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Predicting Outcomes in Hepatocellular Carcinoma Surgery: ALBI is the Better Tool. An Observational Cohort Study

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Rezumat

Predicția prognosticului în chirurgia carcinomului hepatocelular: scorul ALBI, instrument superior de evaluare. Studiu observațional de cohortă

Introducere: Rezecția hepatică rămâne o opțiune curativă principală pentru carcinomul hepatocelular (CHC), însă morbiditatea postoperatorie şi mortalitatea precoce continuă să fie factori limitativi importanți, în special la pacienții cu funcție hepatică compromisă. Stratificarea preoperatorie precisă a riscului este esențială pentru optimizarea rezultatelor.
Material şi Metode: A fost efectuat un studiu retrospectiv pe 55 de pacienți care au suferit rezecție hepatică pentru CHC între 2013 şi 2024, într-un centru terțiar unic. Scorurile preoperatorii MELD, ALBI şi Child-Pugh au fost calculate şi corelate cu morbiditatea postoperatorie şi mortalitatea la 30 de zile. Performanța predictivă a fost evaluată prin sensibilitate, specificitate, valori predictive şi curbe ROC.
Rezultate: Morbiditatea postoperatorie a fost de 23,6%, iar mortalitatea la 30 de zile de 9,1%. Scorul ALBI a prezentat cea mai bună specificitate (73,8%) şi valoare predictivă negativă (81,6%) pentru predicția complicațiilor, precum şi sensibilitate şi VPN de 100% pentru insuficiența hepatică postrezecție (PHLF), cu un AUC de 0,85. Pacienții cu ALBI Grad 1 au prezentat mai puține complicații şi durate reduse de spitalizare. MELD a avut o valoare predictivă moderată, utilă în excluderea mortalității. Child-Pugh a demonstrat cea mai slabă performanță, datorită sensibilității scăzute.
Concluzie: Scorul ALBI s-a dovedit a fi cel mai precis şi obiectiv instrument pentru identificarea pacienților cu risc crescut supuşi rezecției hepatice pentru CHC. Utilizarea sa preoperatorie ar putea îmbunătăți procesul decizional chirurgical şi stratificarea riscului. Scorurile MELD şi Child-Pugh oferă informații suplimentare, însă performanța lor este inferioară.

Cuvinte cheie: carcinom hepatocelular, rezecție hepatică, MELD, ALBI, Child-Pugh

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Abstract

Background: Hepatic resection is a key curative option for hepatocellular carcinoma (HCC), but postoperative morbidity and early mortality remain significant concerns, especially in patients with impaired liver function. Accurate preoperative risk stratification is essential to improve outcomes. This study compares the predictive value of three liver function scores – MELD, ALBI, and Child-Pugh – for postoperative morbidity and 30-day mortality.

Methods: A retrospective study was conducted on 55 patients who underwent hepatic resection for HCC between 2013 and 2024 at a single tertiary center. Preoperative MELD, ALBI, and Child-Pugh scores were calculated and analyzed in relation to postoperative complications and mortality. Diagnostic performance was assessed using sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and ROC curves.

Results: Postoperative morbidity occurred in 23.6% of patients, with a 30-day mortality rate of 9.1%. The ALBI score showed the highest specificity (73.8%) and NPV (81.6%) for morbidity prediction. It also demonstrated perfect sensitivity (100%) and NPV (100%) for post-hepatectomy liver failure (PHLF), with an AUC of 0.85. Patients with ALBI Grade 1 had fewer complications and shorter hospital stays. MELD showed moderate predictive value, particularly in ruling out mortality. The Child-Pugh score had the weakest performance, primarily due to low sensitivity.

Conclusion: ALBI is the most accurate and objective score for identifying high-risk patients undergoing liver resection for HCC. MELD provides additional value in mortality exclusion. The limited sensitivity of Child-Pugh suggests it should be used with caution. Incorporating ALBI into preoperative assessment may enhance surgical decision-making and risk stratification.

Keywords: hepatocellular carcinoma, hepatic resection, MELD, ALBI, Child-Pugh

Introduction

Hepatocellular carcinoma (HCC) is the most common primary liver malignancy and ranks as the third leading cause of cancer-related death globally. Curative treatment options for HCC include liver transplantation, local ablative therapies, and hepatic resection. For patients who are not candidates for transplantation and have resectable disease with preserved liver function, hepatic resection remains the primary potentially curative modality (1).

Despite advances in surgical techniques, perioperative care, and patient selection, hepatic resection for HCC still carries significant risks. Postoperative morbidity rates range from 20% to 50%, and 30-day mortality can reach up to 10%, particularly in patients with underlying chronic liver disease or compromised physiological reserve. Moreover, long-term survival outcomes are influenced not only by tumor biology but also by liver function and the patient's general health status. Therefore, accurate preoperative risk stratification is essential to optimize surgical outcomes, minimize perioperative complications, and guide patient counseling (2,3).

Several scoring systems have been developed to evaluate liver function and operative risk in patients with HCC. The Child-Pugh score, one of the oldest and most widely used systems, incorporates both clinical (encephalopathy, ascites) and biochemical (bilirubin, albumin, prothrombin time) parameters. However, its subjectivity and limited granularity may reduce its predictive accuracy in some clinical scenarios (4). The Model for End-Stage Liver Disease (MELD) score, originally developed to predict mortality in patients undergoing transjugular intrahepatic portosystemic shunt (TIPS) procedures, is an objective and widely validated tool that uses bilirubin, creatinine, and INR (international normalized ratio) to estimate short-term mortality. Its use has been extended to liver transplant prioritization and surgical risk assessment in patients with liver disease (5-7).

