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Review

Effects of Bariatric and Metabolic Surgery on Steatohepatitis Resolution and Liver Fibrosis Regression in Adults with MASLD: A Systematic Review and Meta-Analysis

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ABSTRACT

Objective: To synthesize the effects of bariatric and metabolic surgery on histological resolution of metabolic dysfunction-associated steatohepatitis (MASH), improvement in fibrosis, and long-term liver outcomes in adults with obesity. Methods: A systematic review was conducted in accordance with PRISMA 2020. MEDLINE/PubMed and ClinicalTrials.gov were searched from database inception through July 16, 2026, supplemented by reference and citation tracking. Clinical trials, comparative studies, and cohorts with paired liver biopsies or major liver outcomes were included. Proportions were pooled after logit transformation; adjusted hazard ratios (HRs) were synthesized on the logarithmic scale. Random-effects models, restricted maximum likelihood estimation, and 95% confidence intervals (95% CIs) were used. Results: Sixteen studies contributed to the qualitative synthesis and 15 to at least one meta-analysis. Across nine studies, 263 of 336 participants achieved histological resolution of MASH/NASH without worsening of fibrosis. The pooled proportion was 81.2% (95% CI 73.6–87.0%; I^2=35.3%). Across five studies, the pooled proportion with improvement or regression of fibrosis was 73.8% (95% CI 55.1–86.6%; I^2=70.3%). In the BRAVES trial, NASH resolution was more frequent after gastric bypass or sleeve gastrectomy than after intensive lifestyle intervention. Three controlled cohorts totaling 10,152 participants indicated a lower risk of progression to cirrhosis or major adverse liver outcomes after surgery (pooled HR=0.29; 95% CI 0.19–0.43; I^2=0%). Conclusion: Bariatric and metabolic surgery was associated with a high frequency of MASH resolution and fibrosis improvement, as well as a lower risk of long-term liver disease progression. Certainty was moderate for MASH resolution based on comparative evidence and low for single-arm proportions and fibrosis regression because of selection for repeat biopsy and methodological heterogeneity.

1. Introduction

Metabolic dysfunction-associated steatotic liver disease (MASLD) replaced the term nonalcoholic fatty liver disease and now encompasses a spectrum ranging from isolated steatosis to MASH, fibrosis, cirrhosis, and hepatocellular carcinoma. This terminology change is not merely semantic: it emphasizes the link between adiposity, insulin resistance, and cardiometabolic risk while preserving comparability with most historical NAFLD/NASH cohorts.[1,2]

Fibrosis is the histological component most closely associated with Previous meta-analyses reported improvements in steatosis, inflammation, ballooning, and fibrosis after surgery; however, they combined markedly different procedures, definitions, and follow-up periods and were dominated by uncontrolled before–after series. The review by Mummadi et al. found improvement or resolution of steatohepatitis in 81.3%, whereas Lee et al. estimated resolution of steatosis in 66% and fibrosis in 40%, but rated the overall certainty as very low. Later reviews added studies without eliminating the problems of overlapping cohorts and mixing histological, biochemical, and imaging outcomes.[5–8]

Since those syntheses, a randomized trial comparing surgery with intensive medical treatment, new paired-biopsy cohorts, and controlled studies of major liver outcomes have been published. This review therefore aimed to evaluate the effects of bariatric and metabolic surgery on histological resolution of MASH/NASH, improvement in fibrosis, and long-term liver disease progression while keeping comparative evidence separate from single-arm estimates.

liver prognosis. Contemporary recommendations therefore prioritize the identification of clinically significant fibrosis and interventions capable of producing MASH resolution without worsening fibrosis or improvement of at least one fibrosis stage. Lifestyle changes remain fundamental, but sustaining sufficient weight loss is difficult for people with severe obesity.[3] Bariatric and metabolic surgery produces durable weight loss and improves diabetes, dyslipidemia, and hypertension. Current indications recognize its metabolic role in adults with obesity and comorbidities, although MASLD alone is not yet a universal indication in all healthcare systems.[4]

2. Materials and Methods

2.1 Design and reporting

This systematic review and meta-analysis was planned and reported in accordance with the PRISMA 2020 statement. The protocol was not prospectively registered; all analytical decisions used in the synthesis are presented in this section and in the reproducible search strategies provided at the end of the document.[9]

2.2 Eligibility criteria

Eligible studies enrolled adults aged 18 years or older with obesity and a diagnosis of NAFLD/NASH, MAFLD, or MASLD/MASH who underwent sleeve gastrectomy, Roux-en-Y gastric bypass, or another recognized

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bariatric/metabolic procedure. Histological analyses required a biopsy before or at the time of surgery and a repeat biopsy after the intervention, or comparison with a nonsurgical group undergoing serial biopsies. Long-term analyses accepted controlled cohorts reporting adjusted HRs for cirrhosis, decompensation, hepatocellular carcinoma, transplantation, or liver-related mortality.

Case reports, series with fewer than ten participants, exclusively pediatric studies, protocols without results, reports without postoperative liver assessment, diagnostic studies without a longitudinal outcome, and liver diseases attributed predominantly to alcohol, viral hepatitis, drugs, or genetic disorders were excluded. Publications from the same cohort were linked; only the most informative report for each outcome and time point was used, thereby avoiding duplicate counting.

2.3 Information sources and search strategy

Searches covered MEDLINE/PubMed and ClinicalTrials.gov from database inception through July 16, 2026. Controlled and free-text terms relating to MASLD, MAFLD, NAFLD, MASH, NASH, bariatric surgery, metabolic surgery, sleeve gastrectomy, gastric bypass, RYGB, biopsy, and histology were combined. References of previous reviews and included studies were examined, and forward citation searches and searches for publications linked to trial registrations were performed. No language restrictions were applied during the electronic search. The full PubMed strategy is provided in Supplementary Material 1.

