Journal of Biosciences and Medicines, 2026, 14(9), 345-363
https://www.scirp.org/journal/jbm
ISSN Online: 2327-509X
ISSN Print: 2327-5081

Current Evidence on the Impact of Preoperative Nutritional Assessment on Outcomes after Liver Resection

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How to cite this paper: Yang, Z.C., Yang, Y.L., Zhang, K.M. and Lu, H.F. (2026) Current Evidence on the Impact of Preoperative Nutritional Assessment on Outcomes after Liver Resection. *Journal of Biosciences and Medicines*, **14**, 345-363.
https://doi.org/10.4236/jbm.2026.149021

Received: August 16, 2026
Accepted: September 14, 2026
Published: September 17, 2026

Abstract

Hepatectomy is the primary treatment for hepatocellular carcinoma (HCC), intrahepatic cholangiocarcinoma (ICC), and certain benign liver diseases; however, postoperative complications, post-hepatectomy liver failure (PHLF), and tumor recurrence remain major determinants of prognosis. In recent years, preoperative nutritional status has received increasing attention as a modifiable prognostic factor. The Prognostic Nutritional Index (PNI), Controlling Nutritional Status (CONUT), Nutritional Risk Index (NRI), Geriatric Nutritional Risk Index (GNRI), Hemoglobin-Albumin-Lymphocyte-Platelet Score (HALP), Naples Prognostic Score (NPS), and Nutritional Risk Screening 2002 (NRS-2002) can capture nutritional reserves, immune function, and systemic inflammatory status. Numerous studies have shown that low PNI, high CONUT, low GNRI, low HALP, and high NPS are associated with a higher incidence of postoperative complications, increased risk of PHLF, and shorter overall survival (OS) and recurrence-free survival (RFS). Based on a scoping review of the published literature from the past decade, this review summarizes recent advances in the application of preoperative nutritional scoring in patients undergoing liver resection, with a focus on its predictive value for short- and long-term outcomes, potential mechanisms, and perioperative intervention strategies. We also discuss emerging directions, including sarcopenia assessment, artificial intelligence-based prediction, and textbook outcome (TO) evaluation, with the aim of providing evidence-based support for accurate risk stratification and individualized perioperative management.

Keywords

Liver Resection, Nutritional Scoring, Prognostic Nutritional Index, Controlling Nutritional Status, Geriatric Nutritional Risk Index, Naples

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Prognostic Score, Sarcopenia, Textbook Outcome, Prognosis

1. Introduction

Liver resection is the primary curative treatment for hepatocellular carcinoma (HCC), intrahepatic cholangiocarcinoma (ICC), liver metastases, and certain benign liver diseases. With continuous advancements in perioperative management, liver function assessment techniques, and minimally invasive surgical techniques, the safety and efficacy of liver resection have significantly improved. However, postoperative complications, post-hepatectomy liver failure (PHLF), and tumor recurrence remain key factors affecting patient prognosis [1] [2].

Patients with liver disease and liver tumors often present with comorbid conditions such as chronic inflammation, impaired liver function, metabolic disorders, and inadequate nutritional intake; the prevalence of malnutrition ranges from 30% to 70% [3] [4]. Malnutrition can impair protein synthesis and immune function, weaken the liver's regenerative capacity, and thereby increase the risk of complications such as infection, bile leakage, and PHLF, ultimately affecting patients' long-term survival outcomes. In recent years, a growing body of research has confirmed that preoperative nutritional status has become a key modifiable factor influencing both short-term and long-term outcomes following liver resection [5].

Traditional nutritional assessment methods include the Subjective Global Assessment (SGA) and the Patient-Generated Subjective Global Assessment (PG-SGA); although they offer good accuracy, they have limitations such as being time-consuming and subjective. In contrast, preoperative nutritional scoring based on objective laboratory indicators has been widely adopted for perioperative risk screening and prognostic assessment due to its simplicity, objectivity, quantifiability, and standardization. Among these, tools such as the NRS-2002, PNI, CONUT, NRI, GNRI, HALP, and NPS can capture a patient's overall condition across multiple dimensions—including nutritional reserves, immune function, and inflammatory status—and are closely associated with postoperative complications, PHLF, RFS, and OS [6]-[9].

Furthermore, the Global Leadership Initiative on Malnutrition (GLIM) criteria, published in 2018, provide an internationally unified framework for the diagnosis of malnutrition. Prospective studies have shown that the GLIM criteria can effectively predict the risk of postoperative complications and mortality in patients with hepato-pancreato-biliary (HPB) tumors [10]. As research on sarcopenia deepens, nutritional assessment models that rely solely on biochemical indicators are gradually shifting toward a comprehensive evaluation paradigm that encompasses nutrition, immunity, and muscle. Textbook outcomes (TO), an emerging comprehensive measure of surgical quality, have also provided a new perspective for research on the relationship between nutritional status and perioperative outcomes [11] [12]. This review aims to systematically summarize the progress in the application of the aforementioned nutritional scoring systems in liver resection, focusing on their prognostic value, potential mechanisms, and perioperative intervention strategies, while also outlining future research directions.

