Salubris Open | IJADD

Review

Diabetes and MASLD: An Updated Narrative Review of Emerging Therapeutic Approaches

Banshi Saboo[1], Kunal Jhaveri[2]

[1] Chief Diabetologist, Department of Diabetes, Diacare-Diabetes Care and Hormone Clinic, Ahmedabad, Gujarat, India

[2] DGM – Medical Affairs, Zydus Lifesciences Limited, Mumbai, India

Corresponding author: Banshi Saboo, M.D., Chief Diabetologist, Department of Diabetes, Diacare-Diabetes Care and Hormone Clinic, Ahmedabad, Gujarat, India

Email: banshisaboo@hotmail.com

Article information

Received date: 26/09/2025; **Accepted date:** 16/10/2025; **Published date:** 19/11/2025

Abstract

Background: Metabolic dysfunction-associated steatotic liver disease (MASLD), previously termed NAFLD, is a leading cause of chronic liver disease and is closely linked with Type 2 Diabetes Mellitus (T2DM). Both conditions share a bidirectional relationship, driven by insulin resistance, lipotoxicity, and systemic inflammation, which accelerates hepatic fibrosis and worsens glycaemic control. Individuals with T2DM are at higher risk of developing MASH, advanced fibrosis, and hepatocellular carcinoma, while MASLD increases the likelihood of incident diabetes. Globally, the prevalence of MASLD and T2DM is rising rapidly, highlighting a growing public health challenge. Lifestyle modification remains central to management, but pharmacologic agents such as GLP-1 receptor agonists, SGLT2 inhibitors, and PPAR agonists are increasingly used to target shared metabolic pathways. These advances underscore the need for integrated, mechanism-based strategies to improve outcomes in patients with coexisting MASLD and T2DM.

Materials and Method: This narrative review synthesizes current evidence on MASLD and T2DM, covering pathophysiology, screening, and management. A targeted literature search of PubMed, Scopus, and Google Scholar up to August 2025 was conducted, including clinical studies, trials, and guidelines, with data qualitatively summarized.

Conclusion: MASLD and T2DM frequently coexist, sharing mechanisms that worsen hepatic and systemic complications. Early detection, risk stratification, and integrated management, including lifestyle interventions and emerging pharmacologic therapies, are key to improving outcomes and preventing disease progression.

Keywords: MASLD, T2DM, insulin resistance, fibrosis assessment, lifestyle and pharmacologic interventions

Introduction

Metabolic dysfunction-associated steatotic liver disease (MASLD), previously termed non-alcoholic fatty liver disease (NAFLD), is increasingly recognized as the hepatic manifestation of systemic metabolic dysfunction and has emerged as one of the most prevalent causes of chronic liver disease worldwide. Its strong bidirectional relationship with T2DM underscores the need for integrated management strategies. Individuals with T2DM not only exhibit a higher prevalence of MASLD but are also more likely to develop its aggressive form, metabolic dysfunction-associated steatohepatitis (MASH), advanced fibrosis, and hepatocellular carcinoma (HCC).[1-3]

The pathophysiological interplay between MASLD and T2DM is mediated by insulin resistance, systemic inflammation, and lipotoxicity, creating a self-perpetuating cycle of metabolic dysfunction. T2DM accelerates hepatic fibrogenesis, while MASLD increases the risk of incident diabetes. Meta-analyses estimate that nearly two-thirds of individuals with T2DM have MASLD, with 31.6% progressing to MASH and up to 15% developing advanced fibrosis.[3,4] This coexistence also amplifies extra-hepatic complications, including cardiovascular disease, chronic kidney disease, and certain malignancies.[3]

The global epidemiological burden of both conditions continues to rise. Diabetes affects over 537 million adults worldwide, with projections reaching 783 million by 2045,[4] while MASLD currently affects more than 35% of the population

and is anticipated to increase to 55% by 2040.[4] Contributing factors include urbanization, sedentary lifestyles, dietary changes, and regional genetic predispositions. Prevalence estimates in India vary widely, ranging from 9% to 53%, depending on socioeconomic and geographic factors.[5]

Despite the magnitude of this dual epidemic, therapeutic options remain limited. Diabetes management primarily focuses on glycaemic control, whereas MASLD has few approved pharmacological interventions. Lifestyle modification remains the cornerstone of treatment for both conditions. The overlapping pathophysiology, however, has spurred interest in agents that target shared metabolic pathways. Drugs such as GLP-1 receptor agonists and SGLT2 inhibitors, initially developed for T2DM, are under investigation for their potential benefits in MASLD through improved insulin sensitivity, reduced hepatic steatosis, and mitigation of cardiovascular risk.[4]

Consensus on terminology and diagnostic criteria is also evolving. The adoption of MASLD over NAFLD emphasizes a non-stigmatizing, pathophysiology-based framework that incorporates metabolic risk factors, allowing for more accurate prevalence estimates and improved patient stratification. Evidence-based reviews are critical to refine diagnostic tools, validate non-invasive assessments, and clarify the influence of lifestyle and cardiometabolic factors on disease progression.[4]

Finally, the concept of T2DM remission defined as a sustained return to near-normal glycemia illustrates the potential for altering disease trajectory through intensive interventions such as weight loss and metabolic surgery.[6] In MASLD, similar advances in risk stratification and the development of dual-purpose therapeutic agents may shift management paradigms from mere control toward remission and prevention.

In summary, the intertwined epidemics of MASLD and T2DM represent both a clinical challenge and an opportunity for innovation. Early detection, multidisciplinary care, and emerging therapeutics that address shared pathophysiological mechanisms are essential to reducing liver-related and cardiometabolic complications.[1-6]

Given the rising prevalence of MASLD in patients with T2DM, the evolving understanding of disease mechanisms, and the rapid expansion of pharmacological and lifestyle-based interventions, there is a critical need to consolidate current evidence. This review aims to provide a comprehensive overview of contemporary management strategies, highlight emerging therapeutic approaches, and offer guidance on optimizing care for patients with MASLD and coexisting diabetes.

Materials and Methods

This narrative review summarizes current evidence on MASLD and T2DM, including pathophysiology, screening, and management strategies. A literature search was conducted in PubMed, Scopus, and Google Scholar using terms such as “MASLD,” “NAFLD,” “T2DM,” “insulin resistance,” “fibrosis,” and “GLP-1 receptor agonists.” Studies in adults reporting pathophysiological mechanisms, diagnostic tools, pharmacologic or lifestyle interventions, and clinical outcomes were included. Data from randomized trials, cohort studies, case series, real-world evidence, and clinical guidelines were extracted and synthesized qualitatively to provide an integrated overview of current knowledge and therapeutic approaches.

