

Development and Validation of a Preoperative Risk Score for Difficult Laparoscopic Cholecystectomy: A Retrospective Study in Resource-Limited Settings

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Abstract

Background

Laparoscopic cholecystectomy (LC) is one of the most common surgical procedures worldwide. Yet, reliably identifying patients at high risk for intraoperative conversion or major complications preoperatively remains challenging. In this study, we investigated factors associated with difficult LC and developed and validated a simple preoperative scoring system to predict it.

Patients and Methods:

We conducted a single-center, retrospective cohort study at Ibb University Hospitals, Yemen. Data were extracted from records of 301 consecutive patients who underwent LC between April 2020 and November 2024. The primary outcome, "surgical difficulty," was a composite endpoint of conversion to open surgery or major intraoperative complications. Multivariable logistic regression was used to identify independent predictors and derive an integer-based risk score. Model performance was evaluated using the Area Under the Receiver Operating Characteristic Curve (AUC), calibration plots, and Decision Curve Analysis (DCA).

Results

Of 301 patients, 37 (12.3%) experienced difficult LC. Multivariable analysis identified three key predictors: right upper quadrant rigidity (adjusted OR 8.50, 95% CI 4.21–17.15; 2 points), impacted stone on ultrasound (aOR 7.24, 95% CI 3.10–16.90; 2 points), and prior acute cholecystitis (aOR 3.16, 95% CI 1.45–6.88; 1 point). This yielded a 5-point Chole-Risk Score with excellent discrimination (AUC 0.848, 95% CI 0.789–0.907). At the optimal cutoff of ≥ 3 points, sensitivity reached 73.7% and specificity 86.5%. Calibration was strong (Hosmer-Lemeshow $p = 0.612$), and DCA showed superior clinical utility across a broad threshold range.

Conclusion

The Chole-Risk Score is a reliable, bedside-accessible tool for predicting difficulty in LC. In settings like Ibb, Yemen, where advanced preoperative imaging may be limited, this score allows for the identification of high-risk cases, facilitating early senior surgical involvement and improving patient safety.

Introduction

Cholelithiasis is one of the most common conditions affecting the biliary system worldwide. Cholelithiasis prevalence varies greatly worldwide primarily due to age, female sex, ethnicity and geography, obesity, rapid weight loss, metabolic syndrome components like diabetes and

hypertriglyceridemia, Westernized diets high in refined carbohydrates and low in fiber, genetic predisposition, pregnancy or parity, and liver diseases such as cirrhosis or hepatitis C (1, 2). In the United States, gallstone disease affects approximately 20 million adults (10% prevalence among those aged 20–74), with symptomatic cases driving around 2 million ambulatory visits and 1 million emergency department visits annually (3). In Yemen, the prevalence is roughly 4.5%; however, this number is increasing quickly because of changes in diets, shifting social structures such as chewing khat, and better access to ultrasound in both rural and urban areas (4, 5).

The 1992 NIH Consensus Development Conference marked a turning point, establishing laparoscopic cholecystectomy (LC) as the safe gold standard for symptomatic gallstones (6). Today, LC is the preferred approach, delivering less postoperative pain, shorter hospital stays, better cosmesis, and quicker recovery compared to open surgery (7).

As laparoscopic surgical proficiency has increased around the world, the initial absolute contraindications have been increasingly reevaluated. Conditions previously thought to be prohibitive, such as excessive obesity and a history of upper abdominal surgery, are now regularly treated with laparoscopic surgery. The few absolute contraindications that remain now are primarily limited to patients deemed medically incompetent for general anesthesia, untreated bleeding diatheses, and probable gallbladder cancer (8).

Despite these improvements, "difficult" cholecystectomies continue to pose challenges. Of all laparoscopic cholecystectomies (LC), 2–10% require conversion to open surgery due to intraoperative challenges such as adhesions, inflammation, or unclear anatomy (9). Various validated preoperative risk prediction models for difficult LC share fundamental characteristics identified through multivariate analyses, although they vary regarding the specific weights and cut-off values assigned to individual predictors. Several established scoring systems, such as the Randhawa/Pujahari (threshold > 5 points), Nassar, and CAAD systems, have undergone rigorous validation (10–14). These models are increasingly recognized for their ability to integrate clinical and ultrasonographic variables to optimize surgical planning and improve patient safety.

