

PERSPECTIVE

Anesthetic strategies for preserving hepatic function in hepatobiliary tumor surgery

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1 INTRODUCTION

Given that patients with hepatobiliary tumors are often complicated by liver cirrhosis and chemotherapy-induced liver damage, and their liver function reserve varies significantly, the risk of perioperative liver injury and complications remains very high. Clinicians usually use Child-Pugh score combined with laboratory parameters, including albumin, bilirubin, and coagulation function, to assess liver function, but an increasing number of studies show that these methods are insufficient [1]. Liver function reserve is a key factor affecting a patient's surgical tolerance, incidence of ischemia-reperfusion injury and anesthetic drug metabolism capacity. This article focuses on constructing a perioperative individualized anesthesia management system with liver function reserve as its core. The preoperative aspect includes risk stratification through liver function scoring, multidisciplinary collaboration and imaging technology. The intraoperative stage optimizes anesthetic drug selection, maintains hemodynamic stability, precisely regulates anesthesia depth and protects liver perfusion. The postoperative stage dynamically monitors liver function, controls metabolic load and conducts prognostic follow-up. This system runs through the entire perioperative period, thereby effectively reducing the incidence of perioperative liver injury, which provides a standardized and individualized reference for the clinical

practice of perioperative liver function protection in patients with hepatobiliary tumors.

2 INDIVIDUALIZED STRATEGIES FOR PREOPERATIVE ANESTHETIC ASSESSMENT

Patients with hepatobiliary tumors often have underlying diseases, including liver cirrhosis and portal hypertension, which pose huge challenges to intraoperative anesthesia management, while reasonable preoperative anesthesia assessment is established on the basis of liver function evaluation [2]. Contemporary preoperative liver function assessment relies on advanced imaging technologies, including computed tomography, magnetic resonance imaging (MRI), magnetic resonance elastography, and technetium-99m-labeled galactosyl human serum albumin, which can evaluate liver volume, perfusion and fibrosis, thereby improving the prediction accuracy of postoperative liver failure. The HOPE4LIVER trial confirmed that preoperative imaging assessment, intraoperative ultrasound guidance and early postoperative computed tomography or MRI evaluation are effective means to determine treatment response [3]. Diffusion kurtosis imaging can measure microstructural differences in tumors and can also detect severe types of liver cancer at an early stage, and these technologies can facilitate the implementation of liver protection protocols and optimize patient treatment outcomes [4]. However, a single modality has