2.4 Study selection, data extraction, and outcome definitions

Titles and abstracts were assessed against predefined criteria; potentially eligible full texts were examined in full. Country, design, sample size, diagnostic criteria, procedure, biopsy technique, follow-up duration, losses to follow-up, outcome definition, and adjusted estimates were extracted. Results reported only as percentages were converted to counts only when the denominator was unambiguous; adjusted estimates were not treated as raw counts.

The primary outcome was resolution of MASH/NASH without worsening of fibrosis at the last eligible biopsy. Secondary outcomes were improvement or regression of fibrosis, improvement in NAS, and major liver outcomes. For historical studies, the terms NASH and NAFLD were retained when describing the original criteria but were interpreted within the current MASH/MASLD spectrum when clinically compatible.

2.5 Risk of bias and certainty of evidence

The randomized trial was assessed across the RoB 2 domains. Nonrandomized comparative studies were examined according to ROBINS-I principles, with attention to confounding, selection, and outcome measurement. Single-arm cohorts were evaluated for consecutive sampling, diagnostic criteria, completeness of the repeat biopsy, and histological standardization. The certainty of evidence for each outcome was graded by considering risk of bias, inconsistency, imprecision, indirectness, and publication bias.[10]

2.6 Statistical synthesis

Proportions were logit-transformed and pooled using random-effects models. A continuity correction of 0.5 was applied to studies with 100% or 0% events only to estimate the variance. For long-term outcomes, adjusted HRs were pooled on the logarithmic scale. Between-study variance was estimated by restricted maximum likelihood (REML). The 95% CIs, τ^2, Q statistic, and I^2 were reported; a prediction interval was also calculated for the primary analysis. Histological measures were not pooled with enzymes, elastography, or MRI-PDFF.

The BRAVES trial was described primarily according to the intention-to-treat analysis for the comparison with nonsurgical treatment. In the meta-analysis of proportions among participants with a repeat biopsy, per-protocol counts from the surgical arms were used to maintain denominators comparable with paired-biopsy cohorts. Subgroup analyses by procedure were not performed because a meta-analysis published in 2026 had specifically addressed that contrast and several studies did not provide stratified histological results. Tests for asymmetry were not conducted because no meta-analysis of proportions included ten studies and funnel-plot interpretation would be unstable for extreme proportions.

3. Results

3.1 Study selection

The search identified 1,235 records: 1,108 from MEDLINE/PubMed, 105 from ClinicalTrials.gov, and 22 through reference and citation tracking. After removing duplicates and linking records with publications, 1,171 records were screened. Sixty-five full-text reports were assessed and 16 studies were included in the qualitative synthesis; 15 contributed to at least one meta-analysis. Full-text exclusions were mainly due to the absence of paired biopsies or a liver-related comparator, exclusive use of noninvasive markers, duplicate cohort publication, or absence of an eligible outcome.

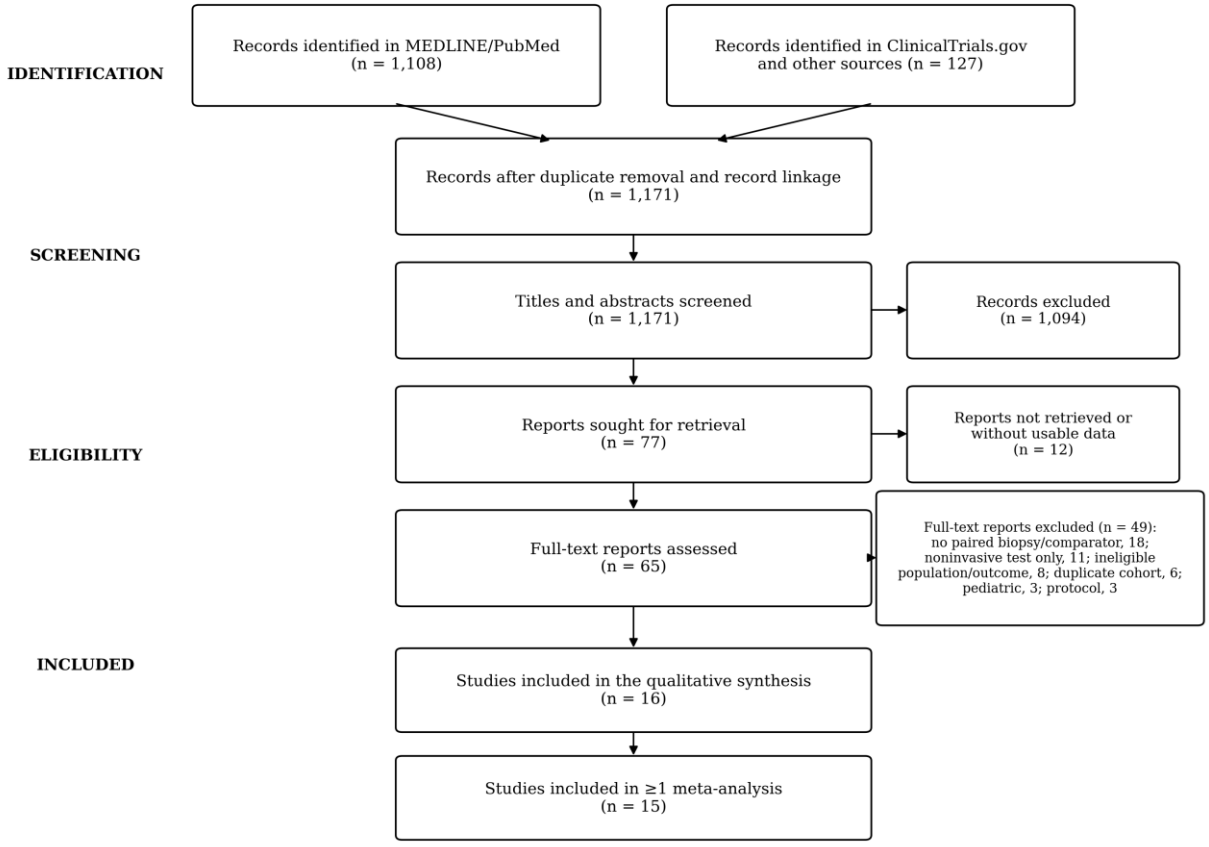

Fig. 1. PRISMA 2020 flow diagram of the study selection process. The search identified 1,235 records; 16 studies were included in the qualitative synthesis and 15 contributed to at least one meta-analysis.