2. Methods

This study is a scoping review conducted in accordance with the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) reporting guideline. No formal risk-of-bias assessment or methodological quality appraisal was performed on included studies; therefore, conclusions are descriptive and focus on mapping the current evidence base rather than grading the strength of evidence.

2.1. Search Strategy

Searches were performed across four databases: China National Knowledge Infrastructure (CNKI), PubMed, Web of Science, and Embase, covering publications from January 2015 to December 2025. Language restrictions were applied: English for PubMed, Web of Science, and Embase; Chinese and English for CNKI.

2.2. PubMed Boolean Search String

(("hepatectomy"[Title/Abstract] OR "liver resection"[Title/Abstract] OR "hepatic resection"[Title/Abstract]) AND ("prognostic nutritional index"[Title/Abstract] OR "PNI"[Title/Abstract] OR "controlling nutritional status"[Title/Abstract] OR "CONUT"[Title/Abstract] OR "nutritional risk index"[Title/Abstract] OR "NRI"[Title/Abstract] OR "geriatric nutritional risk index"[Title/Abstract] OR "GNRI"[Title/Abstract] OR "hemoglobin-albumin-lymphocyte-platelet score"[Title/Abstract] OR "HALP"[Title/Abstract] OR "Naples prognostic score"[Title/Abstract] OR "NPS"[Title/Abstract] OR "sarcopenia"[Title/Abstract] OR "textbook outcome"[Title/Abstract] OR "post-hepatectomy liver failure"[Title/Abstract])).

Equivalent adapted search syntax was used for Web of Science, Embase, and CNKI. Classic landmark publications (e.g., the original PNI validation study) were additionally identified through citation chasing.

2.3. Study Selection Flow

A total of 4286 records were initially identified across all databases. After deduplication, 2612 unique records remained for title and abstract screening. Of these, 2147 records were excluded based on eligibility criteria, leaving 465 full-text articles for full-text assessment. After full-text review, 112 studies met all inclusion criteria and were included in the final scoping review synthesis.

Eligible study types included randomized controlled trials (RCTs), prospective cohort studies, retrospective cohort studies, case-control studies, systematic reviews, and meta-analyses. Inclusion criteria were: 1) study participants were patients who underwent hepatectomy; 2) the study assessed the relationship between preoperative nutritional status or nutritional scores and perioperative outcomes or long-term prognosis; 3) outcome measures included at least one of the following: postoperative complications, PHLF, length of hospital stay, RFS, OS, or TO; 4) studies with complete data were eligible. Exclusion criteria were: 1) duplicate publications; 2) conference abstracts, case reports, expert opinions, and editorials; 3) studies with incomplete data or data that could not be extracted. The screening process was conducted independently by two researchers, and any disagreements were resolved through discussion or adjudication by a third reviewer.

3. Common Preoperative Nutritional Scores and Their Clinical Significane

3.1. Nutritional Risk Screening 2002 (NRS-2002)

The NRS-2002 is a nutritional risk screening tool recommended by the European Society for Clinical Nutrition and Metabolism (ESPEN). It consists of three components: the Impaired Nutritional Status score (0 - 3 points), the Disease Severity score (0 - 3 points), and an age adjustment (1 point for patients aged ≥ 70 years). A total score of ≥3 indicates nutritional risk. The NRS-2002 is easy to administer and widely applicable, making it a practical tool for nutritional risk screening at admission in patients undergoing liver resection. Multiple studies have shown that an NRS-2002 score of ≥3 is significantly associated with a higher incidence of postoperative complications and prolonged hospital stay after liver resection [6] [13]. However, because the NRS-2002 primarily reflects nutritional risk rather than providing a detailed characterization of nutritional status, its predictive accuracy is limited. It should therefore be used in conjunction with other nutritional assessment tools.

3.2. Prognostic Nutritional Index (PNI)

The PNI was first proposed by Onodera *et al.* in 1984, and its calculation formula is: [Formula editable via MathType: PNI = serum albumin (g/L) + 5 × lymphocyte count ($\times 10^9$/L)]. This index reflects both nutritional reserves (albumin) and immune status (lymphocyte count). Originally used to assess perioperative risk in patients undergoing gastrointestinal surgery, it is now widely applied in the prognostic evaluation of various malignant tumors [14].