Discussion

Pathophysiological Link between T2DM and MASLD

Type 2 Diabetes Mellitus (T2DM), driven by insulin resistance and chronic hyperglycaemia, is a growing global health challenge. A frequent and clinically significant comorbidity is metabolic dysfunction-associated steatotic liver disease (MASLD), considered the hepatic manifestation of metabolic syndrome. Both conditions commonly coexist: most individuals with T2DM develop MASLD, while those with MASLD are at increased risk for T2DM onset. This bidirectional relationship is mediated by overlapping mechanisms, including lipotoxicity, systemic inflammation, and disrupted insulin signaling.[4]

Insulin Resistance as the Central Mechanism

Insulin resistance (IR) is the hallmark of both T2DM and MASLD. In the liver, impaired insulin receptor signalling through the IRS/PI3K/Akt pathway leads to reduced glycogen synthesis and increased gluconeogenesis, perpetuating hyperglycemia. In T2DM, poor glycaemic control (e.g., HbA1c >7.0%) has been linked with worsening hepatocyte ballooning and fibrosis severity, with each 1% rise in HbA1c increasing the likelihood of advancing to a higher fibrosis stage by 15%.[4]

Beyond glucose metabolism, IR contributes to hepatic fat accumulation. Excess free fatty acids (FFAs), released from adipose tissue due to impaired adiponectin signalling, are taken up by hepatocytes. When mitochondrial oxidative capacity is exceeded, incomplete β-oxidation produces reactive oxygen species (ROS) and toxic lipid intermediates, driving inflammation, hepatocyte injury, and fibrosis.[4]

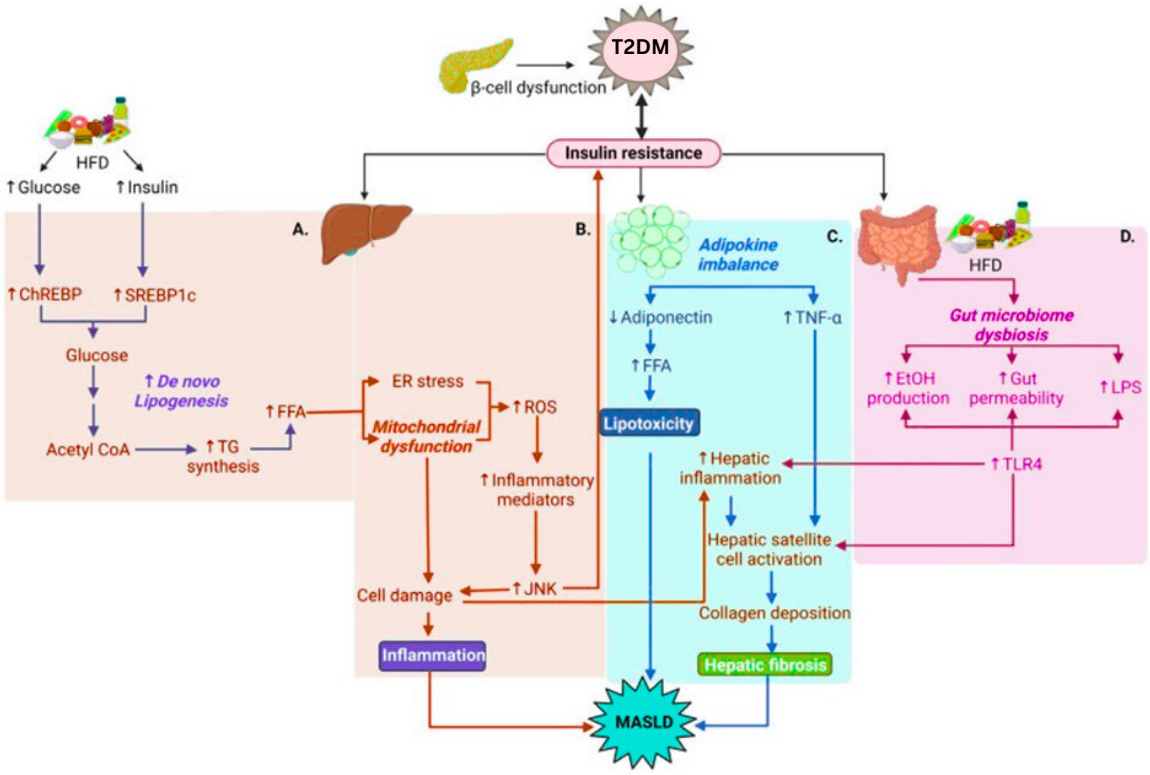

Fig 1. Relationship between T2DM and MASLD.[4]

Lipotoxicity, Adipose Dysfunction, and Systemic Inflammation

Hyperinsulinemia and hyperglycemia stimulate hepatic lipogenesis through transcription factors such as SREBP and ChREBP, promoting lipid droplet accumulation. Once hepatocellular lipid export and oxidation are overwhelmed, toxic metabolites including diacylglycerol and ceramides accumulate, activating ER stress pathways, inflammasomes, and fibrogenic signaling cascades.[3]

Adipose tissue dysfunction further amplifies this pathology. Expanded visceral adipose tissue secretes pro-inflammatory cytokines (TNF-α, IL-1, IL-6, MCP-1) and exhibits a pathogenic adipokine profile with elevated leptin, visfatin, chemerin, and reduced adiponectin. This imbalance contributes to hepatocellular injury, pancreatic β-cell decline, and cardiovascular complications in patients with both MASLD and T2DM.[3]

Role of the Gut–Liver Axis

Gut microbiota dysbiosis is increasingly recognized as a contributor to the MASLD–T2DM relationship. Altered microbial composition increases gut permeability, enabling endotoxin translocation that triggers hepatic toll-like receptor–mediated inflammation. MASLD patients commonly demonstrate reduced Bacteroidetes and increased Prevotella and Porphyromonas species. Ethanol-producing bacteria (e.g., *E. coli*, *Klebsiella*) raise systemic alcohol levels, while metabolites such as trimethylamine-N-oxide (TMAO) exacerbate metabolic dysfunction. In T2DM, reduced populations of *Akkermansia muciniphila* and *Bifidobacterium* are associated with impaired fatty acid oxidation and systemic inflammation, accelerating progression to fibrosis and even hepatocarcinogenesis.[3]

Bile Acid Pathways and Metabolic Crosstalk

Bile acid (BA) signalling, mediated by farnesoid X receptor (FXR) and TGR5, links glucose and lipid homeostasis to MASLD and T2DM progression. FXR activation reduces hepatic lipogenesis, enhances fatty acid oxidation, and suppresses gluconeogenesis, while TGR5 activation stimulates GLP-1 secretion, promoting insulin release and reducing glucagon.7 Altered BA composition in MASLD and T2DM patients disrupts these pathways. Interestingly, bariatric surgery enhances ileal BA exposure, stimulating FXR/TGR5 and contributing to improved insulin sensitivity and hepatic outcomes.[3]