3.2 Study characteristics

The studies were published between 2012 and 2025 and included a randomized trial, prospective paired-biopsy cohorts, retrospective cohorts, and long-term controlled studies. Histological follow-up ranged from approximately seven months to five years. Most studies assessed sleeve gastrectomy, Roux-en-Y gastric bypass, or both. Repeat biopsy was protocol-driven in some cohorts and conditional on clinical indication or reoperation in others, representing the main source of selection bias.

Table 1. Characteristics of the included studies.

Study; country	Design/sample	Intervention	Follow-up/assessment	Main finding
Vargas et al., 2012[11]; Brazil	Prospective cohort; n = 26	RYGB	16±3 months; paired biopsy	NASH decreased from 25 to 4 cases
Raj et al., 2015[12]; India	Prospective cohort; n = 30	SG/RYGB	7.1 months; paired biopsy	Fibrosis resolved or improved in 14/14
Allen et al., 2020[15]; USA	Prospective cohort; n = 38	Mixed	12 months; biopsy + MRE	NASH resolution in 13/13
Lassailly et al., 2020[13]; France	Prospective cohort; n = 180	Mixed	1 and 5 years; biopsies	Resolution in 84% at 5 years
Nikai et al., 2020[14]; Japan	Cohort; n = 28 paired	SG	12 months; biopsy	25/28 no longer met NASH criteria
Murakami et al., 2021[16]; Japan	Retrospective cohort; n = 11	SG	12 months; biopsy	Histological remission in 9/11
Pedersen et al., 2021[17]; Denmark	Prospective cohort; n = 40	SG/RYGB	12 months; biopsy	Resolution in 7/8 with NASH
Agarwal et al., 2021[18]; India	Prospective cohort; n = 58	Mixed	12 months; biopsy + FibroScan	Fibrosis improved in 30/58
Verrastro et al., 2023[19]; Italy	Randomized trial; n = 288	SG/RYGB vs medical care	12 months; biopsy	ITT: 55/96 SG; 54/96 RYGB; 15/96 control
Drai et al., 2024[20]; France	Cohort; n = 37 (18 NASH)	Mixed	Paired biopsy	Resolution without worsening in 15/18
Aminian et al., 2024[21]; USA	Comparative cohort; n = 133	MBS vs usual care	Median 2 years; biopsies	Dual outcome: 50.1% vs 12.1%
Li et al., 2025[22]; China	Multicenter cohort; n = 138	Mixed	12 months; 40 paired biopsies	NAS improved ≥2 points in 80%
Longsomboon et al., 2025[23]; Thailand	Retrospective cohort; n = 13	SG/RYGB	Mean 38 months; biopsies	Complete resolution in 10/13
Wirth et al., 2020[24]; USA	Administrative cohort; n=8,826	MBS vs no surgery	Long term	Progression to cirrhosis: HR 0.31
Aminian et al., 2021[25]; USA	SPLENDOR; n=1,158	MBS vs no surgery	Median 7 years	Major liver outcomes: HR 0.12
Aminian et al., 2025[26]; USA	SPECCIAL; n = 168	MBS vs no surgery	Mean 10 years	MALO in compensated cirrhosis: HR 0.28

Abbreviations: MALO, major adverse liver outcomes; MBS, metabolic/bariatric surgery; MRE, magnetic resonance elastography; NASH, nonalcoholic steatohepatitis; RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy.

3.3 Histological resolution of MASH/NASH

The nine studies included in the primary analysis enrolled 336 participants with MASH/NASH at baseline and a repeat biopsy; 263 achieved resolution without worsening of fibrosis. The pooled proportion was 81.2% (95% CI 73.6–87.0%), with moderate heterogeneity (I^2=35.3%; τ^2=0.143). The prediction interval was 64.7%–91.1%, suggesting an expected benefit across most settings, albeit with clinically relevant variation.