More recently, the Albumin-Bilirubin (ALBI) grade was introduced as a purely biochemical, objective model of liver function. Unlike the Child-Pugh and MELD scores, ALBI excludes subjective clinical parameters and relies only on serum albumin and bilirubin levels. It has been shown in several studies to correlate with postoperative outcomes and survival in patients with HCC (8-10).

While each of these scoring systems provides valuable insight into different aspects of patient health – hepatic function, physiological reserve, and comorbidity burden – their comparative utility in predicting outcomes after hepatic resection for HCC remains underexplored (11-13).

This study aims to compare the predictive value, sensitivity, and specificity of the ALBI grade, MELD score, and Child-Pugh classification in forecasting postoperative morbidity and early (30-day) mortality in patients undergoing hepatic resection for HCC. By identifying the most reliable and practical prognostic tools, we hope to improve patient selection, surgical planning, and ultimately clinical outcomes in this high-risk population.

Materials and Methods

Design and Setting

This is a single centre, single department, single surgeon, observational study on patients diagnosed with HCC based on medical history, imaging, or histopathological examinations. We retrospectively collected patients who underwent elective hepatic resection for hepatocellular carcinoma at our institution between 2013 to 2024. Every patient received the conventional oncological work-up and multidisciplinary meeting-based care. All patients were treated and followed at our institution.

Data Collection and Analysis

Statistical analysis was performed using Fisher's exact test for categorical variables and the independent-samples t-test for continuous variables. Data were collected from a prospectively maintained database on liver resections including perioperative, short-term and long-term outcomes data. Preoperative data included demographics: age, sex, BMI, comorbidities (diabetes, hypertension, cirrhosis, etc.) preoperative laboratory tests to calculate ALBI, MELD, and Child-Pugh scores. Each patient's preoperative status was assessed using the following scoring systems: Child-Pugh was calculated based on five parameters: total bilirubin, albumin, ascites, hepatic encephalo-pathy, and INR. Grade A: 5 - 6 scores; grade B: 7 - 9 scores; grade C: 10 - 15 scores. MELD= 9.57 × ln (creatinine (mg/dL) + 3.78 × loge (bilirubin (mg/dL)) + 11.2 × loge (INR) + 6.43. ALBI = 0.66 × log10 (bilirubin (µmol/L)) − 0.085 × (albumin (g/L)). ALBI is classified into three grades: grade 1 ≤ −2.6; grade 2 > −2.6 and ≤ −1.39; grade 3 > −1.39. Surgical data included tumor characteristics: tumor size, number of lesions, staging and operative details: type of resection, operative time, estimated blood loss.

The main postoperative outcomes were perioperative mortality and morbidity. Morbidity was defined as the development of one or more postoperative complications and was graded by Clavien-Dindo classification (Grade ≥III considered major morbidity). Early mortality was defined as death in hospital or within 30 days for the patients who are discharged from hospital.

Inclusion and Exclusion Criteria

Inclusion criteria were patients with histologically confirmed HCC on final resected specimen and with availability of complete preoperative laboratory and clinical data to calculate ALBI, MELD, and Child-Pugh scores (e.g., bilirubin, albumin, INR, creatinine, platelet count). Patients with Non-HCC liver tumors (cholangiocarcinoma, metastatic liver tumors) or with incomplete laboratory data were excluded to ensure accurate scoring (*Fig. 1*).

Results

Patient Characteristics

This study analyzed 55 patients who underwent liver resection for HCC, with a male predominance (65.4%) and a mean age of 66.5 ± 1.746 years. Viral hepatitis was the primary etiology of liver disease (74.5%), followed by toxic hepatitis (9.09%), while cirrhosis was present in 54.5% of cases. Common comorbidities included cardiac disease (61.8%), diabetes mellitus (25.4%), congestive heart failure (21.8%), smoking history (29.09%), respiratory disease (10.9%), renal disease (16.3%), and previous malignancies (21.8%). Preoperative laboratory tests indicated preserved liver function, with a mean total bilirubin of 0.952 ± 0.124 mg/dL, albumin of 4.32 ± 0.172 g/dL, and INR of 1.127 ± 0.035. Mean platelet count was 183.6 × 10^3/mm^3 (±24.08), and AST levels were elevated (87.9 ± 72.67 U/L). The mean Child-Pugh score was 5.236 ± 0.2, and the MELD score averaged 8.363 ± 0.46. Based on ALBI grading, 69.1% of patients were