Among nutritional scoring systems used in liver resection, the PNI currently has one of the strongest evidence bases. A meta-analysis by Zhang *et al.*, including 19 studies and 9,830 patients with HCC, showed that compared with the high-PNI reference group, patients with low PNI had significantly worse OS (HR = 1.60, 95% CI: 1.44 - 1.77, $p < 0.001$) and RFS (HR = 1.48, 95% CI: 1.30 - 1.69, $p < 0.001$) [5]. A retrospective cohort study and meta-analysis by Fan *et al.* similarly confirmed that low PNI (<45) is an independent risk factor for OS and RFS in HCC patients following liver resection [15]. Regarding ICC, a multicenter retrospective study by Matsuda *et al.* found that a PNI < 50 was independently associated with severe complications (Clavien-Dindo grades III - V) (OR = 2.22, p = 0.013), and infectious complications were significantly more common in the low-PNI group (14.9% vs. 3.5%, p = 0.0021) [16]. A study by Tsukagoshi *et al.* further demonstrated that a PNI < 45 is significantly associated with early postoperative recurrence of HCC and the pattern of extrahepatic recurrence [4].

It is worth noting that the cutoff for PNI varies considerably in the literature, ranging from 40 to 50 (Fan *et al.* used 45; Matsuda *et al.* used 50; Sim *et al.* used 44) [15]-[17]. This heterogeneity may be related to differences in baseline characteristics, etiological composition, and sample size among different study populations; currently, there is still no universally accepted cutoff. Furthermore, Peng *et al.* found that changes in PNI after surgery (ΔPNI), rather than the absolute preoperative PNI value, were independent predictors of OS and RFS in patients with small HCC [18], suggesting that dynamic monitoring of perioperative nutritional status may offer prognostic value beyond a single baseline assessment.

3.3. Controlling Nutritional Status (CONUT) Score

The CONUT score is based on three parameters: serum albumin, lymphocyte count, and total cholesterol level, and was originally developed to screen for nutritional status in hospitalized patients. In recent years, multiple studies have confirmed the important value of the CONUT score in assessing outcomes after liver resection. Li *et al.* found in 1334 HCC patients that the early postoperative CONUT score was significantly associated with Clavien-Dindo grades III - V complications [19]. Wang *et al.* compared the prognostic performance of ALBI, CONUT, PNI, and CT-based nutritional indices in patients with iCCA and found that CONUT was significantly associated with both postoperative complications and overall survival (OS) [20].

3.4. Nutritional Risk Index (NRI) and Geriatric Nutritional Risk Index (GNRI)

The NRI is calculated based on serum albumin and percentage change in body weight, while the GNRI is a modified version of the NRI designed for older adults. Qin *et al.* found an interaction between the ALBI score and the NRI, and that combining the two improves prediction of PHLF [2]. Tsukagoshi *et al.* found in 203 patients with HCC that a low GNRI (<98) and a low PNI (<45) were both significantly associated with poorer OS and RFS, and that the GNRI was significantly associated with body composition (BMI, skeletal muscle index), liver function (Child-Pugh score), and tumor factors (tumor size, microvascular invasion) [4]. Qin *et al.* conducted a large-scale analysis of 1666 HCC patients, further supporting the prognostic value of GNRI and PNI for survival outcomes: A high GNRI (HR = 0.77, 95% CI: 0.70 - 0.85, p < 0.001) and a high PNI (HR = 0.77, 95% CI: 0.70 - 0.86, p < 0.001) were each independently associated with a lower risk of death, and the combined use of GNRI and PNI further improved prognostic performance [21].

In the field of ICC, a study by Wang *et al.* involving 157 older patients with ICC showed that low GNRI, sarcopenia, increased visceral fat, and intramuscular fat deposition were independent risk factors for OS and RFS. A nomogram based on GNRI and body composition indices showed better predictive performance than traditional TNM staging (C-index: OS 0.734, RFS 0.704) [22].

3.5. Hemoglobin-Albumin-Lymphocyte-Platelet Score (HALP)

The HALP score integrates four parameters—hemoglobin, albumin, lymphocyte count, and platelet count—to reflect a patient's oxygen-carrying capacity, nutritional reserves, immune function, and coagulation status. A meta-analysis by Zhang *et al.* confirmed that the HALP score has significant prognostic value for patients undergoing hepatectomy for primary liver cancer [23]. Compared with the PNI and CONUT, the HALP score has the advantage of including hemoglobin and platelet counts, thereby providing a more comprehensive assessment of systemic status.

3.6. Naples Prognostic Score (NPS)

The NPS is a relatively new immunonutritional scoring system that combines four indicators—serum albumin, total cholesterol, the neutrophil-to-lymphocyte ratio (NLR), and the lymphocyte-to-monocyte ratio (LMR)—to capture both nutritional status and systemic inflammation. Xie *et al.* conducted the first systematic evaluation of the prognostic value of the NPS in 476 patients with HCC undergoing liver resection. The results showed that NPS was an independent risk factor for OS (NPS group 3 vs. 1: HR = 2.608, 95% CI: 1.358 - 5.008, $p = 0.004$) and RFS (NPS group 3 vs. 1: HR = 2.002, 95% CI: 1.262 - 3.175, $p = 0.003$), and that its discriminatory prognostic performance (median AUC, 0.675) was superior to that of traditional scoring systems such as PNI and CONUT [24]. The NPS therefore provides a new option for preoperative risk assessment in liver resection; however, the available evidence remains limited and requires further validation in multicenter studies.

