUC was 0.91 (95% CI: 0.88–0.93), as shown in Supplementary Figure 1C.

In addition, we used funnel plots to assess whether there was publication bias among the included studies. The analysis results showed that there was no significant publication bias among the included studies, with P values all greater than 0.05, as shown in Supplementary Figure 1D-F.

## Discussion

This study compared MRI-PDFF with liver biopsy in the diagnostic accuracy of steatosis grading in MASLD patients by including current diagnostic accuracy trials. We used meta-analysis methods to assess the diagnostic value of MRI-PDFF for S0 vs. S1-3, S0-1 vs. S2-3, and S0-2 vs. S3. A total of 10 studies were included, involving 939 MASLD patients, of which two studies were children and one study included both adults and children. The results showed that the sensitivity of MRI-PDFF for steatosis grading diagnosis was between 0.77 and 0.92, and specificity was between 0.87 and 0.94, with ROC between 0.90 and 0.98. In addition, the sensitivity analysis results after excluding children showed that the study results were robust and MRI-PDFF had good diagnostic value.

Our findings are consistent with previous studies. Selvaraj et al. [26] assessed the diagnostic value of MRI-PDFF and transient elastography (TE) in the grading of

**Table 1** Basic characteristics of included studies

| study | location | study design | patients | sample | mean/median age | male% | BMI | steatosis stage (S0/S1/S2/S3) | fibro stage (F0/F1/F2/F3/F4) | the interval between biopsy and MRI-PDFF | blind |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tang A,2013 | USA | prospective single-center | adults children | 77 | 14 (8–61) | 79.2 | adults: 33.2 ± 6.0 children (BMI z score): 2.3 ± 0.4 | 5/26/27/19 | 31/28/10/8/0 | 0-173 days median: 11 days | yes |
| Tang A,2015 | USA | prospective single-center | adults | 89 | 51.0 ± 13.0 | 43 | 30.6 ± 5.0 | 6/39/30/14 | 48/24/4/8/5 | 0-173 days median: 35 days | yes |
| Imajo K,2016 | Japan | retrospective single-center | adults | 142 | 57.5 ± 14.6 | 57.2 | 28.1 ± 4.63 | 10/59/59/24 | 14/51/32/34/11 | within 6 months | yes |
| Di Martino M,2016 | Italy | prospective single-center | children | 54 | 12.5 (8–18) | 50 | 28.7 ± 4.07 | 27/11/9/7 | NA | within 2 weeks | yes |
| Park CC,2017 | USA | prospective single-center | adults | 104 | 50.8 ± 14.6 | 43.3 | 30.4 ± 5.2 | 9/49/29/16 | 47/24/11/13/8 | 42 days | yes |
| Paige JS,2017 | USA | prospective single-center | adults | 60 | 50 ± 14 | 50 | 32.6 ± 6.9 | 0/27/16/17 | 26/18/6/6/4 | within 100 days | yes |
| Middleton MS,2017 | USA | prospective multi-center | adults | 113 | 51 ± 11 | 38 | 33.6 ± 5.2 | 0/38/44/31 | NA | 51 days | yes |
| Middleton MS,2018 | USA | prospective multi-center | children | 110 | 13 ± 3 | 70.9 | 32 ± 6 | 0/19/31/60 | NA | 61 days | yes |
| Hu F,2019 | China | retrospective single-center | adults | 99 | 48.39 ± 17 | 53.54 | NA | 59/22/17/1 | 8/23/16/21/31 | 1 to 6 days | yes |
| Cunha GM,2020 | USA | prospective multi-center | adults | 81 | 48.2 ± 12.5 | 17.3 | 41.7 ± 5.5 | 27/39/11/4 | NA | within 3 days | yes |

Note: BMI, body mass index; MRI-PDFF, magnetic resonance imaging-proton density fat fraction; NA, not available