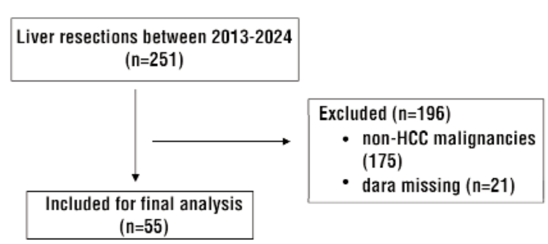

Figure 1. STROBE flowchart of eligibility

Table 1. Preoperative features of patients

Variable	n (%)/ mean (SD)
Total	55 (100%)
Gender (male to female ratio)	36 (65.4%) / 19 (34.6%)
Age, mean (SD)	66.5 ± 1.746
Comorbidities	
Toxic hepatitis	5 (9.09%)
Viral Hepatitis	41 (74.5%)
Cirrhosis	30 (54.5%)
Smoking	16 (29.09%)
Diabetes	14 (25.4%)
Cardiac disease	34 (61.8%)
• CHF	12 (21.8%)
Respiratory disease	6 (10.9%)
Renal disease	9 (16.3%)
Previous Malignancies (gynecological, otorhinolaryngology)	12 (21.8%)
Preoperative laboratory tests	
Total bilirubin (mg/dL)	0.952 ± 0.124
Albumin (g/dL)	4.3207 ± 0.172
INR	1.1267 ± 0.0349
PLT (mmc) x 1000	183.6182 ± 24.079
AST	87.8922 ± 72.667
ALT	44.04 ± 7.908
Scores	
Child-Turcotte-Pugh score	5.236 ± 0.2
A	50 (90.90%)
B	5 (9.09%
Meld score	8.363 ± 0.46
• < 9	33 (60%)
• > 9	22 (40%)
ALBI score	
• Grade 1	38 (69.1%)
• Grade 2	16 (29.1%)
• Grade 3	1 (1.8%)

CHF: chronic heart failure; PLT: platelets; AST: Aspartate Transferase; ALT: Alanine Transaminase;

classified as grade 1, 29.1% as grade 2, and only 1.8% as grade 3, indicating an overall preserved hepatic reserve (*Table 1*).

Of the 55 patients included, 5.45% presented with multiple liver lesions. Most patients underwent atypical resections (65.5%), while hepatectomies and segmentectomies were performed in 20% and 14.5% of cases, respectively. The mean intraoperative blood loss was 672.7 ± 265.1 mL, and the average operative time was 225.3 ± 25.3 minutes. The mean hospital stay was 13 ± 1.3 days. Hospital mortality was 9.09% (*Table 2*).

Postoperative Outcomes

Overall, of the 55 patients included in the study, postoperative morbidity was observed in 13 patients, accounting for 23.6% of the total cohort. Surgical complications were relatively low. No cases of bile leak, bleeding/hematoma or liver abscess were reported. Wound infection occurred in

Table 2. Surgical and postoperative features of patients

Total	55 (100%)
Number of liver lesions (≥ 2)	3 (5.45%)
Type of hepatic resection	
• Right hepatectomies	3 (5.45%)
• Left hepatectomies	3 (5.45%)
• Left lateral sectionectomy	5 (9.09%)
• Segmentectomy	8 (14.5%)
• Atypical resections	36 (65.5%)
Blood loss (ml)	672.7273 ± 265.112
Operative time (min)	225.3273 ± 25.275
Hospital stay (days)	13 ± 1.257

1 patient (1.81%) and ascites in 3 patients. Medical complications included liver failure in 2 patients (3.63%), pulmonary embolism in 1 patient (1.81%), and pneumopathy in 3 patients (5.45%). Cardiovascular complications were seen in 6 patients (10.9%), while renal issues, MODS (multiple organ dysfunction syndrome), and other complications each affected 3 patients (5.45%). One patient (1.81%) required reintervention. Notably, there were no cases of deep venous thrombosis or other thrombotic events. The average ICU stay was 3.62 ± 0.92 days. The 30-day mortality rate stood at 9.09%, with 5 patients dying within the first month post-surgery (*Table 3*).

Predictors of Perioperative Morbidity

Perioperative morbidity was recorded in 13 patients (23.6%), while 42 patients (76.4%) had an

Table 3. Postoperative outcomes

	n (%) /mean (SD)
Total	55 (100%)
Morbidity	13 (23.6%)
Surgical complications	
Bile leak	0
Bleeding/Hematoma	0
Ascites	3 (5.45%)
Wound infection	1 (1.81%)
Medical complications	
Liver failure	2 (3.63%)
DVT (deep venous thrombosis)	0
Other thrombosis	0
Pulmonary embolism	1 (1.81%)
Pneumopathy	3 (5.45%)
Cardiovascular	6 (10.9%)
Renal	3 (5.45%)
Mods	3 (5.45%)
Reintervention	1 (1.81%)
Length of ICU stay (days)	3.6182 ± 0.922
30-day Mortality	5 (9.09%)

uneventful postoperative course. No significant association was found between gender and the occurrence of complications (males: 22.2% vs females: 26.3%, p = 0.995). Patients with complications were older compared to those without (68.4 ± 3.5 vs 66.3 ± 1.7 years, p = 0.0042).Regarding comorbidities, no significant differences were observed between groups in terms of toxic or viral hepatitis, cirrhosis, or renal disease. However, the presence of cardiac comorbidities showed a significant association with postoperative morbidity (69.2% vs 60.9%, p = 0.049). Preoperative MELD and ALBI scores, as well as Child-–Pugh class, were not significantly associated with postoperative morbidity (p > 0.05). Among operative variables, patients undergoing major hepatic resections exhibited a higher complication rate compared to those with minor resections (42.1% vs 13.9%), although this difference did not reach statistical significance (p = 0.30).