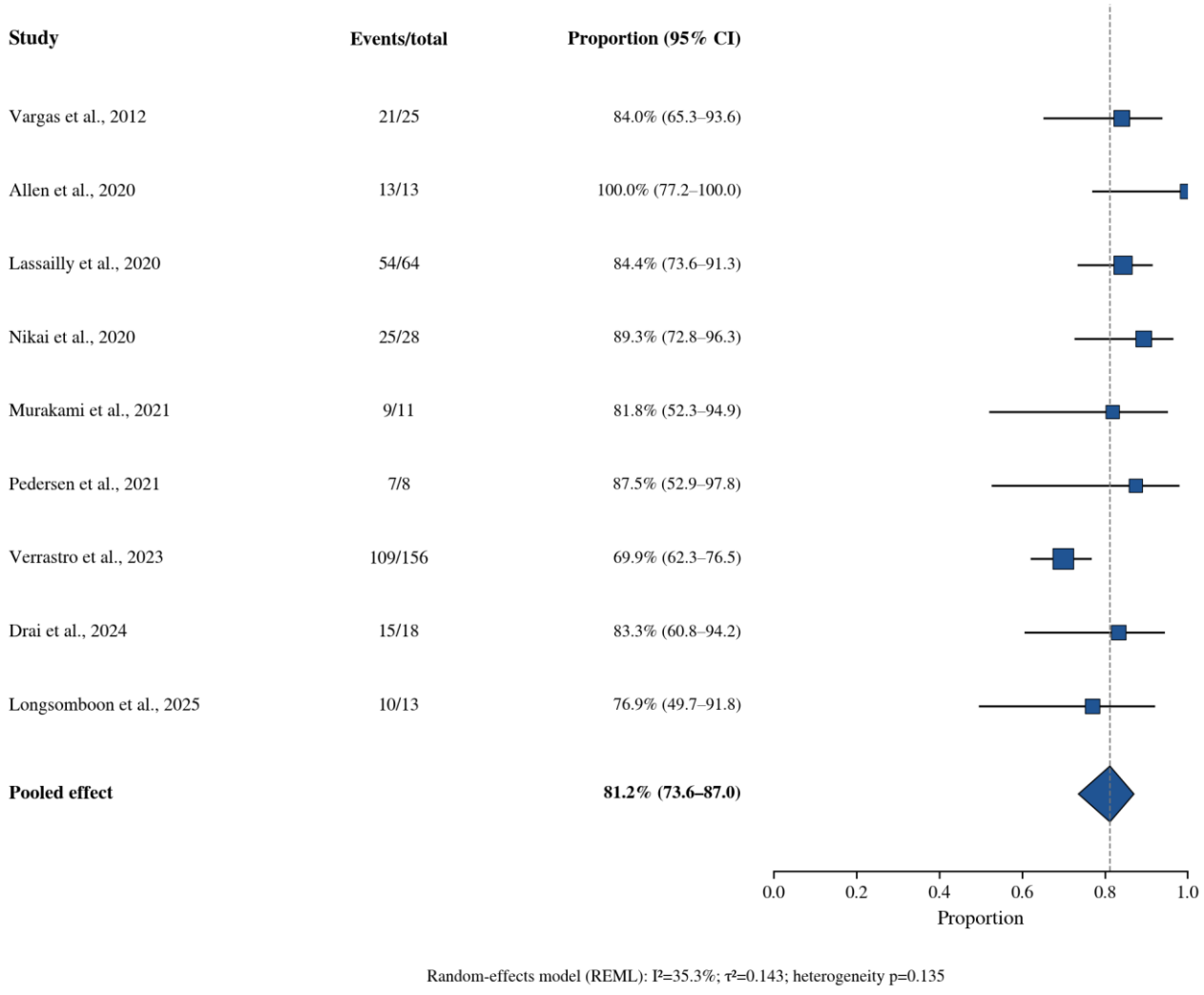

Fig. 2. Meta-analysis of the proportion with histological resolution of MASH/NASH without worsening of fibrosis. Squares represent individual estimates; horizontal lines, 95% CIs; diamond, pooled effect. Random-effects model with REML.

In BRAVES, the intention-to-treat analysis showed the outcome in 56% after RYGB and 57% after SG, compared with 16% in the lifestyle and best medical care group. The odds ratios calculated in the study were 3.60 and 3.67, respectively. In the per-protocol analysis, approximately 70% of participants in both surgical arms achieved resolution. These data provide causal support that is absent from single-arm series.[19]

3.4 Leave-one-out sensitivity analysis

Sequential omission of each study kept the pooled proportion of MASH/NASH resolution between 79.9% and 84.6%. No single omission changed the direction or statistical significance of the result, and every 95% CI remained clearly above 50%. Heterogeneity decreased particularly when the study furthest from the overall set was removed, without a clinically important change in the estimate. This pattern indicates that the pooled effect was not driven by a single cohort, a specific procedure, or a study with a 100% response rate.

