Redesigning MASLD Monitoring: A Game-Theoretic Model for Personalized Follow-Up

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Background

Metabolic dysfunction-associated steatotic liver disease (MASLD) affects over one-third of the global population, with prevalence up to 50–70% in individuals with obesity, type 2 diabetes, hypertension, or metabolic syndrome[1,2]. Rising prevalence and the introduction of new pharmacotherapies—such as resmetirom, GLP-1 agonists (e.g., semaglutide, liraglutide), and PPAR agonists (e.g., pioglitazone, elafibranor)—have increased demand for clinical care[3-5]. While patients with cirrhosis require frequent monitoring, those with mild-to-moderate fibrosis (F1–F2) constitute the majority of MASLD cases, yet optimal follow-up frequency for this group remains undefined.

Follow-up needs are influenced by baseline fibrosis, disease progression risk, clinic capacity, and non-invasive test (NIT) availability. Blood-based Enhanced Liver Fibrosis (ELF) testing is accessible and feasible for patients with logistical barriers, whereas imaging-based tests like vibration controlled transient elastography (VCTE) and magnet resonance elastography (MRE) require in-clinic visits. Adherence to lifestyle or pharmacologic interventions is highly variable, sometimes as low as 25%, due to the asymptomatic nature of MASLD and social determinants of health (SDoH), including income, education, and access to care[6]. Missed visits may reflect these contextual barriers rather than intentional non-adherence, with implications for cardiovascular and liver-related outcomes.

Despite these challenges, no consensus exists for F1–F2 MASLD follow-up, highlighting the need for a structured framework. Game theory provides a mathematical approach to model strategic physician–patient interactions under uncertainty, offering the potential to improve adherence, trust, and resource allocation. This study proposes a theoretical Bayesian game framework to optimize MASLD follow-up by integrating adherence uncertainty, NIT results, and patient choice, laying the groundwork for future empirical validation using electronic medical record (EMR) data to assess clinical utility.

Methods

Game theory provides a framework for analyzing strategic interactions under uncertainty and has been applied in hepatology to biopsy decision-making, liver transplantation, and hepatitis C care[7-9]. However, MASLD follow-up has not yet been modeled in this way.

We developed a Bayesian game to optimize follow-up for patients with F1–F2 MASLD, focusing on uncertainty in adherence to lifestyle or pharmacological therapies. The model incorporates principal–agent concepts: adverse selection (patients know adherence likelihood better than physicians), moral hazard (patients may fail to adhere post-decision), and signaling (actions such as visit choice or test results reveal adherence). The Bayesian normal form representation is shown in Figure 1. The payoff structure (Table 1) reflects clinical outcomes, resource efficiency, and patient satisfaction in the physician-patient interaction.

The game involves two players: physician (principal) and patient (agent). Physicians choose between frequent (AF, ~6 months) or less frequent (CF, 1–2 years) follow-up. AF reduces risks but is resource-intensive; CF is efficient if the patient is adherent but risky otherwise. "Nature" assigns patient type (adherent vs. non-adherent) with probability p, creating imperfect information. Strategies can be physician-led (choice based on prior belief, SDoH [Social Determinants of Health], and risk) or patient-led (choice of AF/CF as a signal of adherence).

Outcomes are modeled in one-shot (initial visit) or repeated games (updated via NITs and clinical data). Payoffs combine health outcomes, resource efficiency, and patient satisfaction. For adherent patients, CF maximizes efficiency and satisfaction; for non-adherent patients, AF improves safety despite greater burden.

This framework highlights how Bayesian games can guide MASLD follow-up by accounting for hidden information, adherence uncertainty, and the value of patient signaling.

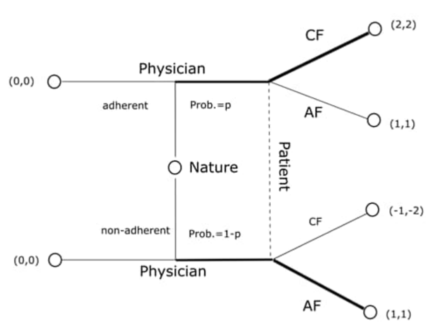

Figure 1. Bayesian game model.

Results

We modeled the new patient visit as a Bayesian game to evaluate physician-led versus patient-signaling approaches to follow-up in MASLD. In the signaling model, physicians offer patients two strategies: AF with frequent visits or CF that is less frequent. The patient's choice functions as a signal of adherence type. In the physician-led approach, AF or CF is assigned based on prior adherence probability (p), clinical risk, and SDoH.

Standard AF and CF alone do not resolve adverse selection (AS) and moral hazard (MH). We demonstrate how modifying CF with mandatory ELF testing introduces accountability, making CF more attractive to adherent patients while discouraging non-adherence. Other mechanisms (digital monitoring, lifestyle logs, co-pays) could serve similar functions.

Payoff analysis shows threshold effects: physicians prefer CF when $p > 2/3$, otherwise AF; patients prefer CF when $p > 1/2$. These asymmetries highlight the importance of accurate p estimates and accounting for noisy patient signals. Neither physician-led nor signaling models are sufficient alone; the former risks overlooking patient heterogeneity, while the latter may misclassify if menu design fails. A hybrid approach—where AF is structured to appeal to non-adherent patients and CF to adherent ones—maximizes separation, improving alignment and outcomes.