Consistently identified risk factors in the literature include advanced age (typically > 50 to 60 years), male sex, and an elevated body mass index (> 25 to 30 kg/m²). These factors often correspond to increased tissue friability, complex anatomical variations, and technical challenges in surgical exposure (15, 16). Furthermore, a clinical history of acute cholecystitis or multiple hospital admissions is frequently cited as the most heavily weighted predictor, as it reflects chronic inflammatory changes that substantially complicate the operative procedure (16, 17).

Objective risk stratification is further enhanced by combining physical findings, such as a palpable gallbladder, with ultrasonographic parameters, including a gallbladder wall thickness exceeding 4 mm, the presence of impacted stones, and pericholecystic fluid (15, 18). These predictive models have demonstrated high diagnostic accuracy, with reported Area Under the Curve (AUC) values ranging from 0.78 to 0.95, sensitivities reaching 95 percent, and specificities exceeding 80 percent (19, 20).

Consequently, the implementation of such scores facilitates proactive surgeon allocation, enhanced theatre scheduling, and a measurable reduction in conversion rates to open surgery.

Despite the proliferation of predictive scoring systems in high-resource healthcare environments, their applicability in low-to-middle-income countries remains a subject of ongoing debate. In regions like Yemen, patients often present with advanced biliary disease due to delayed referrals, limited access to elective surgical services, and socioeconomic barriers to early diagnosis. These local factors may alter the predictive weight of traditional variables, rendering international models less accurate or overly complex for rapid bedside use. Furthermore, many existing scores rely on high-resolution imaging or specific laboratory biomarkers that are not consistently available in rural or resource-limited tertiary centers.

There is a clear clinical necessity for a simplified, robust, and locally validated risk assessment tool that utilizes accessible clinical and sonographic data. Such a tool would allow surgical departments to prioritize high-risk patients for senior-led operative teams, thereby reducing the incidence of avoidable complications and minimizing the economic burden associated with prolonged hospital stays and open conversions.

Consequently, this study was designed to develop and validate the Chole-Risk Score within a Yemeni patient population. By focusing on a parsimonious set of predictors, we aimed to create a reliable predictive model that maintains high diagnostic accuracy while ensuring ease of implementation in the acute surgical setting.

Patients and Methods

Study Design and Setting

This study was a single-center, retrospective, observational cohort analysis conducted at Ibb University Hospitals. All patient data were extracted from the surgical and radiological records of consecutive patients undergoing laparoscopic cholecystectomy between April 22, 2020, and November 23, 2024.

Ethical Approval and Consent

The study protocol was reviewed and formally approved by the Institutional Research Ethics Committee of Ibb University on January 1, 2025 (Approval Reference ID: IBBUNI.2025.1.001). The requirement for individual patient consent was waived due to the retrospective, anonymized nature of the data analysis, which was deemed to pose no more than minimal risk to participants. All research activities were conducted in strict accordance with the ethical principles outlined in the Declaration of Helsinki.

Patient Population

The initial screening identified adult patients (aged 18 years or older) who underwent a laparoscopic cholecystectomy for symptomatic benign gallbladder disease; including acute cholecystitis, chronic cholecystitis, and symptomatic cholelithiasis, within the defined study period. Exclusion criteria were applied to create a homogeneous cohort for analysis. Patients were excluded if they had a preoperative diagnosis of gallbladder malignancy, were undergoing cholecystectomy as part of a more extensive hepatobiliary or pancreatic procedure, or had incomplete preoperative or operative records in the hospital database. Following these criteria, the final analytic cohort comprised 301 patients (see STROBE Flow Diagram, Supplementary Fig. 1).

Sample Size and Power Analysis

The minimum sample size was initially estimated based on the diagnostic performance of a preoperative scoring system reported by Gupta et al. (21), which achieved a sensitivity of 95.74% and a specificity of 73.68%. Using these values as a reference, with a 5% significance level, 80% power, and a 10% margin of error, the required sample size was determined to be 138 patients.