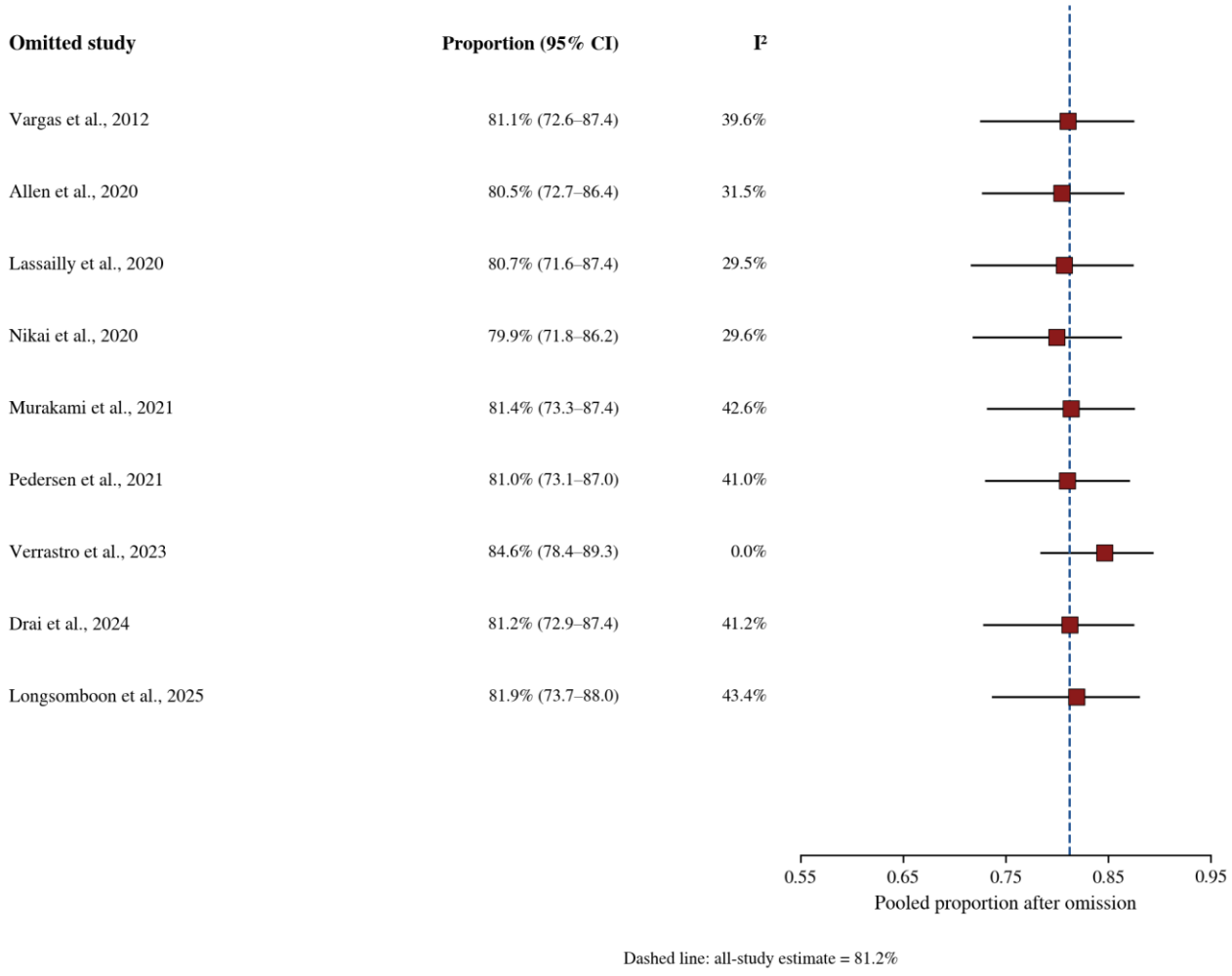

Fig. 3. Leave-one-out sensitivity analysis of histological MASH/NASH resolution. Each row represents a new meta-analysis after omission of the indicated study; the dashed vertical line corresponds to the all-study estimate.

3.5 Improvement or regression of fibrosis

Five studies reported verifiable counts of improvement or regression of fibrosis. The pooled estimate was 73.8% (95% CI 55.1–86.6%), with substantial heterogeneity (I^2=70.3%). The wide range reflected differences in baseline severity, the interval between biopsies, and the definition of improvement. In Lassailly et al., regression progressed between the first and fifth years, reinforcing that the fibrotic response is slower than the reduction in steatosis and inflammatory activity.[13]

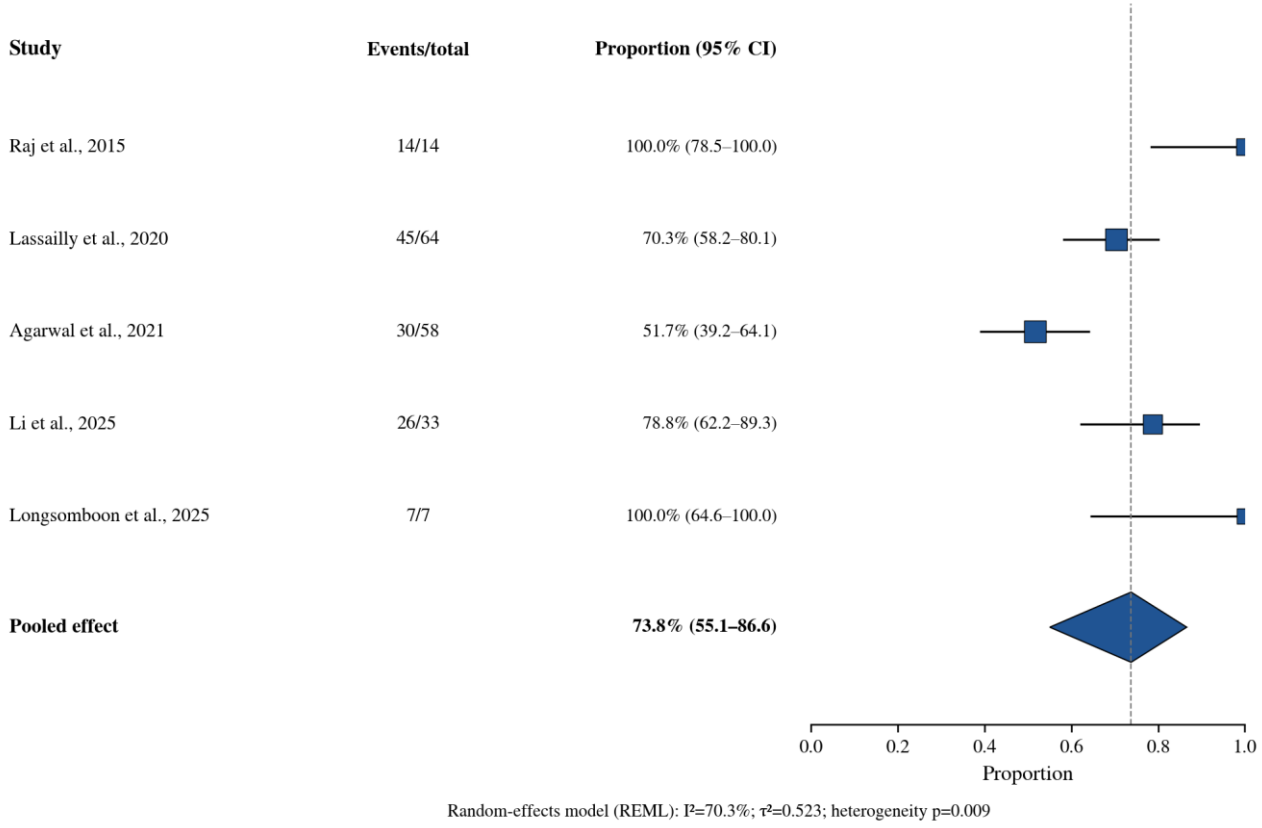

Fig. 4. Meta-analysis of the proportion with histological improvement or regression of fibrosis. Definitions varied across studies and included a decrease of at least one fibrosis stage, improvement, or complete resolution on paired biopsy.