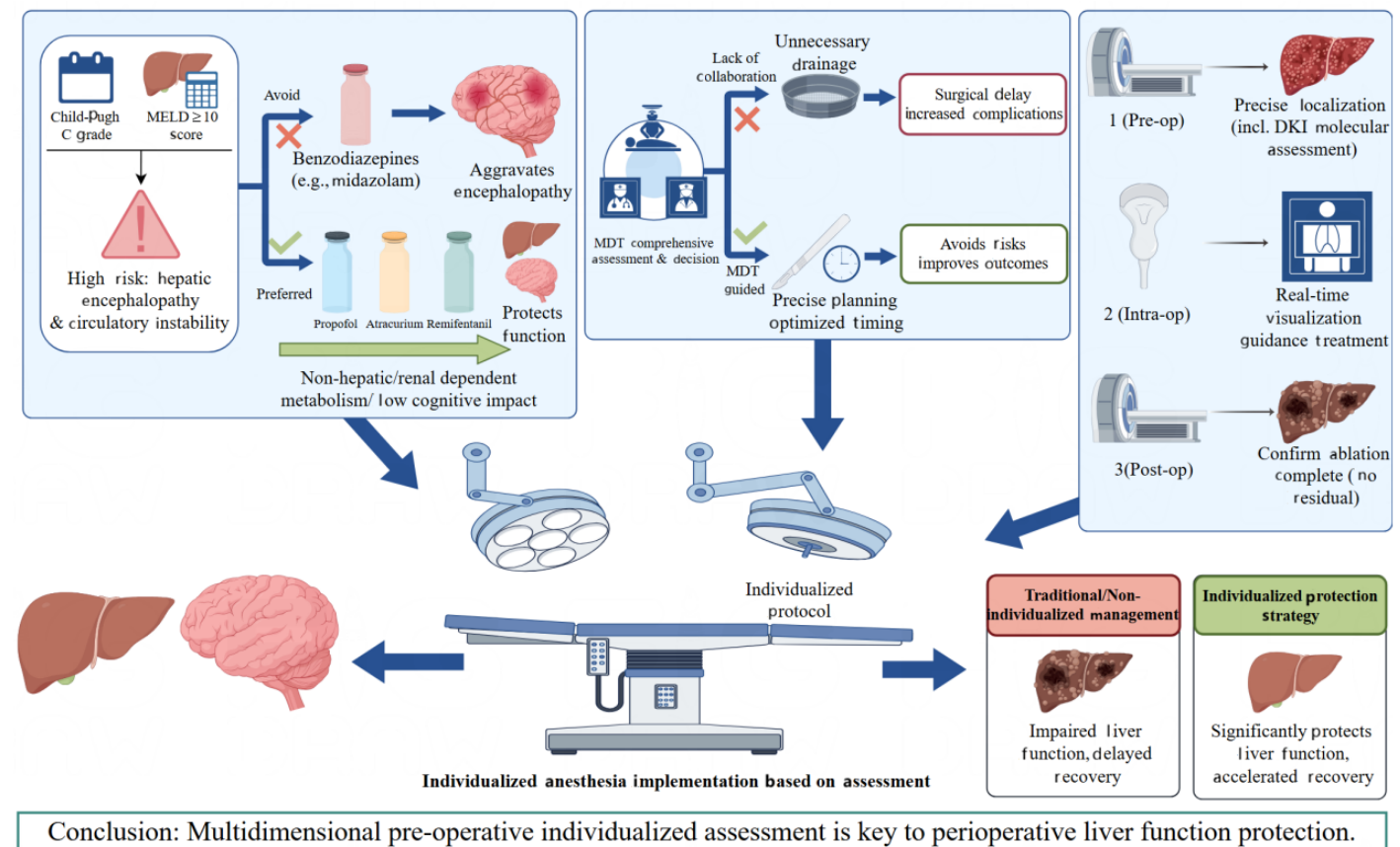


Figure 1. Individualized preoperative anesthetic assessment and management framework for hepatic function protection in hepatobiliary tumor surgery. A conceptual framework of individualized preoperative anesthetic evaluation and perioperative strategies for hepatic function protection during hepatobiliary tumor surgery. Preoperative risk stratification using Child-Pugh classification, MELD score, and hepatic functional assessment influences anesthetic selection, avoiding traditional benzodiazepines and preferentially using agents with minimal hepatic metabolism. The MDT collaboration provides a holistic review, avoids unnecessary interventions such as standard biliary drainage, and optimizes the timing of surgery. Advanced imaging methods, including CT, MRI, and DKI, allow for accurate tumor localization, intraoperative guidance, and postoperative evaluation of treatment efficacy. The synergistic integration of these components enhances personalized anesthetic regimens and optimizes hepatic function preservation, leading to improved perioperative recovery compared with conventional non-individualized approaches. This figure was created with BioRender.com. MELD, Model for End-Stage Liver Disease; MDT, Multidisciplinary Team; CT, computed tomography; MRI, magnetic resonance imaging; DKI, diffusion kurtosis imaging.

limitations, and relying solely on the above-mentioned technologies is insufficient to establish a comprehensive individualized anesthesia management system, therefore, preoperative stratification based on liver function reserve and perioperative surgical risk is crucial for hepatobiliary tumor surgery. Perioperative liver protection should be based on comprehensive preanesthesia assessment, thereby guiding the formulation of individualized intraoperative anesthesia management strategies through reasonable risk stratification.

Comprehensive preoperative assessment must include Child-Pugh classification, Model for End-Stage Liver Disease (MELD) score and other biochemical indicators of liver function, focusing on evaluating portal hypertension, ascites, and hepatic encephalopathy complications. If necessary, imaging examinations should be used to assess liver blood flow and liver tolerance to injury, which, combined with the Child-Pugh

score, helps accurate risk stratification and also helps formulate an individualized anesthesia plan. A multidisciplinary team composed of hepatobiliary surgeons, hepatologists, and intensive care physicians helps complete preoperative risk grouping and individual anesthesia planning, while traditional benzodiazepines (e.g., midazolam) are usually avoided in clinical practice, with priority being given to drugs such as propofol, atracurium, and remifentanyl, as these drugs do not aggravate hepatic encephalopathy and may improve relevant postoperative scores [5]. Patients with MELD score ≥ 10 have a higher incidence of intraoperative hypotension, which poses additional requirements for anesthesia management, and selecting appropriate anesthesia induction drugs and effective blood pressure management are crucial for these patients [6]. Standard preoperative assessment and individualized anesthesia plan are crucial for liver function protection during hepatobiliary tumor surgery. **Figure 1** shows an integrated model of indi-