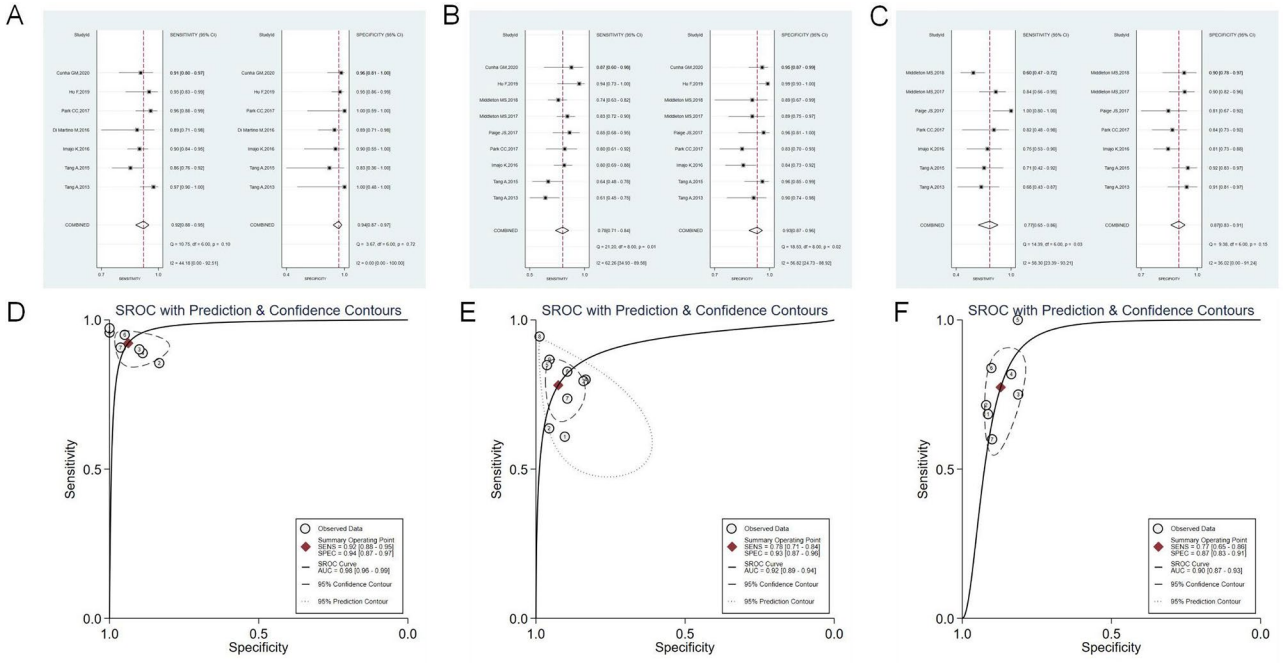


**Fig. 2** **A**: The pooled sensitivity and specificity of the MRI-PDFF for the classification of steatosis S0 vs. S1-3; **B**: Summary receiver operating characteristics curves of the MRI-PDFF for the classification of steatosis S0 vs. S1-3; **C**: The pooled sensitivity and specificity of the MRI-PDFF for the classification of steatosis S0-1 vs. S2-3; **D**: Summary receiver operating characteristics curves of the MRI-PDFF for the classification of steatosis S0-1 vs. S2-3; **E**: The pooled sensitivity and specificity of the MRI-PDFF for the classification of steatosis S0-2 vs. S3; **F**: Summary receiver operating characteristics curves of the MRI-PDFF for the classification of steatosis S0-2 vs. S3

**Table 2** Summary of pooled analysis results of the MRI-PDFF for the classification of steatosis

| | Studies | Pooled sensitivity (95%CI) | Pooled specificity (95%CI) | Pooled AUROC (95%CI) | Pooled PLR (95%CI) | Pooled NLR (95%CI) | Diagnostic score (95%CI) | Pooled DOR (95%CI) |
|---|---|---|---|---|---|---|---|---|
| **S0 vs. S1-3** | 7 | 0.92 (0.88–0.95) | 0.94 (0.87–0.97) | 0.98 (0.96–0.99) | 14.71 (7.14–30.33) | 0.08 (0.05–0.13) | 5.18 (4.21–6.14) | 176.92 (67.66-462.66) |
| **S0-1 vs. S2-3** | 9 | 0.78 (0.71–0.84) | 0.93 (0.87–0.96) | 0.92 (0.89–0.94) | 10.43 (6.02–18.05) | 0.24 (0.17–0.32) | 3.79 (3.04–4.53) | 44.05 (20.94–92.67) |
| **S0-2 vs. S3** | 7 | 0.77 (0.65–0.86) | 0.87 (0.83–0.91) | 0.90 (0.87–0.93) | 6.01 (4.54–7.97) | 0.26 (0.16–0.41) | 3.14 (2.57–3.72) | 23.21 (13.11–41.09) |