3.7. GLIM Criteria for Malnutrition Diagnosis

The GLIM criteria are a consensus framework for the diagnosis of malnutrition jointly published in 2018 by major international clinical nutrition societies. They comprise two dimensions: phenotypic criteria (unintentional weight loss, low BMI, reduced muscle mass) and etiological criteria (reduced food intake or malabsorption, inflammation/disease burden). A diagnosis of malnutrition requires fulfillment of at least one phenotypic criterion and one etiological criterion. A prospective observational study by Toutouzas *et al.* preliminarily evaluated the predictive value of the GLIM criteria for postoperative complications and mortality in patients with hepatopancreatobiliary (HPB) cancers [10]. Combining the GLIM criteria with traditional nutritional scoring is expected to further enhance the standardization and international comparability of preoperative nutritional assessment.

Each rating method has its own advantages and limitations, along with its respective application scenarios, as detailed in Table 1.

Table 1. Comparison of common preoperative nutritional assessment tools.

Tools	Main Components	Reflected Content	Advantages	Limitations	Clinical Applications
NRS-2002	Nutritional status score, disease severity score, age (add 1 point for age ≥ 70)	Nutritional Risk	Easy to administer, recommended by international guidelines, suitable for initial screening of hospitalized patients	Primarily reflects nutritional risk; cannot comprehensively assess nutritional status; has limited predictive accuracy	Nutritional risk screening upon admission to guide further nutritional assessment
PNI	Albumin + 5 × lymphocyte count	Nutritional reserves, immune function	Simple to calculate, with the strongest evidence; can predict OS, RFS, PHLF, and postoperative complications	Cutoff values vary in the literature (approximately 40 - 50) and are susceptible to the effects of inflammation and liver function	Preoperative Risk Stratification and Long-Term Prognosis Prediction for Liver Resection
CONUT	Albumin, lymphocytes, total cholesterol	Nutritional status, immune function	Comprehensively evaluates nutritional and immune status; demonstrates good ability to predict postoperative complications	May be subject to bias in patients with biliary tract disease due to cholesterol levels	Prediction of postoperative complications and long-term survival
NRI	Albumin, current weight, ideal weight	Nutritional Risk	Reflects changes in body weight and is suitable for assessing nutritional status	Susceptible to factors such as edema and ascites	PHLF and Perioperative Risk Prediction
GNRI	Albumin, current weight, ideal weight	Nutritional risk in elderly patients	Particularly suitable for elderly patients; has high predictive value for OS and RFS	Primarily applicable to the elderly population; limited evidence for use in younger patients	Risk Assessment for Elderly Patients Undergoing Liver Resection
HALP	Hemoglobin, albumin, lymphocytes, platelets	Nutritional, immune, inflammatory, and coagulation status	Comprehensively reflects the body's overall condition and has strong predictive power	Relatively few clinical studies exist, and standardized cutoff values are currently lacking	Prognostic Assessment Following Hepatectomy for Primary Liver Cancer
NPS	Albumin, Total Cholesterol, NLR, LMR	Nutritional and Inflammatory Status	A composite immunological and inflammatory marker; some studies indicate that its predictive performance is superior to that of PNI and CONUT	Considered an emerging scoring system; clinical evidence remains limited	Prediction of OS, RFS, and Recurrence Risk
GLIM	Phenotypic criteria (weight loss, BMI, muscle mass) + etiological criteria (inadequate intake, inflammation)	Diagnosis of malnutrition	Internationally standardized diagnostic criteria with a high degree of standardization	Requires assessment of muscle mass; relatively complex to perform	Malnutrition Diagnosis and Perioperative Comprehensive Assessment

Continued

CT-based sarcopenia assessment (SMI, PMI, etc.)	CT measurement of skeletal muscle area or psoas major index	Muscle mass, sarcopenia	Allows for objective evaluation of body composition and improves the accuracy of risk prediction	Requires imaging software and specialized measurement techniques	Combined with nutritional scoring to establish a precise predictive model

Note: Table is fully editable; all abbreviations are defined in the text.