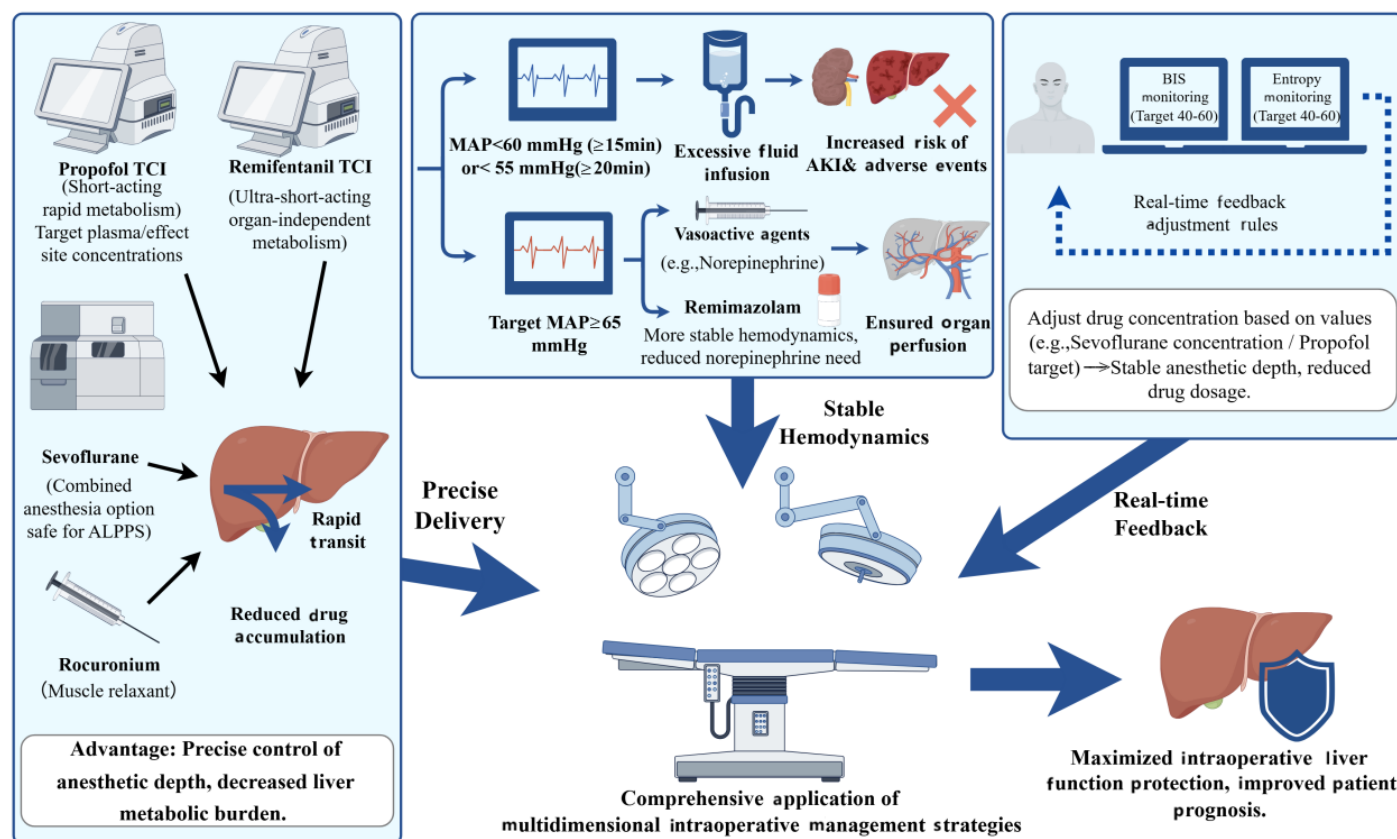


Figure 2. Intraoperative precision anesthesia strategies for hepatic protection in hepatobiliary tumor surgery. Intraoperative precision anesthesia strategy for hepatic protection in hepatobiliary tumor surgery: the conceptual framework. To minimize drug accumulation and metabolic burden, short-acting anesthetic agents such as propofol and remifentanyl delivered via TCI are preferred in hepatobiliary tumor surgery, along with adjunctive agents such as sevoflurane and rocuronium as needed. Hemodynamic stability is achieved with prompt and continuous monitoring of MAP to avoid prolonged hypotension, using vasoactive agents such as norepinephrine preferentially rather than administering excessive fluid, to ensure sufficient organ perfusion. Advanced monitoring technologies, such as the BIS and entropy, allow for feedback-directed titration of anesthetic depth in real time (target range 40–60). The introduction of targeted drug delivery, goal-directed hemodynamic management, and real-time monitoring enables stable intraoperative physiology, associated with optimized hepatic perfusion and improved postoperative recovery, compared with traditional methods. This figure was created with BioRender.com. TCI, target-controlled infusion; MAP, mean arterial pressure; AKI, acute kidney injury; BIS, bispectral index; ALPPS, associating liver partition and portal vein ligation for staged hepatectomy.

visualized preoperative anesthesia assessment and perioperative liver protection.

3 INTRAOPERATIVE STRATEGIES FOR HEPATIC PROTECTION

Patients with hepatobiliary tumors often have impaired liver function, which leads to decreased ability of the liver to metabolize drugs, and therefore, clinical selection should prioritize short-acting, easily titratable, and low hepatotoxicity intravenous anesthetic drugs. Propofol combined with remifentanyl target-controlled infusion (TCI) is a commonly used clinical regimen. Propofol is metabolized rapidly and has significant extrahepatic metabolic pathways, while remifentanyl metabolism is independent of liver and kidney function, which can minimize drug accumulation to the maximum extent, thereby maintaining stability of intraoperative anesthesia and protect-

ing liver function, with partial hepatectomy being a complex surgical procedure, as complex procedures such as associating liver partition and portal vein ligation for staged hepatectomy (ALPPS) are often involved. In such surgeries, between combined intravenous-inhalational anesthesia (propofol TCI plus sevoflurane) and total intravenous anesthesia, no statistically significant differences were observed in postoperative liver function indicators including total bilirubin, alanine aminotransferase, and aspartate aminotransferase. This finding indicates that the combined anesthesia regimen does not cause additional burden on liver recovery and has a good safety profile [7]. **Figure 2** shows combined application of precise anesthesia and liver protection during surgery.