Intraoperative factors were significantly correlated with postoperative morbidity: patients with complications had higher intraoperative blood loss (969.23 ± 425.04 ml vs 580.95 ± 316.16 ml, p = 0.0035) and longer operative times (291.92 ± 61.8 min vs 204.71 ± 23.77 min, p = 0.0028). The 30-day postoperative mortality rate was 8.4%, occurring exclusively in the group with complications (p = 0.009).

Table 4. Relationship between variables and morbidity

	Complications		p value
	Yes	No	
Total	N=13	N=42	
Gender			0.995
• Males	8 (22.2%)	28 (77.8%)	
• Females	5 (26.3%)	14 (73.7%)	
Age, mean (SD)	68.4 ± 3.5	66.3 ± 1.7	0.0042
Comorbidities			
Toxic hepatitis			0.324
Yes	0 (0%)	5 (100%)	
No	13 (26%)	37 (74%)	
Viral Hepatitis	10 (24.4%)	31 (75.6%)	1.000
Cirrhosis	7 (23.3%)	23 (76.7%)	1.000
Cardiac disease	9 (26.5%)	25 (73.5%)	0.689
• CHF	0	12 (100 %)	0.049
Respiratory disease	2 (33.3%)	4 (66.7%)	0.049
Renal disease	3 (33.3%)	6 (66.7%)	0.428
Scores			
MELD			0.461
• < 9	6 (18.2%)	27 (81.8%)	0.351
• > 9	7 (31.8%)	15 (68.2%)	
ALBI			
• Grade 1	7 (18.4%)	31 (81.6%)	0.190
• Grade 2	6 (37.5%)	10 (62.5%)	0.165
• Grade 3	0 (0%)	1 (100 %)	1.000
Child-Pugh score	5.15 ± 0.3	5.26 ± 0.2	1.000
Child-Pugh class			
• A	12 (24 %)	38 (76 %)	1.000
• B	1 (20 %)	4 (80 %)	1.000
Operative factors			
Resections			
• Major resections	8 (42.1 %)	11 (57.9 %)	0.30
• Minor resections	5 (13.9 %)	31 (86.1 %)	
Blood loss	969.23 ± 425.04	580.95 ± 316.16	0.0035
Operation time	291.92 ± 61.8	204.7143 ± 23.77	0.0028
30 - days mortality	5 (100%)	0 (0%)	0.0090

Fisher's exact test was used to compare number of events between groups as for some variables there were less than 5 observations; Chi-square test was used when expected frequencies > 5; t-test was used to compare means between the 2 groups;

Predictors of Perioperative Mortality

Of the 55 patients included in the study, 5 deaths (9.1%) occurred within 30 days post-operatively (*Table 4*). All deaths occurred in the group that experienced postoperative complications, indicating a strong association between postoperative complications and short-term mortality.

In terms of liver function scores, 53.9% of patients with complications – and hence a higher mortality rate – had a MELD score greater than 9, compared to 35.7% in the no-complications group. A similar trend was observed in the ALBI classification: 46.2% of patients with complications (including those who died) had ALBI Grade 2, compared to only 23.8% in the no-complications group. Notably, no patients in the mortality group had ALBI Grade 3, possibly due to preoperative selection. Child-Pugh scores were similar between groups (5.15 vs. 5.26) and all deaths occurred in patients classified as Child-Pugh Class A (12 of 13 patients with complications were Class A, including all four deaths), suggesting limited sensitivity of this score in predicting early mortality in this context.

Operative factors also showed notable associations. Major resections were more frequent among patients who died: 61.5% of those with complications (where most deaths occurred) underwent major resections compared to 26.2% in the no-complications group. Blood loss and operative time were considerably higher in the complication group – both known risk factors for postoperative mortality – with mean blood loss at 969.23 ± 425.04 mL and operative time at 291.92 ± 61.8 minutes. In contrast, patients without complications and notably those who survived, had significantly lower blood loss (580.95 ± 316.16 mL) and shorter operative times (204.71 ± 23.77 minutes).

MELD, ALBI, Child-Pugh Scores and Perioperative Mortality, Morbidity, and Hospital Stay - Specificity, Sensitivity, PPV, and NPV

MELD score

In evaluating the predictive performance of the MELD score for postoperative outcomes, a MELD score greater than 9 demonstrated a sensitivity of 60%, specificity of 62%, PPV of 13.6%, and NPV of 93.9% for predicting postoperative mortality. For predicting all postoperative complications (morbidity), the MELD > 9 cut-off yielded a sensitivity of 53.8%, specificity of 64.3%, PPV of 31.8%, and NPV of 81.8%. These results suggest that while the MELD score has moderate sensitivity and specificity, its strongest utility lies in its high negative predictive value for mortality (*Table 5*).

The MELD score, evaluated using a cut-off value of >9 to define high risk, demonstrated moderate sensitivity and specificity in predicting both morbidity and mortality. While its positive predictive value (PPV) was low (31.8% for complications, 13.6% for mortality), the negative predictive value (NPV) was considerably higher (81.8% and 93.9%, respectively).