In the repeated game, follow-up strategies evolve with new signals from NITs and clinical markers (e.g., ELF, VCTE, Body Mass Index [BMI], low-density lipoprotein [LDL]). Improved signals support CF; worsening signals trigger AF. Missed visits are interpreted cautiously to distinguish barriers from moral hazard.

This framework illustrates how intentional design of AF/CF options, combined with Bayesian updating, can improve efficiency, satisfaction, and adherence in MASLD management.

Table 1. Scoring system of payoff matrix.

Scenario	Physician Payoff	Patient Payoff	Notes
Adherent, CF	+2, treatment success, resource efficiency, reduced cardiovascular risk	+2, health improvement and high satisfaction due to minimal burden from fewer visits, lower costs, reduced anxiety, and manageable lifestyle effort	Successful, resource-efficient, reduced cardiovascular risk; high patient satisfaction (minimal burden: time for visits, costs, anxiety, lifestyle effort)
Adherent, AF	+1, treatment success but inefficient resource use due to frequent visits/tests	+1, health improvement offset by low satisfaction due to high burden from time for visits, financial costs, anxiety, and lifestyle effort	Successful but inefficient; low patient satisfaction (high burden: time for visits, costs, anxiety, lifestyle effort)
Non-Adherent, CF	-1, treatment failure due to lack of intervention, e.g., undetected disease progression	-2, no health improvement and low satisfaction due to lack of engagement	Treatment failure, increased cardiovascular complications (e.g., myocardial infarction, stroke); low patient satisfaction (minimal engagement, no health improvement)
Non-Adherent, AF	+1, treatment success but high resource use due to frequent visits/tests	+1, health improvement offset by lower satisfaction from frequent follow-up	Successful via monitoring, reduced cardiovascular risk; moderate patient satisfaction (health benefit despite burden: time for visits, costs, anxiety, minimal lifestyle effort)

Discussion

We present a Bayesian game model to optimize follow-up in F1–F2 MASLD by addressing uncertainty in adherence, which drives fibrosis progression and cardiovascular risk. In this framework, physicians interpret patient choices using prior beliefs about adherence (p), informed by population data, NIT scores, clinical risk factors, and SDoH. Standard conventional follow-up (CF) with less frequent visits lacks interim monitoring; adding accountability measures such as ELF testing deters non-adherence while preserving efficiency for adherent patients. The model emphasizes incentive-compatible design, where adaptive follow-up (AF) with more frequent visits appeals to non-adherent patients, while CF remains optimal for adherent ones.

In one-shot games, the AF/CF menu elicits patient preferences and mitigates adverse selection by allowing self-identification through follow-up choice. In repeated games, NITs and clinical markers (e.g., LDL, blood pressure) enable Bayesian updating of physician beliefs, refining follow-up based on observed adherence and outcomes. Missed visits are interpreted in the context of SDoH, reducing misclassification of moral hazard. Emerging therapies, including FDA-approved resmetirom and semaglutide for F2–F3 MASH, further underscore the need for robust adherence monitoring frameworks that can adapt to pharmacologic as well as lifestyle-based management.

The Bayesian game model thus provides a structured and flexible framework that aligns patient incentives with adherence behavior through self-selection and physician oversight. It highlights two key insights: (1) standard AF and CF strategies alone fail to adequately address adverse selection and moral hazard, requiring redesigned follow-up strategies that enable effective self-sorting; and (2) a hybrid Bayesian game approach, integrating accountability mechanisms such as ELF testing within CF, offers the most robust solution—balancing clinical outcomes, resource utilization, and patient satisfaction. By combining patient signaling, data-driven physician priors, and adaptive feedback loops, this approach supports efficient, personalized follow-up. Future integration of AI and machine learning may further enhance real-time adherence estimation using EMR and SDoH data, enabling dynamic, individualized scheduling that strengthens patient engagement and optimizes MASLD management.

References

1. Riazi K, et al. The prevalence and incidence of NAFLD worldwide: a systematic review and meta-analysis. Lancet Gastroenterol Hepatol. 2022;7(9):851-61.
2. Sanyal AJ, et al. Prospective Study of Outcomes in Adults with Nonalcoholic Fatty Liver Disease. N Engl J Med. 2021;385(17):1559-69.
3. EASL-EASD-EASO Clinical Practice Guidelines on the management of metabolic dysfunction-associated steatotic liver disease (MASLD). J Hepatol. 2024;81(3):492-542.
4. Loomba R, et al. Tirzepatide for Metabolic Dysfunction-Associated Steatohepatitis with Liver Fibrosis. N Engl J Med. 2024;391(4):299-310.
5. Sanyal AJ, et al. Phase 3 Trial of Semaglutide in Metabolic Dysfunction-Associated Steatohepatitis. N Engl J Med. 2025;392(21):2089-99.
6. Vilar-Gomez E, et al. Weight Loss Through Lifestyle Modification Significantly Reduces Features of Nonalcoholic Steatohepatitis. Gastroenterology. 2015;149(2):367-78 e5; quiz e14-5.
7. Diamond GA, et al. Playing doctor: application of game theory to medical decision-making. J Chronic Dis. 1986;39(9):669-82.
8. Mendonça FV, et al. Improving medical decision-making with a management science game theory approach to liver transplantation. Omega. 2020;94.
9. Scheckelhoff K, et al. A Game-Theoretic Model of Optimal Clean Equipment Usage to Prevent Hepatitis C Among Injecting Drug Users. Mathematics. 2025;13 (14)(2270).

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