In liver surgery, correctly selecting anesthetic drugs, regulating hemodynamics, and implementing liver protection strategies to maintain liver perfusion are crucial to surgical success.

By reasonably selecting anesthetic drugs, precisely titrating dosages, and simultaneously adopting real-time monitoring of anesthesia depth and goal-directed fluid therapy, we can more effectively and reliably maintain intraoperative anesthesia and circulatory stability, while reducing liver injury related to hepatobiliary tumor surgery and promoting early recovery of postoperative liver function. A closed-loop feedback system based on the bispectral index or electroencephalogram entropy index can quantitatively measure the depth of sedation, and these parameters can be combined with measurements of mean arterial pressure, cardiac output, and near-infrared spectroscopy-derived parameters to comprehensively assess liver perfusion and tissue oxygenation status. Adjusting drug dosages according to anesthesia depth monitoring helps maintain blood pressure and cardiac function stability during surgery. In laparoscopic liver resection, excessive anesthesia depth can lead to circulatory suppression and reduced hepatic blood flow, but conversely, insufficient anesthesia depth may trigger stress and inflammatory responses, thereby aggravating ischemia-reperfusion injury. Persistent intraoperative hypotension is associated with increased risk of postoperative adverse events, which is related to the severity and duration of hypotension. Fluid management and use of vasoactive drugs are also very important, as goal-directed fluid therapy can achieve individualized fluid administration under guidance of dynamic hemodynamic monitoring. It optimizes circulatory parameters and tissue oxygen delivery to prevent volume overload or hypovolemia, and maintains adequate organ perfusion [8]. In case of intraoperative hypotension, a small dose of norepinephrine ($0.1\text{--}0.3\text{ }\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) as an alternative to aggressive fluid resuscitation can elevate mean arterial pressure to ≥ 65 mmHg, protect hepatic artery blood flow and improve lactate clearance, thereby reducing the risk of hepatic venous obstruction and bleeding caused by fluid overload. A postoperative 24-hour lactate level >3.0 mmol/L is associated with high risk of liver failure, which can be significantly reduced through this treatment.