4. Predictive Value of Preoperative Nutritional Scoring for Short-Term Outcomes

Postoperative complications and PHLF are the most important short-term adverse outcomes after liver resection. Wang *et al.* evaluated the incremental value of various inflammatory markers in a model for predicting PHLF using the Incremental Diagnostic Improvement (IDI) and Net Reclassification Improvement (NRI) metrics in a cohort of 2824 patients with HCC, and found that SII and PCT provided meaningful incremental predictive value [1]. A study by Sim *et al.* showed another association between nutritional status and perioperative safety: a PNI < 44 was associated with a significantly higher risk of intraoperative transfusion, which itself was an independent risk factor for postoperative complications [17].

Multiple studies consistently indicate that low PNI, high CONUT, and low GNRI are significantly associated with an increased incidence of postoperative complications (including infection, biliary leakage, and abdominal effusion) and PHLF [14] [19] [20]. Delayed wound healing, impaired immune defense, and insufficient hepatic reserve in malnourished patients may underlie these complications. Risaliti *et al.* further showed that combining APRI and PNI can improve prediction of 5-year survival in patients with HCC [25].

5. Predictive Value of Preoperative Nutritional Scoring for Long-Term Prognosis

Long-term outcomes, including OS and RFS, are key endpoints for evaluating the effectiveness of liver resection. Qin *et al.* performed Cox regression and restricted cubic spline analyses in a large cohort of 1666 patients with HCC, showing that the risks of death and recurrence decreased rapidly and then plateaued as GNRI and PNI scores increased. A combined analysis of GNRI and PNI indicated that patients with both high GNRI and high PNI scores had significantly better OS and RFS than other subgroups [21].

Utsumi *et al.* confirmed in 151 patients with advanced HCC that an AGR < 1.25 (HR = 2.504, 95% CI: 1.325 - 4.820, $p < 0.05$) and sarcopenia (HR = 1.908, 95% CI: 1.009 - 3.776, $p < 0.05$) were independent predictors of OS, and the combination of sarcopenia and low AGR was associated with the poorest prognosis [26]. Zeng *et al.* investigated the prognostic value of combined PNI, FIB-4 index, and SII categorization in patients with ICC and found that patients in the high SII + low PNI + low FIB-4 group had the poorest prognosis [27]. These findings suggest that a single nutritional score provides limited information, whereas a multidimensional combined assessment can significantly improve the predictive accuracy of long-term prognosis.

Regarding prediction of tumor recurrence, Tsukagoshi *et al.* found that low PNI and low GNRI were significantly associated with early postoperative recurrence (≤2 years) and extrahepatic recurrence patterns in HCC patients [4]. Wei *et al.* developed an MRI-based model to predict very early recurrence within 1 year after HCC resection using an international multicenter cohort, supporting the combined use of imaging and nutritional scores [12]. Xu *et al.* developed a nomogram to predict recurrence risk in patients with unresectable HCC who underwent conversion to resection following treatment with lenvatinib combined with a PD-1 inhibitor and interventional therapy, suggesting that nutritional indicators remain of significant value in the era of conversion therapy [28].

6. Potential Mechanisms by Which Nutritional Scores Influence Prognosis

The association between preoperative nutritional status and outcomes after liver resection is not merely a statistical association but may reflect an imbalance in the nutrition-immunity-inflammation-metabolism network. This section discusses potential mechanisms across five domains: immune function, inflammatory response, tissue repair, metabolic disorders, and the muscle-liver axis.

6.1. Impaired Immune Function

The liver is a vital immune-regulatory organ in the body, and patients with liver disease often exhibit dysregulation of both innate and adaptive immune functions. Lymphocyte counts in the PNI, CONUT, GNRI, and NPS scores are key indicators of cellular immune function. Preoperative lymphocytopenia suggests weakened T-cell-mediated antitumor immune surveillance, which facilitates the survival and progression of postoperative micrometastases [25] [29]. Furthermore, albumin is not only a marker of nutritional reserves but also contributes to maintaining the stability of immune cell membranes and facilitating cytokine transport. Surgical trauma from liver resection can further exacerbate the postoperative immunosuppressed state, whereas patients with good preoperative nutritional status are better able to maintain postoperative immune homeostasis.

6.2. Systemic Inflammatory Response

Chronic systemic inflammation is considered an important driver of adverse outcomes after liver resection [30]. A bidirectional vicious cycle may occur between malnutrition and inflammation: malnutrition can impair intestinal barrier function, promote bacterial translocation and endotoxemia, and thereby activate hepatic Kupffer cells to release pro-inflammatory factors (TNF-α and IL-6); conversely, persistent inflammation can accelerate protein catabolism and inhibit hepatic albumin synthesis, further exacerbating malnutrition. A study by Wang *et al.* demonstrated that the systemic immune-inflammatory state represented by SII provides significant incremental predictive value for PHLF [1]. Utsumi *et al.* found that patients with sarcopenia had significantly higher NLR and lower AGR, suggesting a close association between muscle loss and systemic inflammation [26].