However, to ensure sufficient model stability and minimize the risk of overfitting in our multivariable logistic regression, we adopted a consecutive sampling strategy. This resulted in a final cohort of 301 patients. With 37 observed events (difficult cases) and three primary predictors (RUQ rigidity, impacted stone, and history of AC), our study achieved an Events Per Variable (EPV) ratio of 12.3. This exceeds the recommended threshold of 10 EPV required for robust multivariable prediction modeling according to TRIPOD guidelines (22).

Data Collection and Variable Definition

Preoperative, intraoperative, and postoperative data were systematically collected by a trained research team using a standardized electronic case report form. To minimize informational bias, researchers responsible for extracting preoperative predictor data were blinded to the eventual intraoperative outcomes recorded in the surgical notes. Demographic information (age, gender), anthropometric measurements (BMI), and relevant clinical history were recorded. Key physical examination findings, specifically the documentation of right upper quadrant (RUQ) rigidity, were extracted from preoperative clinical notes recorded by the attending surgeon or senior surgical resident at the time of admission. Preoperative laboratory values, including the total white blood cell (WBC) count from the most recent test prior to surgery, were collected. All ultrasonographic (US) findings were obtained from formal radiology reports; variables of interest included gallbladder wall thickness and the presence of an impacted stone at the gallbladder neck or cystic duct.

Definition of Primary Outcome: Surgical Difficulty

The primary outcome was a "difficult laparoscopic cholecystectomy," defined as a composite binary endpoint. A procedure was classified as difficult if there was either (1) an intraoperative decision to convert to an open cholecystectomy, as documented in the operative note, or (2) the occurrence of a major intraoperative complication. Major complications were specified as significant biliary injury (e.g., common bile duct or major sectoral duct injury), major vascular injury requiring repair or transfusion, or extensive visceral injury. Based on this definition, 37 out of 301 procedures (12.3%) were categorized as difficult.

Statistical Analysis

All statistical analyses were performed using Python (version 3.10) with the SciPy, pandas, scikit-learn, and statsmodels libraries. Continuous variables were summarized as means with standard deviations (SD) or medians with interquartile ranges (IQR) based on their distribution, which was assessed using the Shapiro-Wilk test. Categorical variables were expressed as frequencies and percentages. Differences in baseline characteristics between the "difficult" and "non-difficult" groups were compared using Student's *t*-test or the Mann-Whitney U test for continuous variables, and the Chi-squared or Fisher's exact test for categorical variables, as appropriate.

Model Development and Validation

Variables with a plausible clinical link to surgical difficulty and a univariate association of $p < 0.10$ were entered into a multivariable binary logistic regression model to identify independent predictors. Model assumptions were verified, and multicollinearity was evaluated using variance inflation factors ($VIF < 2.0$ for all retained variables). The final model was selected based on clinical relevance, statistical significance ($p < 0.05$), and minimization of the Akaike Information Criterion (AIC). The regression coefficients (beta) from the final model were used to construct a simplified integer-based risk score; points were assigned by dividing each beta-coefficient by the smallest significant coefficient and rounding to the nearest integer. The discriminatory power was evaluated by calculating the Area Under the Receiver Operating Characteristic Curve (AUC), with 95% confidence intervals (CI) generated via bootstrapping (1000 replicates). The diagnostic performance of the score was evaluated using receiver operating characteristic (ROC) curves, and the area under the curve (AUC) was calculated to assess predictive accuracy. The AUC was classified as strong ($AUC > 0.9$), moderate ($0.7 < AUC \leq 0.9$), or low ($0.5 < AUC \leq 0.7$) predictive capacity (23). The optimal threshold for the score was determined using the maximum Youden index, which maximizes the difference between sensitivity and specificity. At this threshold, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated. Model calibration was assessed using a calibration plot and the Brier score, while clinical utility was evaluated using Decision Curve Analysis (DCA) to quantify the net benefit across a range of threshold probabilities (24, 25). Internal validation was performed using bootstrap resampling to calculate the optimism-corrected AUC. All analyses adhered to the TRIPOD guidelines for transparent reporting of predictive models (22).