Genetic Susceptibility

Genetic predisposition modifies individual risk for both diseases. Over 400 loci have been associated with T2DM, influencing β-cell function, insulin action, and adiposity. For MASLD, variants in genes such as PNPLA3, TM6SF2, MBOAT7, and HSD17B13 affect hepatocellular lipid handling, VLDL secretion, and fibrogenesis. These variants increase lipotoxicity, hepatic insulin resistance, and progression to advanced liver disease in genetically susceptible individuals.[3]

The pathophysiological relationship between T2DM and MASLD is underpinned by a complex network of insulin resistance, lipotoxicity, adipose tissue dysfunction, gut microbiota alterations, bile acid signalling, and genetic predisposition. Together, these mechanisms explain the frequent coexistence and mutual acceleration of both disorders, highlighting the need for therapeutic approaches targeting shared metabolic pathways.[3,4]

Screening for MASLD in T2DM

The strong association between T2DM and progressive hepatic fibrosis highlights the need for timely screening, given its impact on mortality and liver-related complications. Several non-invasive approaches, including serum-based tests and imaging modalities, are available to assess fibrosis risk in this population. Among these, vibration-controlled transient elastography (VCTE) is regarded as one of the most reliable tools.[7]

A stepwise strategy is often applied to stratify risk, beginning with the Fibrosis-4 (FIB-4) index, followed by VCTE in individuals with FIB-4 scores above 2.67. Nonetheless, the accuracy of individual non-invasive tests (NITs)—such as FIB-4, the NAFLD fibrosis score (NFS), and the aspartate aminotransferase-to-platelet ratio index (APRI)—remains limited in patients with T2DM.[7]

In a prospective study of 96 biopsy-confirmed MASLD patients (50 followed for 12 months), liver stiffness (LS) by elastography, PRO-C3, and multiple NITs (ADAPT, FIB-4, NFS, APRI) were compared. LS demonstrated the best diagnostic performance for advanced fibrosis (AUROC 0.82, threshold 9.4 kPa), with ADAPT showing the highest accuracy among the NITs (AUROC 0.80, cut-off 5.02, sensitivity 62%, specificity 89%). No significant difference was observed between LS and ADAPT (DeLong test, $p = 0.348$). Over the follow-up period, LS showed a slight reduction, whereas PRO-C3 and ADAPT increased significantly, suggesting progression of fibrosis. Other markers (FIB-4, NFS, APRI) remained unchanged.[7]

Similarly, a cross-sectional study of 213 patients reported AUCs of 0.85 (FIB-4), 0.86 (APRI), and 0.64 (NFS) for detecting advanced fibrosis in T2DM, all lower in accuracy compared with N-terminal propeptide of type 3 collagen, a direct marker of fibrogenesis. Another cohort analysis found the AUC of FIB-4 to be markedly lower in patients with T2DM (0.653) compared with those without diabetes (0.826).[7]

To address these limitations, newer diagnostic models have been introduced. The Fibrotic MASH Index, for example, achieved an AUC of 0.89 in T2DM, outperforming FIB-4 (AUC 0.67), with consistent accuracy across different disease durations and HbA1c levels. Other emerging assays, including the Enhanced Liver Fibrosis (ELF) panel, FibroSpect, and the FIB-C3 model, integrate biomarkers of fibrogenesis and may further improve detection. However, their utility still requires validation specifically in diabetic cohorts.[7]

Recent clinical practice guidelines advocate routine screening for liver fibrosis in individuals with T2DM. Yet, uncertainties persist regarding the most effective NIT combinations and the optimal thresholds to apply. For these strategies to be integrated into real-world care, they must be validated within structured pathways in both primary care and diabetes-focused settings. Additionally, many studies fail to clearly distinguish fibrosis due to MASLD/MASH from fibrosis caused by other conditions, which can introduce bias into risk assessment and subsequent management.[7]

Pharmacological Therapies with Evidence in MASLD and Diabetes

Metabolic dysfunction-associated steatotic liver disease (MASLD), previously termed non-alcoholic fatty liver disease (NAFLD), has emerged as a major global public health concern, particularly in populations with rising rates of obesity and T2DM. It encompasses a spectrum ranging from simple steatosis to metabolic dysfunction-associated steatohepatitis (MASH) with varying degrees of fibrosis, increasing the risk of progression to cirrhosis, hepatocellular carcinoma, and cardiovascular complications. While lifestyle modification remains the cornerstone of management, pharmacologic therapies are increasingly essential for patients with progressive disease or higher risk of complications.

Therapeutic strategies for MASLD in patients with T2DM leverage agents initially developed for diabetes and obesity, such as glucagon-like peptide-1 receptor agonists (GLP-1 RAs), sodium-glucose cotransporter 2 inhibitors (SGLT2is), and peroxisome proliferator-activated receptor (PPAR) agonists—as well as liver-specific drugs including thyroid hormone receptor-β agonists (resmetirom), fibroblast growth factor (FGF) analogues, farnesoid X receptor (FXR) agonists, and acetyl-CoA carboxylase (ACC) inhibitors. These agents target key pathogenic mechanisms in MASLD, including hepatic steatosis, insulin resistance, inflammation, and fibrosis. Recent advances have enabled histological improvements in steatohepatitis and fibrosis, particularly with GLP-1 RAs, PPAR agonists, and thyroid hormone receptor-β agonists, while SGLT2 inhibitors and combination therapies provide additional metabolic, cardiovascular, and renal benefits. The evolving pharmacologic landscape underscores a shift toward mechanism-based, disease-modifying strategies for MASLD in patients with diabetes, with combination therapies offering potential to address multiple pathogenic pathways simultaneously.

PPAR Agonists in MASLD/MASH

Pioglitazone, a peroxisome proliferator–activated receptor gamma (PPARγ) agonist, enhances insulin sensitivity, modulates glucose and lipid metabolism, reduces hepatic and intestinal inflammation, and redistributes adipose tissue by lowering the visceral-to-subcutaneous fat ratio while increasing circulating adiponectin levels. Multiple randomized controlled trials (RCTs) and meta-analyses have demonstrated that pioglitazone can induce resolution of NASH and improve fibrosis, even in patients without diabetes, although weight gain and fluid retention remain notable adverse effects. A deuterium-stabilized R-enantiomer (PXL065) has been developed to retain non-genomic benefits while limiting weight gain and edema, showing encouraging results in phase 2 trials.[8]

Real-world evidence also supports these findings; for example, a retrospective study of 65 Brazilian patients treated with pioglitazone for 1–10 years reported significant improvements in aminotransferases, GGT, and steatosis assessed by CAP, representing the first Brazilian cohort evaluating pioglitazone in MASLD.[9] Similarly, Cusi et al. reported 47% NASH resolution with pioglitazone in patients with and without diabetes, accompanied by reductions in liver enzymes, which, while not definitive markers of disease severity, have been associated with histological improvement.[9–11]