The coexistence of average improvement and individual progression was clinically important. Agarwal et al. observed improvement in 30 of 58 participants, stability in 18, and worsening in ten. Surgery should therefore not be presented as guaranteeing regression in every patient, particularly with short follow-up or persistent advanced fibrosis.[18]

3.6 Long-term liver outcomes

Three controlled cohorts, comprising 10,152 participants, evaluated progression to cirrhosis or major liver outcomes. The pooled HR was 0.29 (95% CI 0.19–0.43; I^2=0.0%), corresponding to an approximate relative reduction of 71%. The absence of statistical heterogeneity should be interpreted cautiously because outcomes and baseline severity differed across cohorts.[24–26]

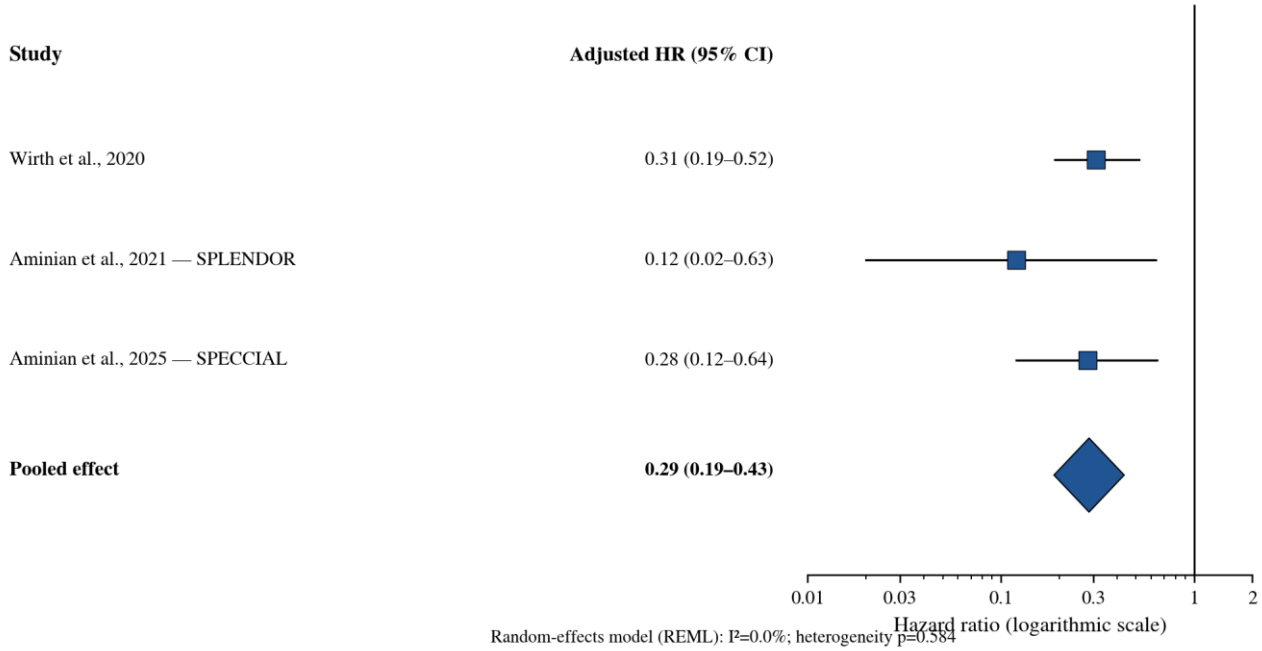

Fig. 5. Exploratory meta-analysis of major liver outcomes or progression to cirrhosis. Hazard ratios below 1 favor surgery. Outcomes were progression to cirrhosis in Wirth et al. and composite major adverse liver outcomes in the SPLENDOR and SPECCIAL cohorts.

3.7 Risk of bias and certainty of evidence

BRAVES had low risk for sequence generation and histological measurement, but some concern related to the open-label design and losses before follow-up biopsy. In paired-biopsy cohorts, the main problem was selection of participants who underwent repeat biopsy.

Studies in which the second sample was obtained during a subsequent operation had a serious risk of selection bias. Long-term controlled cohorts used matching or weighting, but residual confounding by surgical indication cannot be excluded.

Table 2. Summary of risk of bias in the included studies.

Study/studies	Overall judgment	Main rationale
Verrastro et al., 2023	Some concerns	Open label; losses before repeat biopsy; standardized histological assessment
Lassailly et al., 2020	Moderate	Prospective cohort; incomplete repeat biopsy, particularly at five years
Vargas; Raj; Nikai; Murakami; Pedersen; Agarwal; Drai	Moderate to serious	Selection for paired biopsy, small samples, and confounding
Allen et al., 2020	Moderate	Small cohort, but prospective assessment and paired histology
Li et al., 2025	Moderate	Multicenter cohort; only a subsample underwent repeat biopsy
Longsomboon et al., 2025	Serious	Repeat biopsy during a subsequent operation; n = 13
Aminian et al., 2024	Moderate	Overlap weighting; possible residual confounding
Wirth 2020; SPLENDOR 2021; SPECCIAL 2025	Moderate	Control by matching/weighting; robust outcomes, but observational design

Table 3. Certainty of evidence by outcome.

Outcome	Evidence base	Certainty	Rationale
MASH/NASH resolution — surgery vs nonsurgical care	Randomized trial + comparative cohort	Moderate	Downgraded for losses/open-label design; large and consistent effect
Proportion with resolution after surgery	Paired cohorts + surgical arms	Low	Selection for repeat biopsy and no comparator in most studies
Fibrosis improvement/regression	Paired cohorts	Low	Substantial heterogeneity and variable definitions
Major liver outcomes/progression	Three controlled cohorts	Low	Consistent effect, but residual confounding and nonidentical outcomes

4. Discussion

4.1 Interpretation of the main findings

This review indicates that bariatric and metabolic surgery is associated with histological resolution of MASH in approximately four of every five patients who underwent serial biopsies. Improvement or regression of fibrosis was also frequent, although less uniform and more time-dependent. The most relevant finding is the convergence of different levels of evidence: paired cohorts showed reversal of histological activity, the randomized trial demonstrated superiority over intensive medical treatment, and long-term controlled studies indicated less progression to cirrhosis and major liver outcomes.[13,19,24–26]