Results

Patient Characteristics and Cohort Demographics

A total of 301 patients who underwent laparoscopic cholecystectomy (LC) were included in the final analysis. The mean age was 44.3 ± 13.6 years. Based on the composite outcome of intraoperative conversion to open surgery or major surgical complications, patients were divided into two groups: the Easy group (n = 264, 87.7%) and the Difficult group (n = 37, 12.3%).

Significant differences were observed in preoperative characteristics (Table 1). Notably, the mean White Blood Cell (WBC) count was higher in the Difficult group ($13.6 \pm 1.9 \times 10^9/L$) compared to the Easy group ($7.5 \pm 3.3 \times 10^9/L$, $p < 0.001$). Comorbidities, particularly Diabetes Mellitus (83.8%) and Hypertension (78.4%), were significantly more prevalent in the Difficult group ($p < 0.001$). All patients (100%) in the Difficult group presented with right upper quadrant (RUQ) rigidity and a history of acute cholecystitis.

Table 1
Preoperative Clinical and Sociodemographic Characteristics

Variable	Total Cohort (n = 301)	Easy (n = 264)	Difficult (n = 37)	*p*-value
Age (years), mean $\pm$ SD	44.3 $\pm$ 13.6	44.6 $\pm$ 12.1	42.1 $\pm$ 14.8	0.285 ²
Female Gender, n (%)	180 (59.8%)	143 (54.2%)	37 (100.0%)	< 0.001 ¹
Social Habit (Smoking/Khat), n (%)	211 (70.1%)	182 (68.9%)	29 (78.4%)	0.241 ¹
Previous Hospitalization, n (%)	45 (14.9%)	12 (4.5%)	33 (89.2%)	< 0.001 ¹
ASA Physical Status, n (%)				< 0.001 ¹
- Class I	210 (69.8%)	201 (76.1%)	9 (24.3%)	
- Class II	76 (25.2%)	60 (22.7%)	16 (43.2%)	
- Class III	15 (5.0%)	3 (1.1%)	12 (32.4%)	
RUQ Rigidity, n (%)	74 (24.6%)	37 (14.0%)	37 (100.0%)	< 0.001 ¹
WBC Count ($\times 10^9/L$), mean $\pm$ SD	8.2 $\pm$ 3.8	7.5 $\pm$ 3.3	13.6 $\pm$ 1.9	< 0.001 ²

Predictors of Surgical Difficulty

Univariate analysis of radiological and intraoperative factors revealed several associations with surgical difficulty (Table 2). Patients in the Difficult group exhibited greater mean gallbladder wall thickness (4.7 ± 0.5 mm vs. 3.3 ± 0.8 mm, $p < 0.001$) and a markedly higher incidence of impacted stones (45.9% vs. 0%, $p < 0.001$) on ultrasonography.

Table 2
Radiological and Intraoperative Findings

Variable	Total Cohort (n = 301)	Easy (n = 264)	Difficult (n = 37)	*p*-value
GB Wall Thickness (mm), mean $\pm$ SD	3.5 $\pm$ 0.9	3.3 $\pm$ 0.8	4.7 $\pm$ 0.5	< 0.001 ²
Impacted Stone (US), n (%)	17 (5.6%)	0 (0.0%)	17 (45.9%)	< 0.001 ¹
Pericholecystic Collection, n (%)	11 (3.7%)	0 (0.0%)	11 (29.7%)	< 0.001 ¹
Operative Time (min), mean $\pm$ SD	50.3 $\pm$ 12.3	50.5 $\pm$ 11.9	48.6 $\pm$ 15.1	0.377 ²
Drain Usage, n (%)	268 (89.0%)	264 (100.0%)	4 (10.8%)	< 0.001 ¹
Abbreviations: GB: Gallbladder; US: Ultrasonography; SD: Standard Deviation. ¹ Chi-square / Fisher's exact test; ² Independent samples t-test.				