6.3. Impaired Tissue Repair and Wound Healing

Proteins and albumin serve as the essential material foundation for collagen synthesis, tissue reconstruction, and immune defense. When patients are malnourished, insufficient protein reserves in the body can lead to delayed wound healing, reduced tissue repair capacity, and increased susceptibility to infection [13]. Hypoalbuminemia can also affect local microcirculation and tissue oxygen supply by reducing plasma colloid osmotic pressure, further delaying the wound healing process [31]. Therefore, maintaining good preoperative nutritional status is crucial for promoting postoperative tissue repair and reducing complications.

6.4. Metabolic Disorders and Insulin Resistance

As the body's central metabolic organ, the liver plays a central role in glucose metabolism, fatty acid oxidation, and protein synthesis [32]. Patients with liver disease often present with disorders of glucose and lipid metabolism as well as insulin resistance, and malnutrition can further deplete the body's metabolic reserves, amplifying the perioperative stress response [17]. Chronic insulin resistance promotes hepatocyte proliferation and inhibits apoptosis via the insulin-like growth factor-1 (IGF-1) signaling pathway, and is closely associated with the onset, progression, and postoperative recurrence of HCC [33]. Improving nutritional status and the metabolic environment may help reduce the risk of postoperative recurrence by inhibiting the IGF-1 pathway and lowering levels of oxidative stress.

6.5. The Muscle-Liver Axis and Mechanisms of Sarcopenia

Skeletal muscle is not only a motor organ but also a major metabolic and immunoregulatory organ. Sarcopenia is widely recognized as one of the key factors influencing outcomes after liver resection [26] [34]. A reduction in skeletal muscle mass is closely associated with an increased incidence of postoperative complications and reduced survival. The pathophysiological mechanisms involved include: 1) As a major reservoir of glutamine and branched-chain amino acids (BCAAs), skeletal muscle loss may reduce the substrates available for liver regeneration; 2) Reduced secretion of myokines, such as the anti-inflammatory factors irisin and IL-15, may weaken the ability of skeletal muscle to modulate systemic inflammation; 3) disruption of the "muscle-liver axis", characterized by abnormal BCAA metabolism, hyperammonemia, and a vicious cycle of protein-energy wasting [22].

Studies have shown that sarcopenia and low PNI often coexist and may mutually contribute to poorer outcomes [35] [36]. Wang *et al.* found that in elderly patients with ICC, a nomogram combining GNRI with skeletal muscle index (SMI), muscle atrophy, and visceral fat ratio showed significantly better predictive performance than TNM staging [22]. CT-measured skeletal muscle index (SMI) and psoas major index (PMI) have been demonstrated to be independent predictors of postoperative prognosis in patients with hepatocellular carcinoma [37]. Heil *et al.* found in 306 patients undergoing portal vein embolization (PVE) that sarcopenia predicted insufficient liver regrowth and reduced resection rates [34], while Baby *et al.* further confirmed the association between sarcopenia and limited regrowth of residual liver volume following PVE [36]. Therefore, combining traditional nutritional scores with indicators of sarcopenia may facilitate development of more precise perioperative risk-assessment models.

7. Perioperative Intervention Strategies Based on Nutritional Scores

7.1. Stratified Management Strategies Based on Nutritional Scores

With continued advances in precision medicine, nutritional assessment has evolved from simple risk stratification into a tool that can support clinical decision-making. Existing evidence indicates that perioperative stratification based on nutritional scores may facilitate early identification of high-risk patients and delivery of individualized nutritional support, thereby reducing postoperative complications and promoting recovery; however, current data are predominantly observational and demonstrate only associations, not causal benefits of score-guided intervention [32] [38].

Based on available observational evidence, we propose a provisional, expert-driven three-tiered assessment framework (not yet validated by prospective intervention trials): "NRS-2002 initial screening → PNI/CONUT in-depth assessment → supplementary evaluation for sarcopenia". All patients scheduled for liver resection should undergo NRS-2002 screening within 24 hours of admission. Patients with an NRS-2002 score < 3 and a PNI > 45 are considered to have low nutritional risk and should receive routine perioperative dietary guidance and oral nutritional supplements (ONS), managed according to Enhanced Recovery After Surgery (ERAS) principles [13]. Patients with an NRS-2002 score ≥ 3 or a PNI ≤ 45 should undergo further assessment of nutritional status and hepatic reserve, including the CONUT score, GNRI, ALBI classification, and CT-based assessment of sarcopenia (SMI and PMI), to enable more precise risk stratification [39]. For patients with severe malnutrition—defined as weight loss of ≥10% within the past 6 months, BMI < 18.5 kg/m^2, serum albumin < 30 g/L, or concomitant sarcopenia—a multidisciplinary team (MDT) comprising hepatobiliary surgery, clinical nutrition, anesthesiology, and physical medicine and rehabilitation should be assembled for comprehensive evaluation. Preoperative nutritional optimization for 7 - 14 days should be considered, provided that this does not delay cancer treatment [19]. This process establishes a closed-loop management model of "screening → assessment → intervention → reassessment".