The pooled proportion of resolution was higher than that observed in some previous reviews. Mummadi et al. estimated complete NASH resolution at 69.5%, whereas Lee et al. included 32 cohorts and separately calculated resolution of steatosis, inflammation, ballooning, and fibrosis. The review by Zhou et al., comprising 37 studies, found fibrosis improvement in approximately one quarter of participants. Differences arise from the search period, procedures included, histological criteria, and, most importantly, the denominator used. The present analysis required baseline MASH/NASH and a repeat biopsy, providing a more directly interpretable measure of remission but one susceptible to selection of patients returning for examination.[5,6,8]

The leave-one-out analysis supported the stability of the main finding. Sequential exclusion of studies did not materially shift the estimate, including when small cohorts with a 100% response or the highest-weight trial were removed. This does not eliminate selection bias shared across cohorts, but it shows that the pooled result does not depend on a single center, country, or procedure. The decrease in heterogeneity after some exclusions suggests that differences in follow-up and eligibility explain part of the variation without changing the clinical conclusion that resolution is frequent among patients undergoing follow-up biopsy.[11,13–20,23]

BRAVES substantially changed the causal interpretation. In the intention-to-treat analysis, 56% of participants undergoing RYGB and 57% of those undergoing sleeve gastrectomy achieved resolution without worsening of fibrosis, compared with 16% in the intensive lifestyle intervention and best medical care group. The difference remained large in the per-protocol analysis. Thus, although loss to follow-up reduces the absolute proportion in a pragmatic setting, the superiority of the surgical strategy cannot be explained solely by natural history or regression to the mean.[19]

4.2 Weight loss, metabolic control, and liver response

Liver improvement after surgery results from interdependent mechanisms. The rapid reduction in energy balance and visceral fat decreases free fatty acid flux to the liver, de novo lipogenesis, and hepatic insulin resistance. In parallel, changes in GLP-1, PYY, bile acids, gut microbiota, and inflammatory signaling may emerge before maximum weight loss. These effects help explain why steatosis and inflammatory activity may improve during the first months, whereas fibrosis remodeling requires a longer period of favorable metabolic exposure.[2–4]

Available data do not support a universal histological advantage for one procedure. In BRAVES, sleeve gastrectomy and RYGB yielded nearly identical resolution rates. Pedersen et al. observed a similar reduction in NAS, although RYGB produced a more pronounced decrease in steatosis. The comparative meta-analysis published in 2026 also found no significant overall difference in NAS; its meta-regression suggested that any potential advantage of bypass accompanied greater weight loss rather than necessarily reflecting a liver-specific effect independent of weight reduction.[17,19,28]

This interpretation is consistent with the comparative study by Aminian et al., in which patients who simultaneously achieved NASH resolution and improvement of at least one fibrosis stage lost more weight than those without a complete response, both in the surgical and usual-care groups. The association in both groups indicates a dose–response relationship between the magnitude of weight loss and histological benefit. Aggregate data, however, cannot define a single threshold applicable to every patient because response also depends on diabetes, fat distribution, fibrosis stage, and disease duration.[21]

Glycemic control appears particularly relevant. Persistent insulin resistance and a smaller reduction in waist circumference were associated with residual disease after RYGB. In sleeve gastrectomy cohorts, improvement in HbA1c accompanied histological regression, and higher preoperative HbA1c was associated with a lower likelihood of fibrosis improvement. Follow-up should therefore not be restricted to weight: diabetes relapse, recovery of central adiposity, and worsening triglycerides may signal a risk of incomplete liver response or recurrence.[14,16,30]

4.3 Fibrosis regression and prognostic significance

Fibrosis should be interpreted more cautiously than inflammatory activity. Its regression depends on sustained interruption of metabolic injury, deactivation of stellate cells, and extracellular matrix remodeling. In the follow-up by Lassailly et al., NASH resolution was already evident during the first year, whereas fibrosis reduction continued through year five. Consequently, studies with six or 12 months of follow-up may underestimate fibrotic benefit, particularly in patients with bridging

fibrosis, whose architecture takes longer to reorganize.[13]

The 70.3% heterogeneity in the fibrosis meta-analysis is consistent with this time dependence. Differences in baseline biopsy, sample type, pathologist, classification system, and response criterion also contributed. Some studies defined improvement as a decrease of at least one stage; others combined resolution and improvement or analyzed only participants with baseline fibrosis. Because biopsy sampling error is relevant in MASLD, one-stage changes should be interpreted alongside activity, sample quality, and metabolic trajectory.[12–14,18,22]

Individual progression despite average improvement deserves emphasis. Agarwal et al. observed worsening fibrosis in ten of 58 participants at one year. In earlier studies, persistent disease was associated with less weight loss or poorer glycemic control. Surgery is therefore not equivalent to universal cure. Patients with F2–F4 fibrosis, persistent diabetes, relevant alcohol use, insufficient weight loss, or weight regain continue to require surveillance and treatment of metabolic risk factors.[18,30]

The synthesis of clinical outcomes bridges histology and prognosis. Wirth et al. identified less progression to cirrhosis in a large administrative cohort. In SPLENDOR, people with fibrotic NASH without cirrhosis experienced less cirrhosis, hepatocellular carcinoma, transplantation, or liver-related death after surgery. SPECCIAL extended this association to selected patients with MASH-related compensated cirrhosis. The pooled HR of 0.29 is substantial but should be interpreted as an association because functional capacity, access to care, and surgical indication may remain unequally distributed even after weighting or matching.[24–26]

Fifteen-year follow-up of the French cohort added biological coherence. Mortality was higher when MASH persisted or fibrosis worsened after surgery, whereas MASH resolution without worsening fibrosis was not associated with excess risk. Similarly, regression of significant fibrosis attenuated the prognostic difference. These findings suggest that histological response may mediate part of the benefit, although individual participant data analyses are needed to separate the contributions of diabetes remission, weight loss, cardiovascular risk reduction, and liver improvement.[27]

4.4 Clinical and research implications

In practice, these results support systematic MASLD assessment in surgical candidates. The initial aim is not to biopsy everyone, but to identify clinically relevant fibrosis through a stepwise strategy beginning with FIB-4 and proceeding, when indicated, to elastography or specialist assessment. People with suspected advanced fibrosis or cirrhosis require joint planning among surgery, hepatology, anesthesia, and nutrition teams because the risk and choice of procedure differ from those in MASLD without advanced portal disease.[3,4]