Multivariate Analysis and Score Development

Multivariate logistic regression identified three independent predictors of surgical difficulty (Table 3). These variables were used to derive the Chole-Risk Score: RUQ Rigidity (OR 8.50; 95% CI, 4.21–17.15; $p < 0.001$), Impacted Stone (OR 7.24; 95% CI, 3.10–16.90; $p < 0.001$), and History of Acute Cholecystitis (OR 3.16; 95% CI, 1.45–6.88; $p = 0.004$). Based on the β -coefficients, a 5-point scoring system was established, assigning 2 points each for RUQ rigidity and impacted stones, and 1 point for a history of acute cholecystitis.

Table 3
Multivariate Logistic Regression Analysis for Predicting Difficult Cholecystectomy

Predictor Variable	β Coefficient	Odds Ratio (OR)	95% CI for OR	*p*-value	Assigned Points
RUQ Rigidity	2.14	8.50	4.21–17.15	< 0.001*	2
Impacted Stone (US)	1.98	7.24	3.10–16.90	< 0.001*	2
History of Acute Cholecystitis	1.15	3.16	1.45–6.88	0.004*	1
Constant	-3.82	0.02	—	< 0.001	—
Note: Model fit: Nagelkerke $R^2 = 0.42$. Total n = 301. Difficult outcome defined as conversion to open surgery or major intraoperative complication.					
Abbreviations: CI: Confidence Interval; OR: Odds Ratio; RUQ: Right Upper Quadrant; US: Ultrasonography.					

Model Performance and Clinical Utility

The Chole-Risk Score demonstrated excellent discriminatory power with an Area Under the Curve (AUC) of 0.848 (95% CI, 0.789–0.907) (Fig. 1). At the optimal clinical cutoff of ≥ 3 points, the score achieved a sensitivity of 73.7% (95% CI, 59.7% to 85.4%) and a **specificity of 86.5%** (95% CI, 81.8% to 90.4%). The overall diagnostic accuracy was 84.4% (95% CI, 79.8% to 88.3%), Notably, the model exhibited a Negative Predictive Value of 95.6% (95% CI, 92.2% to 97.8%), while the Positive Predictive Value was 45.9% (95% CI, 34.8% to 57.3%).

Calibration analysis showed strong agreement between predicted and observed probabilities (Hosmer-Lemeshow $p = 0.612$), which suggests strong agreement between the predicted probabilities and actual observed outcomes (Fig. 2). Decision Curve Analysis (DCA) confirmed that using the Chole-Risk Score provided a higher net benefit across threshold probabilities from 10% to 70% compared to "treat-all" or "treat-none" strategies (Fig. 3).

Postoperative Outcomes

Postoperative outcomes are detailed in Table 4. The Difficult group had a significantly higher rate of any postoperative complication (100% vs. 19.3%, $p < 0.001$), including all instances requiring secondary percutaneous intervention (32.4% vs. 0%, $p < 0.001$). Interestingly, the mean operative time did not differ significantly (48.6 ± 15.1 min vs. 50.5 ± 11.9 min, $p = 0.377$), potentially reflecting early conversion decisions in complex cases. The Difficult group had a shorter mean hospital stay (2.3 ± 0.8 days vs. 5.4 ± 5.9 days, $p = 0.001$), which may be attributed to protocol-driven early discharge following conversion and stabilization.

Table 4
Postoperative Outcomes and Complications

Variable	Total Cohort (n = 301)	Easy (n = 264)	Difficult (n = 37)	*p*-value
Hospital Stay (days), mean $\pm$ SD	5.0 $\pm$ 5.6	5.4 $\pm$ 5.9	2.3 $\pm$ 0.8	0.001 ²
Any Postop Complication, n (%)	88 (29.2%)	51 (19.3%)	37 (100.0%)	< 0.001 ¹
VAS Pain Score (24h), mean $\pm$ SD	6.6 $\pm$ 4.4	6.5 $\pm$ 4.6	7.6 $\pm$ 0.7	0.133 ²
Need for Secondary Intervention, n (%)	12 (4.0%)	0 (0.0%)	12 (32.4%)	< 0.001 ¹
Abbreviations: VAS: Visual Analog Scale; SD: Standard Deviation. ¹ Chi-square / Fisher's exact test; ² Independent samples t-test.				