Table 5. MELD score and perioperative mortality, morbidity, and hospital stay

Variable	MELD < 9 (n=33)	MELD > 9 (n=22)	p value
Mortality	2 (6.06%)	3 (13.64%)	0.061
All complications	6 (18.18%)	7 (31.82%)	0.46
Surgical complications	2 (6.06%)	1 (4.55%)	0.96
Hepatic failure	2 (6.06%)	1 (4.55%)	0.400
Ascites	1 (3.03%)	2 (9.09%)	0.55
Hematoma/bile leak	0 (0%)	0 (0%)	-
Blood loss (ml)	720.9677±419.959	575±273.855	0.0063
Medical complications	5 (15.15%)	5 (22.73%)	<0.9
Hospital stay (days)	12.1935±1.492	13.6087±1.976	0.009

For categorical variables such as mortality, overall complications, surgical complications, hepatic failure, ascites, and medical complications, the statistical comparison between MELD <9 and MELD >9 groups was performed using the Fisher's exact test, due to the small sample sizes and the presence of low expected frequencies in some categories (i.e., event counts <5).For the hematoma/bile leak variable, no statistical test was applied because both groups had zero events, making comparison impossible.

For continuous variables such as blood loss and hospital stay, an independent-samples t-test was used to compare the two groups, under the assumption of approximate normal distribution of the data. A p-value < 0.05 was considered statistically significant.

ALBI score

In assessing the predictive value of the ALBI score for postoperative outcomes, patients were stratified into ALBI Grade 1 versus Grades 2-3. Of the 17 patients with ALBI Grade ≥ 2, 2 (11.8%) experienced postoperative mortality and 6 (35.3%) developed complications. In contrast, among the 38 patients with ALBI Grade 1, 3 (7.9%) died and 7 (18.4%) had complications (*Table 6*).

For postoperative mortality, the ALBI score had a sensitivity of 40%, specificity of 70%, PPV of 11.8%, and NPV of 92.1%. For postoperative morbidity, sensitivity was 46.2%, specificity 73.8%, PPV 35.3%, and NPV 81.6.%.

The ALBI score – when stratified into grade 1 versus grades 2-3 – exhibited a comparable pattern of performance. Sensitivity values remained modest (40% for mortality, 46.2% for complications), but the NPV remained high (92.1% and 81.6%, respectively). These findings reinforce the concept that ALBI grade 1 identifies a relatively low-risk group, while higher grades do not necessarily correlate with poor outcomes.

Table 6. ALBI score and perioperative mortality, morbidity, and hospital stay

Variable (n=38)	ALBI GRADE 1 (n=16)	ALBI GRADE 2 (n=1)	ALBI GRADE 3	p value
Mortality	3 (7.89%)	2 (12.5%)	0 (0%)	0.985
All complications	7 (18.42%)	6 (37.5%)	0 (0%)	0.251
Surgical complications	0 (0%)	3 (18.75%)	0 (0%)	0.036
Hepatic failure	0 (0%)	1 (6.25%)	0 (0%)	0.652
Ascites	1 (2.63%)	2 (12.5%)	0 (0%)	0.152
Blood loss (ml)	747.3684 ±369.032	518.75 ±226.687	-	0.001
Medical complications	7 (18.42%)	3 (18.75%)	0 (0%)	1.000
Hospital stay (days)	12.4737 ±1.449	14.3125 ±2.497	-	<0.001
Type of resection				
Major resection n=19	17	2	0	0.0014
Minor resection n=36	21	14	1	

Categorical variables such as mortality, all complications, surgical complications, hepatic failure, ascites, and medical complications were analyzed using the Chi-square test when all expected cell frequencies were ≥ 5. In instances where cell counts were small or included a subgroup with only one patient (e.g., ALBI Grade 3), the Fisher's exact test was applied to ensure statistical reliability. Continuous variables, such as blood loss and hospital stay, were reported as mean ± standard deviation. T-test was used for comparing means;

Importantly, the ALBI score also demonstrated higher specificity compared to MELD, particularly for morbidity (73.8%), indicating better performance in correctly classifying those without complications.

In terms of type of resections, patients with ALBI Grade 1 underwent significantly more extensive surgical procedures compared to those with ALBI Grade 2. Specifically, 44.73% of the patients in the ALBI Grade 1 group underwent major and complex hepatic resections, while this type of procedure was performed in only 12.5% of the ALBI Grade 2 group (p = 0.0014). Conversely, minor resections were predominant in ALBI Grade 2 patients, accounting for 87.5% of cases. Consistent with the greater surgical extent, intraoperative blood loss was significantly higher in ALBI Grade 1 patients, with a mean value of 747.36 ± 369.03 ml, compared to 518.75 ± 226.68 ml in the ALBI Grade 2 group (p = 0.001).

Table 7. Child-Pugh score and perioperative mortality, morbidity, and hospital stay

Variable	Child Pugh A (n=50)	Child Pugh B (n=5)	p value
Mortality	4 (8%)	1 (20%)	0.391
All complications	12 (24%)	1 (20%)	1.000
Surgical complications	2 (4%)	1 (20%)	0.253
Hepatic failure	1 (2%)	0 (0%)	1.000
Ascites	2 (4%)	1 (20%)	0.175
Blood loss (ml)	702 ±289.085	380 ±273.839	0.0005
Medical complications	10 (20%)	0 (0%)	0.572
Hospital stay (days)	12.98 ±1.338	13.2 ±3.48	0.0005
Type of resection			1.000
Major resection n=20	18 (36%)	2 (40%)	
Minor resection n=35	32 (64%)	3 (60%)	

For categorical variables – including mortality, all complications, surgical complications, hepatic failure, ascites, medical complications, and type of resection – the Fisher's exact test was used due to the small number of patients in the Child-Pugh B group (n = 5), which leads to low expected cell frequencies. For continuous variables such as blood loss (ml) and hospital stay (days), the independent-samples t-test was used to compare the means between the two groups (Child-Pugh A vs B). These variables were reported as mean ± standard deviation.