After surgery, normalization of ALT or reduction in CAP should not be considered in isolation as evidence of fibrosis regression. Transaminases may normalize despite residual disease, whereas liver stiffness may initially fall because of reduced inflammation and congestion. Interpretation should integrate trajectories of weight, diabetes, platelets, FIB-4, and elastography. Persistently elevated values, weight regain, or recurrence of metabolic abnormalities warrant reassessment, particularly in patients with F2–F4 before surgery.[3,18,22]

Surgery should be understood as part of longitudinal care. Appropriate nutrition, physical activity, prevention of protein and micronutrient deficiency, screening for alcohol use, and diabetes control remain necessary. This approach is especially important after procedures with a greater malabsorptive component, in which malnutrition and muscle loss may increase vulnerability in patients with advanced liver disease. The potential benefit does not remove the need to select the procedure carefully and monitor long-term safety.[3,4,26]

Future research should standardize assessments at 12 months, three years, and five years; report MASH resolution without worsening fibrosis and improvement of at least one fibrosis stage without worsening MASH; and present results by procedure, sex, diabetes status, and baseline stage. Integrating MRI-PDFF, elastography, and biomarkers with histological subsamples may reduce reliance on repeated biopsies. Individual participant data studies would also allow mediation by weight loss to be tested and clinically useful response thresholds to be identified.[19,22,27]

4.5 Limitations

Histological classifications, biopsy techniques, procedures, and follow-up intervals also varied. Continuity correction affects studies with a 100% response rate, although the sensitivity analysis showed that none determined the pooled effect. The meta-analysis of long-term events combined related but nonidentical outcomes and included only three observational cohorts. Finally, aggregate data precluded reliable analyses by sex, ethnicity, diabetes, fibrosis stage, procedure, and magnitude of weight loss. These limitations justify moderate certainty for the randomized comparison and low certainty for the other syntheses.[13,19,24–26]

5. Conclusion

Bariatric and metabolic surgery was associated with a high frequency of histological resolution of MASH/NASH without worsening fibrosis and with fibrosis improvement in a substantial proportion of patients with obesity. Randomized evidence demonstrated superiority over intensive lifestyle intervention and medical treatment, whereas controlled cohorts suggested a lower risk of progression to cirrhosis and major liver outcomes. Response was not universal, and certainty remains limited by selection for serial biopsies, heterogeneity, and residual confounding. Multicenter studies using biopsy or validated markers at standardized time points and prolonged clinical follow-up are needed to determine which patients derive the greatest liver benefit and how they should be monitored after surgery.

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Supplementary Material 1 — Search Strategy

MEDLINE/PubMed — final search on July 16, 2026

(("Bariatric Surgery"[Mesh] OR "bariatric surgery"[tiab] OR "metabolic surgery"[tiab] OR "sleeve gastrectomy"[tiab] OR "gastric sleeve"[tiab] OR "Roux-en-Y gastric bypass"[tiab] OR RYGB[tiab] OR "gastric bypass"[tiab]) AND ("Non-alcoholic Fatty Liver Disease"[Mesh] OR NAFLD[tiab] OR NASH[tiab] OR MASLD[tiab] OR MASH[tiab] OR MAFLD[tiab] OR "steatotic liver disease"[tiab] OR "fatty liver"[tiab]) AND (biopsy[tiab] OR biopsies[tiab] OR histology[tiab] OR histological[tiab] OR fibrosis[tiab] OR cirrhosis[tiab] OR "liver outcome"[tiab]))

ClinicalTrials.gov: Condition/disease = "NAFLD OR NASH OR MASLD OR MASH"; intervention/treatment = "bariatric surgery OR metabolic surgery OR sleeve gastrectomy OR gastric bypass". Records were linked to their corresponding publications before final selection.

Supplementary Material 2 — Meta-Analysis Data

Table S1. Histological resolution of MASH/NASH.

Study	Events	Total	Proportion
Vargas et al., 2012	21	25	84.0%
Allen et al., 2020	13	13	100.0%
Lassailly et al., 2020	54	64	84.4%
Nikai et al., 2020	25	28	89.3%
Murakami et al., 2021	9	11	81.8%
Pedersen et al., 2021	7	8	87.5%
Verrastro et al., 2023	109	156	69.9%
Drai et al., 2024	15	18	83.3%
Longsomboon et al., 2025	10	13	76.9%

Table S2. Improvement or regression of fibrosis.

Study	Events	Total	Proportion
Raj et al., 2015	14	14	100.0%
Lassailly et al., 2020	45	64	70.3%
Agarwal et al., 2021	30	58	51.7%
Li et al., 2025	26	33	78.8%
Longsomboon et al., 2025	7	7	100.0%

Table S3. Major liver outcomes or progression to cirrhosis.

Study	Adjusted HR	95% CI
Wirth et al., 2020	0.31	0.19–0.52
Aminian et al., 2021 — SPLENDOR	0.12	0.02–0.63
Aminian et al., 2025 — SPECCIAL	0.28	0.12–0.64

Table S4. Leave-one-out sensitivity analysis results.

Omitted study	Pooled proportion	95% CI	I^2
Vargas et al., 2012	81.1%	72.6–87.4%	39.6%
Allen et al., 2020	80.5%	72.7–86.4%	31.5%
Lassailly et al., 2020	80.7%	71.6–87.4%	29.5%
Nikai et al., 2020	79.9%	71.8–86.2%	29.6%
Murakami et al., 2021	81.4%	73.3–87.4%	42.6%
Pedersen et al., 2021	81.0%	73.1–87.0%	41.0%
Verrastro et al., 2023	84.6%	78.4–89.3%	0.0%
Drai et al., 2024	81.2%	72.9–87.4%	41.2%
Longsomboon et al., 2025	81.9%	73.7–88.0%	43.4%