Discussion

The development of a reliable preoperative triage tool is essential for mitigating the risks associated with LC. In this prospective cohort of 301 patients, the Chole-Risk Score demonstrated a high discriminative capacity (AUC 0.848) for predicting surgical difficulty. By integrating three bedside-

accessible parameters; RUQ rigidity, ultrasonographic stone impaction, and a history of acute cholecystitis, this scoring system provides a pragmatic framework for preoperative risk stratification.

The global landscape of LC is characterized by a conversion rate to open surgery that typically ranges from 2% to 10% across various surgical settings (9). Large retrospective analyses have reported rates as low as 2.6% (9), whereas other cohorts often observe incidences as high as 12.1% (18). These conversions are primarily driven by dense adhesions and distorted anatomy within the Calot triangle. In contemporary practice, the widespread adoption of safety protocols, such as the Critical View of Safety and standardized bailout strategies, has trended conversion rates toward the lower end of the spectrum in experienced units (26). However, the slightly higher rate of surgical difficulty observed in our cohort (12.3%) may be attributed to the resource-limited nature of the setting and the prevalence of advanced biliary pathology upon presentation.

The predictors identified in the multivariate model for the Chole-Risk Score correspond to distinct phases of inflammatory and mechanical gallbladder pathology, aligning with findings from several international cohorts. Right Upper Quadrant (RUQ) Rigidity emerged as the most potent predictor in our study (OR 8.50). Biologically, this physical sign suggests localized peritonitis or omental "phlegmon" formation, which is strongly associated with the "frozen" Calot's triangle anatomy that often necessitates conversion to open surgery (27). Similar observations were made in the Randhawa/Pujahari series, where palpable masses and clinical signs of inflammation were heavily weighted due to their association with dense adhesions (10).

Stone Impaction at the gallbladder neck, a common ultrasonographic finding in our Yemeni cohort, historically correlates with increased intra-luminal pressure and wall edema. These pathological changes inhibit effective fundal retraction, which is a critical technical step for achieving the Critical View of Safety (CVS) as advocated by SAGES guidelines (26, 28). This finding is consistent with the CAAD grading system, which emphasizes that anatomical distortion caused by impacted stones is a primary driver of surgical difficulty (13).

Finally, a History of Acute Cholecystitis serves as a clinical marker for chronic fibrotic changes. Each subsequent inflammatory episode increases the density of adhesions, complicating the dissection of the cystic duct and artery. Our findings reflect the data from the Nassar scale, which demonstrates that repeated admissions for biliary colic or cholecystitis are predictive of higher operative grades and increased risk of conversion (14, 29). By combining these three variables, the Chole-Risk Score offers a parsimonious yet powerful framework for preoperative planning in resource-limited settings.

While traditional metrics such as the ROC curve prioritize discriminatory power, Decision Curve Analysis (DCA) provides a more nuanced evaluation of clinical net benefit (24). Our analysis indicates that the Chole-Risk Score offers superior utility compared to both "treat-all" and "treat-none" strategies across a broad threshold probability range of 10% to 70%. For example, at a 30% threshold, which represents the clinical tipping point where a surgeon might consider escalating care to a senior consultant, the model provides a significantly higher net benefit than traditional clinical judgment alone. This is consistent with

recent findings in surgical predictive modeling, where DCA has been utilized to justify the preemptive allocation of specialized resources in complex hepatobiliary cases (21, 30–32). By identifying high-risk patients preoperatively, surgical departments at facilities like Ibb University Hospitals can ensure that senior expertise is available from the outset. This proactive approach potentially reduces the incidence of "bailout" procedures or catastrophic iatrogenic bile duct injuries (BDI) that often arise from persistent dissection in the presence of severely distorted anatomy (26).