Child-Pugh Score

Of all 55 patients undergoing liver resection, 50 were classified as Child-Pugh A and 5 as Child-Pugh B. Postoperative mortality was 8% in Child-Pugh A group and 20% in Child-Pugh B group, with no statistically significant difference (p = 0.391). Overall complications occurred in 24% of Child-Pugh A and 20% of Child-Pugh B patients (p = 1.000), while surgical complications were observed in 4% and 20% of cases, respectively (p = 0.253). Medical complications were reported in 20% of Child-Pugh A patients, with none observed in the Child-Pugh B group (p = 0.572). Hepatic failure was recorded in one Child-Pugh A patient (p = 1.000), and ascites occurred in 4% of Child-Pugh A and 20% of Child-Pugh B patients (p = 0.175). Intraoperative blood loss was significantly higher in Child-Pugh A patients (702 ± 289 ml) compared to Child-Pugh B patients (380 ± 274 ml; p = 0.000). The mean length of hospital stay was similar between groups (12.98 ± 1.34 days for Child-Pugh A and 13.2 ± 3.48 days for Child-Pugh B; p = 0.000). Major liver resections were performed in 36% of Child-Pugh A and 40% of Child-Pugh B patients (p = 1.000) (*Table 7*).

Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of Child-Pugh B in predicting mortality were 20%, 92%, 20%, and 92%, respectively. For morbidity, sensitivity was 7.7%, specificity 90.5%, PPV 20%, and NPV 76%.

Comparing scores in predicting postoperative morbidity

In *Fig. 2*, this ROC analysis for postoperative morbidity prediction, the area under the curve (AUC) provides a single numerical summary of the overall discriminative ability of each score: ALBI Score shows the highest AUC (~0.60) among the three, suggesting a slightly better ability to differentiate between patients with and without complications. MELD Score follows closely with an AUC of approximately 0.59, reflecting moderate diagnostic accuracy. Child-Pugh Score has the lowest AUC (~0.51), indicating a performance close to random chance due to its very low sensitivity.

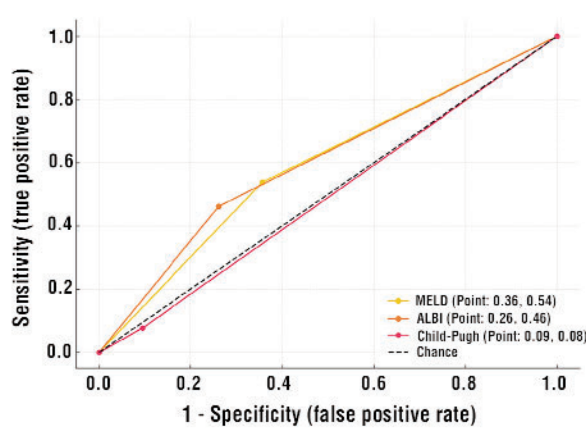

Figure 2. ROC curve comparison for morbidity prediction

Although none of the scores reach strong predictive accuracy (AUC > 0.7), ALBI and MELD show slightly better clinical utility compared to Child-Pugh, especially when used to rule out patients at low risk.

Predictive performance of hepatic scores for post-hepatectomy liver failure

The ALBI score emerged as the most reliable predictor, with an AUC of 0.85, indicating excellent discriminative power. Notably, ALBI achieved a sensitivity of 100%, meaning it correctly identified all patients who developed PHLF, and a specificity of 71.7%. Furthermore, its negative predictive value (NPV) was 100%, suggesting that patients with low ALBI scores are highly unlikely to develop PHLF. Despite a relatively modest positive predictive value (PPV) of 11.8%, the overall utility of ALBI as a screening tool is supported by its high sensitivity and NPV.

In contrast, the MELD score demonstrated limited predictive accuracy with an AUC of 0.54. Its sensitivity was only 50%, and the PPV remained low at 10%, although the NPV was high (97.8%), indicating that MELD may be better suited for ruling out rather than confirming PHLF risk.

The Child-Pugh score performed the weakest, with an AUC of 0.45, reflecting poor discriminative ability. It failed to identify any patients with liver failure (sensitivity = 0%), although it did achieve perfect specificity (100%) (*Fig. 3*).

The ALBI score demonstrated the highest predictive accuracy with an AUC of 0.85, followed by the MELD score (AUC = 0.54). The Child-Pugh score, approximated from categorical classes, showed the weakest predictive power (AUC = 0.45). These results indicate that ALBI is a superior tool compared to MELD and Child-Pugh in identifying patients at risk for PHLF in this cohort.

Comparing scores in predicting postoperative mortality

In *Fig. 4*, MELD Score shows the highest AUC (~0.61), indicating slightly better discrimination than the others. ALBI Score has an AUC of about 0.55, suggesting modest performance. Child-Pugh Score trails slightly behind with an AUC around 0.56, largely due to its very low sensitivity. All three scores show better-than-random performance, but none is a strong stand-alone predictor. Their strength lies more in ruling out high-risk patients (due to high NPVs), rather than definitively identifying them.