Note: AUROC, areas under the summary receiver operating characteristic curves; PLR, positive likelihood ratio; NLR, negative likelihood ratio; DOR, diagnostic odds ratio; CI, confidence interval

steatosis in MASLD patients. The study showed that the AUC of MRI-PDFF for diagnosing ≥ S1 was 0.97, ≥S2 was 0.91, and ≥ S3 was 0.90; the AUC of TE for diagnosing ≥ S1 was 0.85, ≥S2 was 0.83, and ≥ S3 was 0.79; MRI-PDFF was significantly more accurate in assessing the binary classification of steatosis. This advantage may be due to the fact that MRI-PDFF is an imaging-based method to quantify liver fat content. While obtaining liver images, regions of interest can be selected for measurement, which is convenient for longitudinal follow-up of the same liver area [27]. MRI-PDFF can correct for confounding factors such as T1 decay and R2 relaxation, thereby accurately estimating the ratio of liver fat content [23]. Although TE is also a common non-invasive technique for diagnosing steatosis, it is a one-dimensional imaging technique that requires a special mechanical vibration device to generate shear waves and is not suitable for patients with ascites, obesity, and narrow intercostal spaces [28]. Most MASLD patients are accompanied by obesity or overweight [29], so compared with TE, MRI-PDFF may be more suitable for the grading diagnosis of steatosis in MASLD patients.

A series of single-center prospective studies have shown that MRI-PDFF, in conjunction with liver histology, has good utility in assessing changes in liver fat content over 24 weeks [27, 30, 31]. These studies showed that MRI-PDFF was more sensitive than liver histology in assessing changes in liver fat and could be used in clinical trials [32]. These data have been confirmed in multicenter studies in both adult and pediatric populations [23]. Additionally, Patel et al. [33] used MRI-PDFF and liver histology data from two high-quality randomized

trials for comparison, and the results showed that a relative reduction of 29% in liver fat MRI-PDFF was associated with a histological response in MASH (defined as an improvement of 2 points in the MASLD activity score). An increasing number of studies have confirmed that MRI-PDFF can replace liver biopsy and be widely used in MASH subclinical trials as a non-invasive technique to assess drug treatment responses [34]. While the systematic review by Azizi et al. provides valuable insights into MRI applications in metabolic dysfunction-associated steatotic liver disease (MASLD) [35], our study implemented more rigorous patient selection criteria specifically targeting the MASLD population.

This study has several limitations. First, although we systematically searched the relevant literature, the number of studies that met the inclusion criteria was relatively small, and the sample size in each study was also relatively small, which may reduce the diagnostic accuracy of MRI-PDFF due to the small sample size. Due to the insufficient data of children, we only analyzed the diagnostic results of MRI-PDFF for steatosis in adult MASLD patients. In addition, due to the limited variables and data, this study was unable to further fully consider the impact of confounding factors such as waist circumference, diabetes, and liver iron content.

## Conclusion

In summary, this systematic review and meta-analysis show that MRI-PDFF is an effective and non-invasive diagnostic method for the grading of hepatic steatosis in MASLD patients. However, due to the limited current studies, the diagnostic value of MRI-PDFF for different MASLD patient subgroups needs further research.

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12876-025-04017-4.

Supplementary Material 1: Figure A: Summary receiver operating characteristics curves of the MRI-PDFF for the classification of steatosis S0 vs. S1-3 in adult MASLD patients; B: Summary receiver operating characteristics curves of the MRI-PDFF for the classification of steatosis S0-1 vs. S2-3 in adult MASLD patients; C: Summary receiver operating characteristics curves of the MRI-PDFF for the classification of steatosis S0-2 vs. S3 in adult MASLD patients; D: Funnel plot of included studies of the MRI-PDFF for the classification of steatosis S0 vs. S1-3; E: Funnel plot of included studies of the MRI-PDFF for the classification of steatosis S0-1 vs. S2-3; F: Funnel plot of included studies of the MRI-PDFF for the classification of steatosis S0-2 vs. S3.

**Acknowledgements**
Not applicable.

**Author contributions**
Study design: Zhang YX, Feng YP, You CL, Zhang LY. Data acquisition: Zhang YX, Feng YP, You CL, Zhang LY. Data analysis and interpretation: Zhang YX, Feng YP, You CL, Zhang LY. Manuscript preparation: Zhang YX, Feng YP, You CL, Zhang LY. Critical revision of the manuscript for intellectual content: Zhang LY. Manuscript review: Zhang YX, Feng YP, You CL, Zhang LY. Obtaining financing: Zhang LY.

**Funding**
Construction and validation of prediction model for occurrence and severity of metabolism-related fatty liver disease.

**Data availability**
Data sharing is not applicable to this article as no new data were created or analyzed in this study.

## Declarations

**Ethics approval and consent to participate**
Not applicable.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

Received: 7 February 2025 / Accepted: 21 May 2025
Published online: 01 July 2025

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