Meta-analyses indicate an odds ratio (OR) of 3.65 (95% CI 2.32–5.74) for NASH resolution and an OR of 10.17 (95% CI 2.8–36.5) for regression of advanced fibrosis (F3–F4) compared with controls. Despite these outcomes, pioglitazone is not formally approved for MASLD; U.S. guidance permits its use in biopsy-confirmed MASH regardless of diabetes status, whereas European guidelines consider it safe in non-cirrhotic MASH but do not recommend it as a specific therapy.[11]

Other PPAR agonists, including rosiglitazone, lanifibranor, and saroglitazar, have shown potential in MASLD/MASH management. Lanifibranor, a pan-PPAR agonist, significantly reduced SAF-A scores in a phase 2b trial and improved insulin resistance across hepatic, muscle, and adipose tissues, while saroglitazar, a PPAR-α/γ agonist, improved both histological and metabolic markers.[7]

Overall, thiazolidinediones and other PPAR-targeting agents effectively modulate metabolic and inflammatory pathways in MASLD, with pioglitazone consistently demonstrating MASH resolution and improvements in liver inflammation and steatosis.[7]

Saroglitazar, a dual PPAR-α/γ agonist, is currently the only MASLD-approved therapy in India, demonstrating improvements in NAFLD Activity Score without worsening fibrosis.[9] It exerts its effects through multiple metabolic pathways, enhancing insulin sensitivity, modulating adiponectin and leptin levels, promoting fatty acid β-oxidation, and reducing lipotoxicity-mediated oxidative stress. Clinical and preclinical studies have shown that saroglitazar improves lipid profiles, achieves optimal glycaemic control, and reduces liver enzymes in patients with diabetic dyslipidaemia, MASLD,

and T2DM. Notably, its benefits extend to non-diabetic MASLD patients and those with compensated cirrhosis, highlighting its broad therapeutic potential.[12]

Real-world longitudinal evidence further supports its efficacy. In a 2-year case series of four adult T2DM patients with imaging-confirmed MASLD, saroglitazar 4 mg once daily, in combination with semaglutide (7–14 mg as tolerated), led to marked reductions in HbA1c, triglycerides, ALT, and AST. Three patients showed improvements in hepatic steatosis (S2–S3 to S0–S1) and fibrosis (F2–F3 to F0–F1), with one patient demonstrating complete regression from advanced fibrosis (F3) to no fibrosis (F0).[13] Another prospective case series of eight T2DM patients with MASLD treated with saroglitazar 4 mg daily for 32 weeks reported significant reductions in HbA1c, triglycerides, ALT, CAP, and LSM scores, confirming its beneficial effects on glycemic-lipid control and liver health.[13]

These studies collectively indicate that saroglitazar can address both metabolic and hepatic derangements in MASLD, offering potential disease-modifying benefits in patients with T2DM. Its favorable safety profile, broad applicability across diabetic and non-diabetic MASLD populations, and ability to improve fibrosis and steatosis support its role as a promising therapeutic option, pending further confirmatory trials.[12–14]

Efficacy of GLP-1 and Multi-Agonists in MASLD/MASH

Glucagon-like peptide-1 receptor agonists (GLP-1 RAs), synthetic analogs of endogenous GLP-1, enhance insulin secretion, inhibit glucagon release, suppress appetite, and delay gastric emptying. Their benefits in hepatic steatosis are largely attributed to weight loss and systemic metabolic improvements rather than direct hepatic actions. Among the first agents evaluated in MASLD/MASH were liraglutide and semaglutide, both approved for T2DM and obesity, which demonstrated significant histologic resolution of steatohepatitis in phase 2 and 3 trials, though consistent fibrosis improvement remains limited. In the LEAN trial, liraglutide achieved MASH resolution in 39% of patients versus 9% with placebo, with reduced fibrosis progression but no significant fibrosis reversal. Semaglutide showed superior efficacy in glycemic control, weight reduction, and MASH resolution. A phase 2 trial in patients with F1–F3 fibrosis reported resolution rates up to 59% compared with 17% for placebo, while an interim phase 3 analysis revealed 63% resolution and 37% fibrosis improvement versus 34% and 23% with placebo, respectively. However, studies in cirrhotic patients did not show significant histologic benefit. Genetic variants in *GLP1R* and *ARRB1*, which influence glycemic responses, have not yet been linked to variable outcomes in MASLD. Beyond GLP-1 monotherapy, incretin-based combination agents are under active investigation. Tirzepatide, a dual GLP-1/GIP agonist, achieved greater weight loss and HbA1c reduction than GLP-1 RAs, and in a phase 2 trial, produced MASH resolution in up to 62% of patients, with fibrosis improvement in approximately 51–55%, although these fibrosis data require further validation. Survodutide, a GLP-1/glucagon co-agonist, showed notable improvements in MASH resolution (up to 62% vs. 14% for placebo) and modest fibrosis benefit, while pemvidutide, another GLP-1/glucagon co-agonist, remains under evaluation. Retatrutide, a triple GLP-1/GIP/glucagon agonist, achieved dramatic reductions in liver fat (up to 82%) and body weight (24.2% at 48 weeks) in early trials; phase 3 biopsy-based outcomes are awaited, though preliminary data suggest potential to overcome genetic and metabolic barriers in MASLD management. Collectively, incretin-based therapies demonstrate consistent benefits in weight reduction, glycemic control, and hepatic fat reduction, with encouraging but variable effects on fibrosis—positioning them as promising therapeutic candidates for MASLD/MASH.[7,11,15]

The U.S. Food and Drug Administration (FDA) has granted accelerated approval to semaglutide (Wegovy) 2.4 mg once weekly for adults with metabolic dysfunction-associated steatohepatitis (MASH) and moderate-to-advanced liver fibrosis, making it the first GLP-1 receptor agonist approved for this indication.[16,17]

Wegovy, initially approved in 2017 for obesity and overweight, also reduces cardiovascular (CV) events such as myocardial infarction in at-risk individuals. MASH affects approximately 6% of U.S. adults (≈14.9 million people) and continues to rise in prevalence.[16] Semaglutide is not indicated for cirrhotic patients and should be used alongside a reduced-calorie diet and increased physical activity. Semaglutide now joins resmetirom (Rezdiffra), a thyroid hormone receptor-β selective agonist, as the only approved therapies for MASH with fibrosis.[17]