Discussion

In this observational cohort study, the ALBI score emerged as the most effective tool for preoperative risk stratification in patients undergoing hepatic resection for HCC. Our findings demonstrated that ALBI offered the highest sensitivity and negative predictive value for predicting postoperative morbidity and, more notably, post-hepatectomy liver failure. Patients categorized as ALBI grade 1 exhibited significantly fewer postoperative compli-

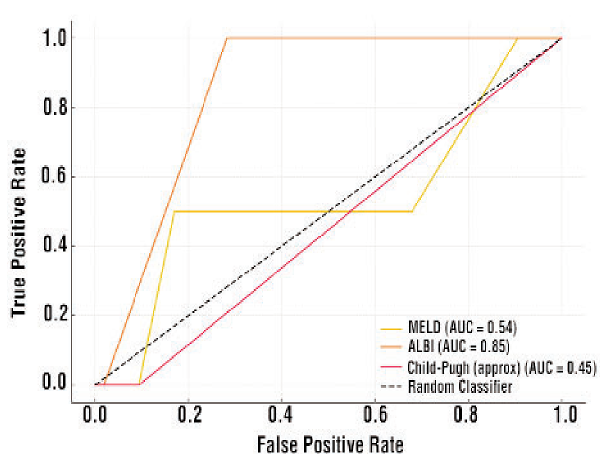

Figure 3. ROC curves comparing the predictive performance of MELD, ALBI, and Child-Pugh scores for posthepatectomy liver failure (PHLF).

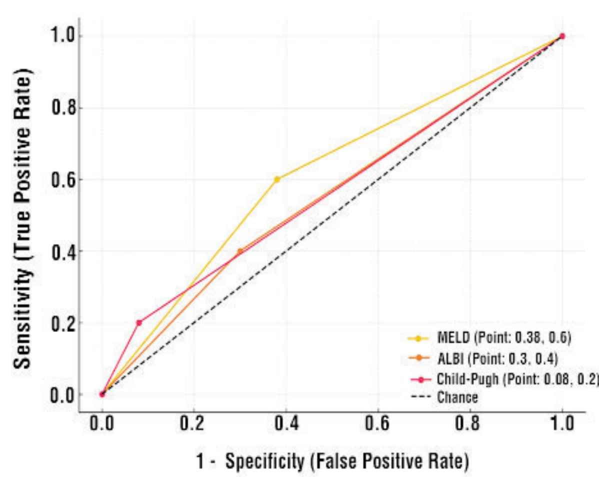

Figure 4. ROC Curve Comparison for Mortality Prediction.

cations and shorter hospital stays, suggesting a lower perioperative risk profile. In contrast, while MELD and Child-Pugh scores maintained moderate utility, particularly in excluding early mortality, their overall predictive performance was inferior to ALBI. Importantly, none of the evaluated scoring systems reached an area under the curve exceeding 0.7 for general morbidity prediction, but ALBI reached an excellent AUC of 0.85 for PHLF prediction, underlining its role as a reliable screening tool for this critical complication.

One of the most significant findings of our analysis was the exceptionally high NPV associated with ALBI. In our cohort, an ALBI grade 1 classification effectively ruled out the occurrence of severe postoperative complications and PHLF, achieving an NPV of 81.6% for morbidity and 100% for PHLF. This remarkable NPV is of critical clinical importance because it provides surgeons with a reliable tool to identify patients who are unlikely to experience severe postoperative liver dysfunction. In practical terms, ALBI can be used as a gatekeeping tool, allowing confident selection of candidates for major hepatic resections with minimized postoperative risks (14,15).

Moreover, patients with ALBI grade 1 not only demonstrated a lower incidence of complications but also experienced shorter hospital stays, indicating a smoother postoperative course and likely reduced healthcare resource utilization. This suggests that ALBI could serve as a valuable parameter not only for predicting immediate surgical risk but also for optimizing perioperative management strategies, including enhanced recovery pathways.

Importantly, the predictive strength of ALBI for PHLF, reflected by an area under the ROC curve of 0.85, was particularly noteworthy. The high sensitivity (100%) achieved for PHLF prediction underscores the potential of ALBI as a screening test: a low ALBI score reliably excludes the likelihood of developing severe postoperative liver failure. Although its PPV remained moderate (11.8%), this is a common characteristic of tests designed primarily to rule out conditions with relatively low incidence rates.

Another aspect that supports the clinical relevance of ALBI is its purely objective nature. Unlike Child-Pugh, which relies on subjective clinical variables such as ascites or encephalopathy, ALBI is calculated using only serum albumin and bilirubin values. These biochemical parameters are easily obtainable, reproducible across institutions, and minimally influenced by examiner variability. This objectivity not only enhances the reliability of ALBI but also facilitates its integration into routine clinical workflows without additional burden on healthcare teams.

In our cohort, ALBI grading also demonstrated a clear stratification of risk. Although the number of patients classified as ALBI grade 3 was very low (only one patient, reflecting a relatively well-preserved liver function cohort), there was a discernible trend of increasing complication rates with worsening ALBI grade. Patients with ALBI grade 2 had a notably higher morbidity rate compared to those with grade 1. Although this did not reach statistical significance, likely due to the limited sample size, it supports the general concept that ALBI stratification corresponds well to postoperative risk profiles.