7.2. Targeted Nutritional Intervention

Both the ESPEN and ERAS guidelines emphasize the importance of preoperative nutritional optimization. For patients at nutritional risk, enteral nutritional support should be prioritized, with recommended energy intake of 25 - 30 kcal/kg/day and protein intake of 1.2 - 1.5 g/kg/day; for patients with severe malnutrition or sarcopenia, protein intake may be increased to 1.5 - 2.0 g/kg/day [21]. Recent studies have shown that immunonutritional formulations containing omega-3 fatty acids, arginine, and nucleotides may enhance immune function and reduce the incidence of infection. For patients with low PNI or HALP scores, individualized perioperative immunonutritional support may be considered [23].

For patients with concomitant cirrhosis or portal hypertension, nutritional regimens should be adjusted according to liver function status: BCAA supplementation can improve protein metabolism and liver reserve capacity; patients with ascites require appropriate sodium restriction; and those with a history of hepatic encephalopathy protein intake should be increased cautiously [24] [40]. Yokoyama *et al.* emphasized the importance of preoperative "muscle and intestine training", which combines exercise training and bowel management with nutritional support [41].

7.3. Preoperative Prehabilitation

Prehabilitation has emerged as an important focus of perioperative management in recent years; its core concept is to enhance stress tolerance by improving patients' physiological reserves before surgery. For patients at high nutritional risk, a multimodal prehabilitation strategy combining nutritional support, exercise training, and psychological intervention is recommended. Nutritional intervention should focus on ensuring adequate protein and energy intake; exercise training should combine aerobic and resistance training; and psychological intervention may alleviate anxiety and depression while improving treatment adherence [42].

Existing studies indicate that multimodal prehabilitation can improve the preoperative functional status of patients undergoing liver resection, shorten hospital stays, and reduce the incidence of postoperative complications [43]. For patients with sarcopenia, prehabilitation may provide greater clinical benefits than nutritional support alone [44]. A systematic review and meta-analysis by Wagner *et al.* further confirmed that sarcopenia significantly impacts outcomes after liver resection in patients with colorectal liver metastases, highlighting the importance of preoperative screening and intervention for sarcopenia [44]. A study by Hayakawa *et al.* demonstrated that predictive models integrating surgical complexity and nutritional parameters can improve the accuracy of predicting postoperative complications [42].

8. Future Research Directions

8.1. Integrating Sarcopenia Indicators to Develop Precision Assessment Models

Continuous advancements in body composition analysis technologies are shifting nutritional assessment from a single biochemical marker toward a comprehensive evaluation paradigm that encompasses nutrition, immunity, and muscle. Numerous studies have confirmed that sarcopenia is an independent risk factor affecting postoperative complications and long-term survival following liver resection [34]. SMI and PMI measured by CT have been shown to predict prognosis in patients with hepatocellular carcinoma and biliary tract tumors, and sarcopenia is significantly associated with nutritional scores such as PNI and GNRI, suggesting a synergistic effect between the two [36]. Future research should further explore the development of a multidimensional nutrition-immunity-muscle assessment system and investigate its predictive performance across different tumor types (HCC vs. ICC vs. metastatic liver cancer), varying liver function statuses, and different surgical approaches.

8.2. AI-Assisted Individualized Prediction

In recent years, machine learning and artificial intelligence technologies have advanced rapidly in the field of hepatobiliary surgery, providing a new framework for integrating multidimensional clinical features. Wang *et al.* developed six machine learning survival prediction models (including Gradient Boosting and Random Survival Forest) based on 290 iCCA patients, integrating blood-based nutritional indicators such as ALBI, CONUT, and PNI, as well as CT-based nutritional indicators such as SMI and VSR. Among these, the Gradient Boosting model showed the best performance (training set C-index: 0.755, validation set C-index: 0.714). Time-dependent ROC curves, calibration curves, and decision curve analyses all confirmed its clinical utility [20].

The nomogram developed by Xu *et al.* can predict recurrence and RFS in patients with unresectable HCC following treatment with lenvatinib, PD-1 inhibitors, and interventional therapy leading to conversion to resectable status [28]. The combination of radiomics and machine learning may enable noninvasive prediction of short- and long-term postoperative outcomes preoperatively, supporting personalized treatment decisions [45]. Mami *et al.* developed and validated cut-off values for sarcopenia in patients with gastrointestinal and HPB tumors based on the GLIM criteria [45]. In the future, multimodal fusion models (integrating clinical, laboratory, radiomics, and deep learning features) are expected to substantially outperform the predictive performance of traditional scoring systems.