Approval was based on part 1 of the phase 3 ESSENCE trial (NCT04822181), which evaluated semaglutide in adults with MASH and stage F2–F3 fibrosis.[17] After 72 weeks, 63% of participants receiving semaglutide achieved resolution of steatohepatitis without worsening fibrosis, compared with 34% in the placebo group (difference = 29 percentage points; 95% CI, 21–36). Improvement in fibrosis without worsening steatohepatitis occurred in 37% of the semaglutide arm versus 22% of the placebo arm (difference = 14 percentage points; 95% CI, 8–21). Furthermore, 33% of Semaglutide-treated participants

achieved both MASH resolution and fibrosis improvement, compared with 16% receiving placebo (difference = 17 percentage points; 95% CI, 10–23). About 88% of patients maintained the target 2.4 mg dose through week 72.22 This conditional approval marks a pivotal milestone for the MASH community, expanding therapeutic options for a population with limited pharmacologic interventions.[17]

Semaglutide, a long-acting GLP-1 RA with proven glycemic and weight-reducing efficacy, has drawn attention for its pleiotropic anti-inflammatory and antifibrotic properties, which may confer additional hepatic benefits. Clinical evidence demonstrates improvements in liver histology, reductions in hepatic fat content, and favorable changes in inflammatory markers. The landmark phase 2 trial of semaglutide in NASH established significant resolution of steatohepatitis without fibrosis worsening compared with placebo, while the STEP program confirmed substantial weight loss benefits—an indirect but crucial factor in MASLD management. More recently, ESSENCE data confirmed that semaglutide 2.4 mg leads to both fibrosis improvement and MASH resolution in patients with stage F2–F3 fibrosis, underscoring its therapeutic promise.[18]

A large real-world retrospective cohort of MASLD patients followed for up to 8 years demonstrated that semaglutide therapy is associated with improved overall survival and reduced liver-related complications. Propensity score matching across 34 baseline parameters minimized confounding by demographics, comorbidities, and liver disease severity. The absolute mortality reduction of 1.11% at 1 year and 2.39% at 5 years reflects substantial clinical benefit, especially in non-cirrhotic, ambulatory patients. These outcomes are consistent with or exceed those seen in other metabolic intervention trials, reinforcing semaglutide's potential to improve long-term MASLD outcomes. Metabolic and cardiovascular findings from this cohort align with prior GLP-1 RA studies, including SUSTAIN-6 and PIONEER 6, which established cardiovascular benefits in diabetic populations, as well as trials of liraglutide showing similar effects. Semaglutide treatment in MASLD was associated with a 44% relative risk reduction in cardiovascular events during follow-up.[18]

SGLT2 Inhibitors in MASLD: Metabolic and Hepatic Outcomes

SGLT2 inhibitors, including empagliflozin, dapagliflozin, canagliflozin, and ertugliflozin, improve glycemic control, reduce visceral adiposity, elevate adiponectin, lower uric acid, decrease systemic inflammation, and confer consistent cardiovascular and renal benefits. Although histological evidence in MASLD is limited, multiple randomized controlled trials (RCTs) and imaging-based studies have demonstrated reductions in hepatic fat, aminotransferase levels, body weight, and HbA1c.[15,19] In patients with biopsy-proven MASLD and type 2 diabetes, tofogliflozin showed trends toward greater improvements in steatosis, hepatocellular ballooning, lobular inflammation, and fibrosis compared with glimepiride over 48 weeks, along with superior reductions in AST, γ-glutamyl transferase, fibrosis-4 index, and body weight. Combination therapy with low-dose pioglitazone and an SGLT2 inhibitor, such as empagliflozin, has demonstrated synergistic reductions in liver fat, stiffness, and fibrosis indices, mediated in part by increased adiponectin and reduced hepatic free fatty acid influx.[20] Empagliflozin and dapagliflozin have shown improvements in liver steatosis and ALT/GGT levels, although fibrosis improvement is modest, and dapagliflozin has been associated with serious renal adverse effects. Large population studies and systematic reviews support the role of SGLT2 inhibitors in reducing liver-related adverse outcomes, likely through both weight- and glucose-lowering effects, as well as potential direct actions including decreased hepatic inflammation, ketogenesis induction, glucagon elevation, and enhanced adiponectin levels.[7]

DEAN Trial (Dapagliflozin Efficacy and Action in NASH)

In the DEAN trial, 48 weeks of treatment with dapagliflozin resulted in a significant improvement in MASH without worsening of fibrosis compared with placebo. The findings also demonstrated that dapagliflozin treatment provided benefits in terms of MASH resolution without worsening fibrosis and fibrosis improvement without worsening MASH among participants with biopsy-confirmed disease, including those with stage 2 or 3 fibrosis. These outcomes suggest that dapagliflozin may influence key pathological aspects of MASH by improving both steatohepatitis and fibrosis.[21]

In this study, 53% of participants receiving dapagliflozin achieved MASH improvement without fibrosis worsening, compared with 30% in the placebo group. Notably, dapagliflozin treatment produced a placebo-subtracted effect of 15% for MASH resolution without worsening of fibrosis and 25% for fibrosis improvement without worsening of MASH. These confirmatory secondary endpoints align with the criteria proposed by the U.S. Food and Drug Administration (FDA) as being reasonably predictive of long-term clinical benefit in MASH. Furthermore, the results indicated that dapagliflozin conferred

similar benefits on MASH improvement and resolution irrespective of participants' obesity or diabetes status, or the severity of their MASH.[21]

Consistent with earlier studies, the DEAN trial also showed that the SGLT2 inhibitor dapagliflozin improved several metabolic parameters, such as body weight, waist circumference, visceral fat, glucose, insulin resistance, lipid profile, and blood pressure, all of which are closely linked to MASH. Moreover, the findings suggested that the beneficial effects of dapagliflozin on MASH improvement and resolution without fibrosis worsening were largely mediated through weight loss.[21]

THR-β Agonists in MASLD/MASH: Targeted Hepatic Therapy

In March 2024, the U.S. Food and Drug Administration (FDA) granted accelerated approval to resmetirom, a selective thyroid hormone receptor-β (THR-β) agonist, as the first pharmacologic therapy for non-cirrhotic metabolic dysfunction-associated steatohepatitis (MASH) with moderate to advanced fibrosis.[18]

Resmetirom exerts its action through liver-selective activation of THR-β, thereby enhancing mitochondrial fatty acid oxidation, reducing de novo lipogenesis, promoting cholesterol efflux, and suppressing pro-inflammatory and pro-fibrotic mediators such as transforming growth factor-β (TGF-β). This targeted mechanism improves hepatic steatosis, necroinflammatory activity, and fibrosis while minimizing systemic thyromimetic effects, distinguishing resmetirom from earlier, non-selective thyroid analogues.[17]