An interesting fact is that, in the present study, patients with ALBI grade 1 experienced significantly higher intraoperative blood loss compared to those with ALBI grades 2 and 3 ($p=0.001$). At first glance, this result may seem counterintuitive, since ALBI grade 1 reflects better baseline liver function and is generally associated with a lower perioperative risk profile. However, this finding is consistent with the surgical strategy applied in our cohort, where patients with ALBI grade 1 were more frequently selected for major or complex liver resections, given their preserved hepatic functional reserve. In our series, a significant proportion of ALBI grade 1 patients underwent extensive procedures, such as right or left hemihepatectomies, and anatomical segmentectomies and bi-segmentectomies. In several cases, surgery also involved vascular reconstruction (portal vein or hepatic vein resection and reconstruction), when oncologic radicality required it. These types of procedures are inherently associated with longer operative times, larger transection planes, and consequently, a higher risk of intraoperative bleeding.

Conversely, patients with ALBI grades 2 and 3, who present with impaired liver function, were mostly indicated for limited resections, such as minor non-anatomical (parenchymal sparing) resections. These approaches are less invasive and generally associated with lower blood loss, in line with the goal of reducing the risk of postoperative liver failure.

Additionally, the relatively small number of patients in the ALBI grade 2 and 3 subgroups may have contributed to variability and should be considered when interpreting the results. Nevertheless, the observed differences reflect a typical clinical scenario in hepatobiliary surgery, where patients with better liver function are selected for more extensive surgical interventions, which inherently lead to increased intraoperative blood loss.

Furthermore, while MELD and Child-Pugh scores showed some ability to predict mortality and morbidity, their performance was inferior to that of ALBI when focused on liver-specific outcomes such as PHLF (16). The partial dependence of MELD on renal function parameters and the inherent subjectivity of Child-Pugh may dilute their specificity for assessing hepatic functional reserve in the surgical setting. By contrast, ALBI directly measures two core elements of hepatic physiology: synthetic capacity (albumin) and excretory function (bilirubin).

Multiple studies have confirmed the predictive value of the ALBI score in various HCC treatment settings. Johnson et al. (2015) were the first to propose the ALBI grading system, demonstrating that it more accurately stratifies liver function and prognosis in HCC patients compared to Child-Pugh (16). In a multicenter study, Toyoda et al. (2016) validated ALBI as a superior predictor of overall survival and postoperative liver failure following hepatic resection (17). Their study included over 600 patients and confirmed that ALBI grading, particularly when combined with tumor characteristics, provided better prognostic stratification than traditional methods. Similarly, Hiraoka et al. (2017) reported that ALBI correlated with hepatic decompensation and short-term mortality post-resection. In their cohort, higher ALBI grades were associated with significantly increased risk of postoperative liver failure (18). Wang et al. (2020) conducted a meta-analysis of 15 studies and over 3,000 patients, concluding that ALBI consistently outperformed both MELD and Child-Pugh in predicting postoperative complications and long-term survival after hepatic resection for HCC (19). Also, our findings align with emerging recommendations, including those from the EASL 2022 Clinical Practice Guidelines, which now recognize the ALBI score as a valuable adjunct in preoperative assessment for liver-directed therapies (20).

Limitations

This study has several limitations. First, the retrospective design inherently introduces potential for selection bias and confounding factors. Data were collected from existing medical records, which may suffer from incomplete documentation or variability in recording practices. Also, the relatively small sample size (n=55) reduces the statistical power of the analysis and limits the generalizability of the conclusions. A larger cohort would provide a more robust validation of our findings and allow for more granular subgroup analyses, such as evaluating score performance by extent of resection or severity of underlying liver disease. In addition, all procedures were performed in a single tertiary center by a specialized surgical team. While this ensures consistency in surgical technique and perioperative care, it also limits the external validity of the results. Outcomes might differ in institutions with varying levels of expertise or different patient populations.

In summary, the findings of this study reinforce the ALBI score as the most effective and clinically practical tool among the three evaluated scoring systems for predicting postoperative outcomes in patients undergoing hepatic resection for hepatocellular carcinoma. With its high sensitivity and negative predictive value for post-hepatectomy liver failure and morbidity, ALBI offers superior discriminative ability compared to MELD and Child-Pugh, particularly in ruling out high-risk patients. Unlike the Child-Pugh score, which showed limited sensitivity and failed to differentiate risk within the class A population, ALBI provides a nuanced, objective evaluation of hepatic reserve that correlates strongly with post-operative outcomes.

Future studies on larger, multicentric cohorts are warranted to validate these findings and refine preoperative risk stratification models that can guide surgical decision-making in HCC patients.

Conclusion

This study assessed preoperative liver function scores in patients undergoing hepatic resection for HCC, identifying the ALBI score as the most effective predictor of postoperative morbidity and PHLF. ALBI demonstrated superior sensitivity and negative predictive value compared to MELD and Child-Pugh scores. While MELD showed moderate utility, particularly in excluding mortality risk, Child-Pugh exhibited the weakest predictive performance. Incorporating ALBI into preoperative evaluation may improve surgical planning, patient selection, and clinical outcomes, supporting its use as the preferred risk stratification tool in HCC surgery.

Conflicts of Interest and Source of Funding

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