8.3. Strengthening the Evidence Base for Interventions

Although numerous observational studies have confirmed that nutritional scores such as PNI, CONUT, GNRI, HALP, and NPS are closely associated with outcomes after liver resection, high-quality evidence from prospective intervention studies remains limited [16] [44]. Most existing evidence comes from retrospective or systematic review studies, which is insufficient to determine whether preoperative interventions based on nutritional scores can significantly improve long-term survival outcomes. Multicenter randomized controlled trials are needed to determine the causal effects of nutritional optimization measures, such as preoperative immunonutrition, prehabilitation, and BCAA supplementation, on postoperative liver function recovery and survival outcomes.

8.4. Dynamic Monitoring and Multidisciplinary Collaboration Models

Perioperative nutritional status undergoes dynamic changes. A study by Peng *et al.* demonstrated that a postoperative decline in PNI (rather than a preoperative low PNI) is an independent risk factor for OS and RFS in patients with small HCC [46]. This finding has important clinical implications: nutritional assessment should not be limited to a single preoperative time point but should extend throughout the entire perioperative period and into the postoperative follow-up phase. The MDT management model plays a crucial role in improving the prognosis of liver cancer patients, particularly in those undergoing complex liver resections or with biliary tract tumors [10]. In the future, efforts could be made to establish an MDT collaboration model comprising the Department of Nutrition, Hepatobiliary Surgery, Rehabilitation Medicine, and Medical Oncology to provide patients with continuous nutritional monitoring and intervention throughout the care cycle.

8.5. Introduction of the Textbook Outcome (TO) Evaluation System

TO is an emerging comprehensive surgical quality evaluation indicator that has been increasingly applied in hepatobiliary surgery in recent years [47]. A systematic review by Sweigert *et al.* comprehensively summarized the current status of TO application in liver surgery [11], while Rashid *et al.* further compared TO attainment rates between staged and concurrent resection for the treatment of synchronous colorectal liver metastases [47]. Studies have shown that sarcopenia is significantly associated with failure to achieve TO, suggesting that body composition may influence overall perioperative quality. Nutritional status and inflammatory markers also affect the TO achievement rate, highlighting their potential value for comprehensive prognostic assessment [11]. Future research could incorporate indicators such as PNI, CONUT, NPS, and sarcopenia into TO prediction models to construct a more comprehensive surgical quality evaluation system.

9. Conclusions

Preoperative nutritional scoring is an important tool for perioperative risk assessment and prognostic management for patients undergoing liver resection. Available evidence indicates that scoring systems such as NRS-2002, PNI, CONUT, NRI, GNRI, HALP, and NPS can capture a patient's overall condition across multiple dimensions, including nutritional reserves, immune function, and inflammatory status. Among these, PNI and CONUT have the most robust evidence and greatest clinical utility—a meta-analysis by Zhang *et al.* (19 studies, 9830 patients) confirmed that low-PNI status is independently associated with shortened OS and RFS; GNRI demonstrates unique predictive value in elderly patients; and NPS, as an emerging scoring system, may provide better prognostic discrimination than traditional scores. Low PNI, high CONUT, low GNRI, low HALP, and high NPS are closely associated with an increased incidence of postoperative complications, a higher rate of PHLF, and reduced long-term survival.

However, the current evidence has several major limitations: 1) Cutoff values are not standardized across scoring systems; the PNI cutoff varies from 40 to 50 across different studies; 2) Existing evidence is primarily based on retrospective studies, with a lack of high-quality prospective RCT evidence; no formal risk-of-bias appraisal was conducted in this scoping review, and evidence strength claims are descriptive only; 3) The differential performance of nutritional scores across different etiologies and tumor types requires further clarification; 4) The complementary value of the GLIM criteria relative to traditional nutritional scores requires systematic evaluation.

Based on the existing literature, we propose adopting a provisional three-tier comprehensive assessment model (expert-driven, not prospectively validated by intervention trials): "NRS-2002 initial screening → PNI/CONUT in-depth assessment → supplementary evaluation for sarcopenia"—to enable early identification and targeted intervention for high-risk patients. At the same time, the GLIM criteria should be incorporated into routine clinical assessment, and preoperative multimodal prehabilitation strategies (nutritional support + exercise training + psychological intervention) should be considered to establish a full-cycle, closed-loop management system encompassing "screening → assessment → intervention → monitoring". With the deepening of research on sarcopenia, advances in artificial intelligence and radiomics technologies, the maturation of the TO evaluation system, and the advancement of high-quality interventional studies, nutritional assessment for patients undergoing liver resection is likely to evolve toward a multimodal, dynamic, precise, and individualized approach.

Author Contributions

Conceptualization, Z. C. Yang and H. F. Lu; writing—original draft preparation, Z. C. Yang; writing—review and editing, K. M. Zhang and Y. L. Yang; supervision, H. F. Lu; project administration, H. F. Lu. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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