In early-phase clinical studies, resmetirom demonstrated favorable pharmacodynamic and safety profiles. Phase 1 trials showed dose-dependent reductions in low-density lipoprotein (LDL) cholesterol (up to 30%), non-high-density lipoprotein (non-HDL) cholesterol, apolipoprotein B, and triglycerides (up to 60%), with predominantly mild gastrointestinal adverse events and no significant alterations in thyroid function or cardiac markers. Phase 2 studies in biopsy-confirmed MASH demonstrated a 32.9% reduction in hepatic fat, accompanied by improvements in aminotransferases, non-invasive fibrosis biomarkers, NAFLD activity score (NAS), and atherogenic lipid parameters, collectively supporting both hepatic and cardiometabolic benefits.[7]

Resmetirom's pharmacologic selectivity for THR-β avoids thyrotoxic effects mediated through THR-α, thereby conferring a liver-specific metabolic advantage. Other THR-β agonists, including sobetirome, eprotirome, and VK2809, have also demonstrated reductions in hepatic triglycerides and steatosis in clinical and preclinical studies, although effects on insulin sensitivity and glycaemic control have been variable.[7] Resmetirom is generally well tolerated, with mild gastrointestinal adverse effects and no evidence of weight gain or fluid retention. It is currently approved for adults with non-cirrhotic MASH and moderate to advanced fibrosis, in combination with lifestyle modification.[8]

The pivotal Phase 3 MAESTRO program (MAESTRO-NAFLD-1, MAESTRO-NAFLD-OLE, and MAESTRO-NASH) evaluated once-daily resmetirom at 80 mg and 100 mg in a diverse MASH population. At week 52, MASH resolution without worsening of fibrosis was achieved in 25.9% (80 mg) and 29.9% (100 mg) of participants, compared with 9.7% for placebo ($p < 0.0001$ for both). Improvement in fibrosis by ≥1 stage occurred in 24.2% and 25.9% of participants receiving 80 mg and 100 mg, respectively, versus 14.2% with placebo ($p < 0.0001$ for both). The treatment effect (active minus placebo) was 16.4% and 20.7% for MASH resolution and 10.2% and 11.8% for fibrosis regression with 80 mg and 100 mg, respectively—corresponding to approximately two in ten patients achieving MASH resolution and one in ten demonstrating fibrosis improvement.[19]

MAESTRO-NASH was the first Phase 3 trial in MASH to meet both histologic endpoints required for conditional regulatory approval, establishing the feasibility of large-scale, biopsy-driven efficacy assessment in this population. The ongoing MAESTRO-NASH OUTCOMES study is designed to evaluate long-term efficacy over 54 months, including progression to cirrhosis, all-cause mortality, and liver-related events (LREs), while post-approval (Phase 4) investigations will assess cardiovascular and oncologic outcomes.[19]

As of late 2025, Rezdiffra (resmetirom) and Wegovy (semaglutide) remain the only FDA-approved pharmacotherapies for MASH, while no treatment options are available for early-stage MASLD.[19]

Future research is focused on evaluating combination regimens (e.g., with incretin-based agents) and expanding therapeutic use in patients with compensated cirrhosis, who represent the highest unmet need and greatest disease burden. Results from the MAESTRO-NASH OUTCOMES program are anticipated to further delineate resmetirom's long-term hepatic and cardiometabolic benefits in MASLD/MASH populations.[7]

FGF-21 Analogues and ACC Inhibitors: Modulating Hepatic Lipid Metabolism and Fibrosis

Fibroblast growth factor 21 (FGF-21) analogues, including pegozafermin, efruxifermin, and pegbelfermin, have emerged as promising therapies for MASLD and MASH by targeting FGF receptors (FGFR1–3) and the β-klotho co-receptor to enhance energy expenditure, improve insulin sensitivity, modulate dyslipidaemia, and increase adiponectin levels. In phase 2b trials, pegozafermin led to MASH resolution in 23–37% of patients and fibrosis improvement in 25–44%, without significant changes in body weight or HbA1c. Efruxifermin demonstrated similar improvements in MASH activity and fibrosis. Meta-analyses of five phase 2 trials confirmed that FGF-21 analogues consistently produced higher rates of MASH resolution and fibrosis improvement compared with placebo.[11]

Acetyl-CoA carboxylase (ACC) inhibitors, such as PF-05221304, act by suppressing hepatic lipogenesis, thereby reducing steatosis, inflammation, and fibrosis. Phase 2a studies demonstrated 50–65% reductions in liver fat, with additive benefits when combined with complementary agents like PF-06865571.[7]

Fibroblast growth factor 19 (FGF19) analogues, including aldafermin and NGM282, provide an alternative pathway by promoting hepatocyte proliferation and repair, reducing liver fat, and showing trends toward fibrosis improvement in early-phase trials.[7]

FXR Agonists: Targeting Metabolic and Inflammatory Pathways in MASLD/MASH

Farnesoid X receptor (FXR) agonists represent another therapeutic class targeting metabolic and inflammatory pathways in MASLD/MASH. Obeticholic acid (OCA) improves insulin sensitivity and reduces inflammatory markers, while newer FXR modulators such as EDP-305, MET409, tropifexor, and nidufexor have demonstrated reductions in ALT, liver fat, steatosis, and inflammation in phase 2 studies. However, adverse effects such as pruritus have been noted with some agents. In addition, combination therapy with cilofexor and firsocostat in patients with advanced fibrosis or compensated cirrhosis improved NAS, liver biochemistry, and fibrosis markers compared with placebo.[7]

Gut Microbiome Modulators: Emerging Adjunctive Therapies

Emerging therapies targeting the gut–liver axis aim to modulate microbiome dysbiosis, which contributes to increased gut permeability and hepatic inflammation. Preliminary interventions include IMM-124E, a bovine colostrum-derived product, which reduced AST and ALT levels over 24 weeks, and faecal microbiota transplantation (FMT), though clinical evidence remains limited.[7]

Pharmacologic management of MASLD in patients with T2DM has evolved to encompass therapies that target both metabolic and hepatic derangements. Agents such as PPAR agonists, GLP-1 receptor agonists, SGLT2 inhibitors, and thyroid hormone receptor-β agonists have demonstrated efficacy in improving liver steatosis, inflammation, and, in some cases, fibrosis, while also providing glycemic, cardiovascular, and renal benefits. Emerging therapies—including FGF analogues, ACC inhibitors, FXR agonists, and gut microbiome modulators—offer additional mechanisms to address key pathogenic pathways, including insulin resistance, lipotoxicity, and hepatic inflammation. Real-world evidence and clinical trials highlight the potential of combination strategies to achieve superior outcomes by targeting multiple pathways simultaneously.

Individualized therapy should consider disease severity, fibrosis stage, comorbidities, and patient-specific metabolic risk. While lifestyle modification remains foundational, multi-targeted pharmacologic approaches provide a mechanism-based, disease-modifying strategy in MASLD, particularly for patients with T2DM and advanced fibrosis. Ongoing studies and novel agents promise further expansion of effective treatment options, with the goal of improving both hepatic and systemic outcomes in this high-risk population.