4 POST-ANESTHETIC RECOVERY AND HEPATIC FUNCTION MONITORING

In the early period after liver resection, hepatic blood flow and the systemic stress state of patients with hepatobiliary tumors undergo significant changes, which can easily lead to abnormal liver perfusion, hypoxia, and more severe ischemia-reperfusion injury. In addition, postoperative decline in liver function reserve and metabolic clearance capacity significantly increases the burden of liver detoxification, protein synthesis, and metabolism, thereby making the early postoperative period a high-risk stage for liver dysfunction, therefore, it is necessary to strengthen postoperative liver function monitoring, control the metabolic burden of the liver, and conduct post-anesthesia follow-up throughout the entire recovery process, which has important clinical significance for protecting postoperative liver function. These measures further support complete recovery

of the liver, early identification of complications, and good long-term tumor prognosis.

A total bilirubin level $>50\text{ }\mu\text{mol/L}$ (2.9 mg/dL) within 72 hours after liver surgery, together with a lactate level >3.0 mmol/L at 24 hours postoperatively, indicates insufficient recovery of liver function and high risk of liver failure [9]. A strategy of using early predictive biomarkers and risk stratification management can guide monitoring, optimize fluid therapy and hemodynamic support, and improve postoperative outcomes [10]. Lactate is a key biomarker for assessing liver function reserve and predicting adverse postoperative outcomes, with an elevated lactate level indicating microcirculatory dysfunction, while perioperative dynamic lactate monitoring and calculation of the ratio of postoperative to preoperative arterial lactate have higher accuracy in predicting postoperative complications, which is less affected by confounding variables [11]. Delayed lactate clearance, especially when combined with coagulation dysfunction and hyperbilirubinemia, requires early optimization of volume status, perfusion level, and supportive therapy to promote liver function recovery and reduce the incidence of complications. Continuous monitoring of liver function, coagulation status, lactate clearance, metabolic and nutritional parameters can achieve dynamic risk stratification, thereby guiding optimization of analgesia, fluid therapy and nutritional support to ensure adequate liver perfusion and metabolic homeostasis. Serial measurements of serum biomarkers can longitudinally assess liver function recovery and support monitoring of minimal residual disease and tumor recurrence. A decline or normalization of alpha-fetoprotein levels is associated with good prognosis, while persistently elevated levels indicate ongoing tumor activity, and incorporation of these biomarkers into follow-up protocols can accurately predict recurrence risk and guide individualized treatment interventions, thereby improving long-term survival outcomes [12].

5 CONCLUSIONS AND FUTURE PERSPECTIVES

Patients with hepatobiliary tumors often have underlying liver disease, including cirrhosis. The core of perioperative anesthesia management is an individualized liver protection strategy, in which accurate preoperative assessment, reasonable intraoperative regulation, and dynamic postoperative monitoring are key elements. Combining MRI with technetium-99m-labeled galactosyl human serum albumin scintigraphy, and imaging modalities with Child-Pugh classification, MELD score, and multidisciplinary team collaboration enables accurate risk stratification, thereby establishing a solid foundation for individualized treatment plans. During surgery, clinicians should primarily use short-acting anesthetic drugs with low hepatotoxicity, and propofol combined with remifentanyl TCI is the preferred method. Compared with large-volume fluid resuscitation, this regimen preferentially uses norepinephrine to maintain stable blood pressure, which, when combined with goal-directed fluid therapy, can effectively protect liver perfu-

sion. Postoperatively, examining lactate levels, coagulation parameters, and liver function tests helps in the early detection of liver injury, thus guiding subsequent management. Future efforts should focus on the combined application of imaging technologies and biomarkers, optimization of clinical protocols for new anesthetic drugs, and construction of a more precise individualized liver protection system, thereby further reducing the risk of perioperative liver injury and improving long-term prognosis of patients.

DECLARATIONS

Author contributions

Ruilin Li and Tong Chu contributed to the manuscript writing and figure preparation; Tongyao Li and Xingtong Ren designed the work; Tongyao Li supervised the work. All authors read and approved the final manuscript.

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Data availability

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study. All information is derived from publicly available articles and datasets.

Ethics approval and consent to participate

Not applicable. This manuscript does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication

Not applicable. This manuscript does not include details, images, or videos relating to an individual person.

Competing interests

The authors declare that they have no competing interests.

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