Lifestyle and Weight-Loss Interventions for MASLD Management

Weight Loss as the Cornerstone

Weight loss remains the primary intervention for managing MASLD. According to the 2024 European Association for the Study of the Liver (EASL) guidelines, a reduction of ≥5% of body weight decreases liver fat, 7–10% improves liver inflammation, and ≥10% is required for fibrosis regression. Even in adults without overweight or obesity, modest weight

loss of 3–5% is recommended to reduce hepatic lipid content and metabolic risk. Achieving and maintaining these targets, however, is challenging, as long-term adherence to behavioural interventions often declines, with most weight loss occurring within the first six months and an average net loss of ~5% by 12–24 months, often accompanied by partial return of liver fat and stiffness.[2]

Dietary Interventions

Caloric restriction and high-quality diets are effective non-pharmacologic strategies to improve MASLD biomarkers, including liver enzymes, steatosis, MASH, and fibrosis. A deficit of ~500 kcal/day or a total intake of 1200–1500 kcal/day is recommended for weight reduction. Diets rich in whole grains, vegetables, fruits, legumes, nuts, olive oil, and fish, such as the Mediterranean diet have demonstrated benefits in reducing hepatic fat and providing cardiovascular protection.[22,23]

Saturated fats, particularly from red and processed meats, and added sugars, especially fructose, should be limited, as they promote intrahepatic triglyceride accumulation and progression to MASH. Coffee consumption, with or without caffeine, may offer protective effects against MASLD.[23]

For patients with sarcopenia or advanced fibrosis, protein intake of 1.2–1.5 g/kg and shorter overnight fasting periods are advised.[19] In India, dietary patterns high in refined carbohydrates and low in protein and fiber highlight the need for culturally tailored interventions emphasizing plant-based proteins and healthy fats.[22]

Physical Activity

Sedentary behaviour independently predicts MASLD progression. Regular physical activity improves hepatic and peripheral insulin sensitivity, reduces free fatty acid flux to the liver, and decreases de novo lipogenesis. Patients are advised to engage in ≥150 minutes/week of moderate-intensity or 75 minutes/week of vigorous-intensity activity. Aerobic, resistance, high-intensity interval training, or combined approaches have all been shown to reduce liver fat, even without significant weight loss. Exercise also enhances gut microbiota composition, bile acid metabolism, and cardiometabolic outcomes, reinforcing its systemic benefits.[2,23]

Behavioural and Support-Based Interventions

Long-term adherence to lifestyle interventions is enhanced by structured behavioural strategies, including self-monitoring, goal setting, stimulus control, and cognitive-behavioural approaches addressing emotional and environmental triggers. Individualized medical visits facilitate early detection, monitoring, and management of comorbidities, while group-based programs and peer support foster accountability, improve adherence, and can be delivered virtually. Studies have shown that both group-based and internet-based interventions can achieve significant weight loss, reduce liver fat, and lower diabetes risk, with comparable effectiveness.[19]

Digital and Mobile Interventions

Web-based programs and mobile applications provide scalable, personalized approaches for MASLD management. Interventions using smartphone apps or social media platforms have demonstrated improved weight loss, reductions in liver enzymes, and favourable changes in liver stiffness, highlighting their potential as adjuncts to conventional care.[19]

Surgical Interventions

Bariatric surgery, including Roux-en-Y gastric bypass (RYGB), is effective in achieving substantial and sustained weight loss and improving obesity-related comorbidities such as T2DM, hypertension, dyslipidaemia, and obstructive sleep apnoea. It also reduces hepatic steatosis, inflammation, and fibrosis, with studies reporting resolution of steatosis in 91.6%, steatohepatitis in 81.3%, and fibrosis in 65.5% of patients at one-year post-surgery. Improvements in liver inflammation markers such as MCP-1, IL-8, TGF-β1, TIMP-1, α-SMA, and collagen-a1 (I) have been documented, emphasizing the metabolic and hepatic benefits of surgical weight reduction.[23]

Gaps and Future Directions

Key gaps in managing MASLD in patients with T2DM include limited awareness among clinicians and patients, delayed diagnosis, fragmented multidisciplinary care, inconsistent adherence to guidelines, and inadequate training of primary care providers. The lack of structured screening pathways and systematic risk stratification often results in missed opportunities for early intervention. Addressing these challenges requires enhanced education and awareness, routine implementation of non-invasive fibrosis and steatosis assessments, development of coordinated interprofessional care models, and optimized use of lifestyle interventions and emerging pharmacologic therapies. Emphasis on early detection and integrated management is critical to reduce progression to advanced liver disease and associated cardiometabolic complications.

Conclusion

MASLD and T2DM frequently coexist, sharing complex pathophysiological mechanisms that amplify hepatic and systemic complications. Early detection, risk stratification, and integrated management—encompassing lifestyle modification, weight loss, and pharmacologic therapies targeting shared metabolic pathways—are essential to improve outcomes. Emerging agents, including PPAR agonists, GLP-1 receptor agonists, SGLT2 inhibitors, THR-β agonists, and FGF analogues, offer promising disease-modifying potential, particularly when combined with individualized lifestyle interventions. Continued research, real-world evidence, and mechanism-based strategies are crucial to optimize care, prevent progression, and reduce cardiometabolic and liver-related morbidity in this high-risk population.

Box: Approved Pharmacotherapies for MASH/MASLD (as of late 2025)

USFDA has approved **resmetirom (Rezdiffra)** and **semaglutide (Wegovy)** for the treatment of MASH with moderate-to-advanced fibrosis.[19,16]

The **CDSCO** has approved **saroglitazar** for the treatment of MASH (formerly NASH). No therapies are approved for early-stage MASLD.[24]

References

1. Isaacs SD, Farrelly FV, Brennan PN. Role of anti-diabetic medications in the management of MASLD. *Frontline Gastroenterology.* 2025;16:239–49.
2. Ntikoudi A, Papachristou A, Tsalkitzi A, Margari N, Evangelou E, Vlachou E. Metabolic-Associated Steatotic Liver Disease (MASLD) and Type 2 Diabetes: mechanisms, diagnostic approaches, and therapeutic interventions. *Diabetology.* 2025, 6(4), 23.
3. Barrera F, Uribe K, Olaveres N, Huerta P, Cabrera D, Romero-Gomez M. The Janus of a disease: diabetes and metabolic dysfunction-associated fatty liver disease. *Annals of Hepatology.* 2024:1–10.
4. Ferdous SE, Ferrell JM. Pathophysiological relationship between type 2 diabetes mellitus and metabolic dysfunction-associated steatotic liver disease: novel therapeutic approaches. *Int J Mol Sci.* 2024;25(16):8731.
5. Mohan V, Joshi S, Kant S, Shaikh A, Sreenivasa Murthy L, Saboo B, Singh P, Sosale AR, Sanyal D, Shanmugasundar G, Singh SK, Pancholia AK, Mondal S, George R, Jaiswal A, Jhaveri K. Prevalence of metabolic dysfunction-associated steatotic liver disease: mapping across different Indian populations (MAP Study). *Diabetes Ther.* 2025:16(7):1435–50.
6. Riddle MC, Cefalu WT, Evans PH, Gerstein HC, Nauck MA, Oh WK, Rothberg AE, le Roux CW, Rubino F, Schauer P, Taylor R, Twenefour D. Consensus report: definition and interpretation of remission in Type 2 diabetes. *Diabetes Care*. 2021;44(10):2438–44.
7. Knezovic E, Hefer M, Blazanovic, Petrovic A, Tomicic V, Srb N, Smolic R, Smolic M. Drug Pipeline for MASLD: What Can Be Learned from the Successful Story of Resmetirom. *Curr. Issues Mol. Biol.* 2025; 47(3), 154.
8. Ciardullo S, Muraca E, Vergani M, Invernizzi P, Perseghin G. Advancements in pharmacological treatment of NAFLD/MASLD: a focus on metabolic and liver-targeted interventions. *Gastroenterol Rep (Oxf).* 2024;12:goae029.

9. Adinolfi LE, Marrone A, Rinaldi L, Nevola R, Izzi A, Sasso FC. Metabolic dysfunction-associated steatotic liver disease (MASLD): a systemic disease with a variable natural history and challenging management. *Explor Med.* 2025;6:1001281.
10. Pereira ISA, de Oliveria ABS, Zitelli PMY, Barboeri LA, Cardoso AC, de Sousa Dias Monteiro MJ, de Oliveira JS, Stefano JT, Altikees R, Reis ALG, de Figueiredo Mendes C, Couto C, Leite NC, Villela-Nogueira CA, Oliveira CP, Pessoa MG. Long-term pioglitazone use in MASLD patients: insights from a multicentric preliminary study. *Clinics*. 2025;80:1–5.
11. Stefan N, Yki-Jarvinen Hannele, Neuschwander-Tetri BA. Metabolic dysfunction-associated steatotic liver disease: heterogeneous pathomechanisms and effectiveness of metabolism-based treatment. *Lancet Diabetes Endocrinol*. 2025;13:134–48.
12. Das S, Gupta S, Lathia T, Swain J, Mittal S, Kumar S, Dm M, Garg N, Teja R, Beatrice A, Sooragonda BG, Mohd Razi S, Jaiswal A, Jhaveri KS, Shah S, Verma G. Evaluation of effectiveness and tolerability of saroglitazar in metabolic disease patients of India: a retrospective, observational, electronic medical record-based real-world evidence study. *Cureus*. 2025;17(7):e89028.
13. Dang N, Wairokpam T. Clinical case series on assessment of therapeutic efficacy of saroglitazar in MASLD patients. *Asian Journal of Medicine and Health.* 2024;22 (9):11–8.
14. Dang N, Jain M. Long-term impact of saroglitazar on advanced hepatic fibrosis and metabolic dysfunction in MASLD patients: a two-year case series. *Asian Journal of Case Reports in Medicine and Health*. 2025;8 (1):260–65.
15. Brouwers B, Rao G, Tang Y, Rodrigues A, Glass LC, Hartman ML. Incretin-based investigational therapies for the treatment of MASLD/MASH. *Diabetes Research and Clinical Practice*. 2024:1–11.
16. FDA Approves Treatment for serious liver disease known as 'MASH'. FDA. Accessed on 14 Oct 2025. Available at: https://www.fda.gov/drugs/news-events-human-drugs/fda-approves-treatment-serious-liver-disease-known-mash#:~:text=The%20U.S.%20Food%20and%20Drug,and%20its%20prevalence%20is%20expanding
17. FDA approves Semaglutide for MASH with fibrosis. *AJMC*. Accessed on 14 Oct 2025. Available at: https://www.ajmc.com/view/fda-approves-semaglutide-for-mash-with-fibrosis
18. Suki M, Amer J, Milgrom Y, Massarwa M, Hazou W, Tiram Y, Perzon O, Sharif Y, Sackran J, Alon R, Lourie NEE, Raz I, Imam A, Khalaileh A, Safadi R. Semaglutide in MASLD patients: improved survival and liver outcomes. *Pharmaceuticals (Basel).* 2025;18(7):1075.
19. Brennan PN, Kopka CJ, Agirre-Garrido L, Hansen CD, Alkhouri N, Schattenberg JM, Ivancobsky-Wajcman D, Isaacs S, Michel M, Lazarus JV. Reviewing MAESTRO-NASH and the implications for hepatology and health systems in implementation/accessibility of Resmetirom. npj Gut and Liver. 2025;2(3):1–9.
20. Colagiuri S, Ceriello A, IDF Technical Working Group. Management of metabolic dysfunction-associated steatotic liver disease (MASLD) in type 2 diabetes. *Diabetes Research and Clinical Practice.* 2025:222 (1):1–5.
21. Lin J, Huang Y, Xu B, Gu X, Huang J, Sun J, Jia L, He J, Huang C, Wei X, Chen J, Chen X, Zhou J, Wu L, Zhang P, Zhu Y, Xia H, Wen G, Liu Y, Liu S, Zeng Y, Zhou L, Jia H, He H, Xue Y, Wu F, Zhang H. Effect of dapagliflozin on metabolic dysfunction-associated steatohepatitis: multicentre, double blind, randomised, placebo controlled trial. *BMJ*. 2025;389:e083735.
22. Zargar AH, Bhansali A, Majumdar A, Maheshwari A, Bhattacharyya A, Dasgupta A, Saboo BD, Sethi BK, Sanyal D, Seshadri KG, Deshpande NR, Kapoor N, Lakhani OJ, Talwalkar PG, Kalra P, Mehrotra RN, Sahay RK, Shukla R, Kant S, Das S, Agarwal SC, Phatak SR, G S, Joshi SR, Shaikh SS, Aravind SR, Goswami S, Ghosh S, Panikar VK, Mohan V. Management of metabolic dysfunction-associated steatotic liver disease (MASLD): an expert consensus statement from Indian diabetologists' perspective. *Diabetes Obes Metab*. 2025:(Suppl 4):3–20.
23. Kravchuk S, Bychkov M, Kozyk M, Strubchevska O, Kozyk A. Managing metabolic dysfunction-associated steatotic liver disease (MASLD) in the digital era: overcoming barriers to lifestyle change. *Cureus*. 2025;17(5):e84803.
24. Kumar A. MASLD Pharmacotherapy: current standards, emerging treatments, and practical guidance for indian physicians. *JAPI*. 2025;73(7):Pe45–e60.