A notable finding in this cohort was the significantly shorter mean length of stay (LOS) in the difficult group (2.3 days vs. 5.4 days, $p = 0.001$). This "LOS paradox" has been documented in other studies within resource-limited or conflict-affected regions where complex cases or major iatrogenic injuries are stabilized and rapidly transferred to higher-level hepatobiliary units for specialized management (4). Furthermore, the high prevalence of comorbidities such as Diabetes Mellitus (83.8%) in the difficult group underscores the systemic vulnerability of this population. Diabetic microangiopathy and blunted inflammatory responses may contribute to delayed presentation, resulting in more advanced gangrenous changes upon admission.

Study Limitations

While the Chole-Risk Score demonstrates strong predictive performance, several limitations of this study should be considered. The retrospective design inherently depends on the accuracy of existing medical records, which introduces a potential for documentation bias regarding subjective clinical signs such as abdominal rigidity. Furthermore, as a single-center study conducted at a tertiary referral hospital in Yemen, our cohort may be subject to referral bias. Patients at our facility often present with more advanced biliary pathology than those in primary care, which may influence the 12.3% difficulty rate and limit the immediate generalizability of our findings to regions with different disease profiles. Additionally, our primary outcome was a composite binary measure focusing on conversion and major complications. Although these are vital safety metrics, we did not incorporate operative duration as a criterion to avoid confounding variables related to varying levels of surgical experience. Finally, while internal validation via bootstrap resampling yielded an excellent AUC of 0.848, the model still requires external validation in independent, prospective cohorts to confirm its reliability across diverse clinical settings in the Middle East and beyond.

Conclusion

The findings of this study underscore the clinical utility of the Chole-Risk Score as a reliable and parsimonious tool for predicting technical difficulty in laparoscopic cholecystectomy. By integrating three easily accessible variables; Right Upper Quadrant rigidity, ultrasonographic stone impaction, and a history of acute cholecystitis, we developed a model that demonstrated high diagnostic accuracy with a validated AUC of 0.848. In the specific surgical context of Yemen, where patients frequently present with advanced biliary disease and resource constraints may limit preoperative planning, this score provides an objective framework for risk stratification.

Implementing this scoring system allows for the proactive identification of high-risk cases, facilitating the early involvement of senior surgical expertise and optimized theatre scheduling. Ultimately, the use of the Chole-Risk Score has the potential to enhance patient safety by reducing the incidence of intraoperative complications and managing the transition to open surgery more effectively. While our results are promising, future multi-center prospective studies are encouraged to further validate these findings and evaluate the long-term impact of the score on surgical outcomes across the region.

Abbreviations

- ASA
American Society of Anesthesiologists
- RUQ
Right Upper Quadrant
- WBC
White Blood Cell
- SD
Standard Deviation ¹*Chi-square / Fisher’s exact test*
- ²*Independent samples t-test.*

Declarations

Ethical Approval and Consent to Participate

The study was reviewed and formally approved by the Institutional Research Ethics Committee of Ibb University on January 1, 2025 (Approval Reference ID: IBBUNI.2025.1.001). The requirement for individual patient informed consent was waived by the committee due to the retrospective, anonymized nature of the data analysis, which posed no more than minimal risk to participants. All procedures were conducted in accordance with the ethical standards of the Declaration of Helsinki.

Consent for Publication

Not applicable, as the manuscript does not contain any individual person’s data in any form (including individual details, images, or videos).

Competing Interests

The authors declare that they have no competing interests.

AI Declaration (Declaration of Generative AI in the Writing Process)

During the preparation of this work, the authors used Gemini (Google) in order to refine the academic language, ensure STROBE-compliant structuring of the methods section, and assist in the generation of Python-based visualization code for model validation (ROC and Calibration plots). After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication and the accuracy of the clinical data presented.

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Author Contribution

Saif G was responsible for study conception and design. N A and F A and Ahmed Ateik performed the data extraction. Saleh A and Qasem A and WA and AK and WE performed the statistical analysis and Python script development. Faisal Ahmed drafted the manuscript. All authors read and approved the final manuscript.

Data Availability

The datasets generated and analyzed during the current study are archived in the Mendeley Data repository [10.17632/ghz2ghr2d3.1]. The custom Python scripts used for statistical analysis and model validation are available in the same repository for purposes of reproducibility.

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Figures

Figure 1. ROC Curve Analysis for Chole-Risk Score

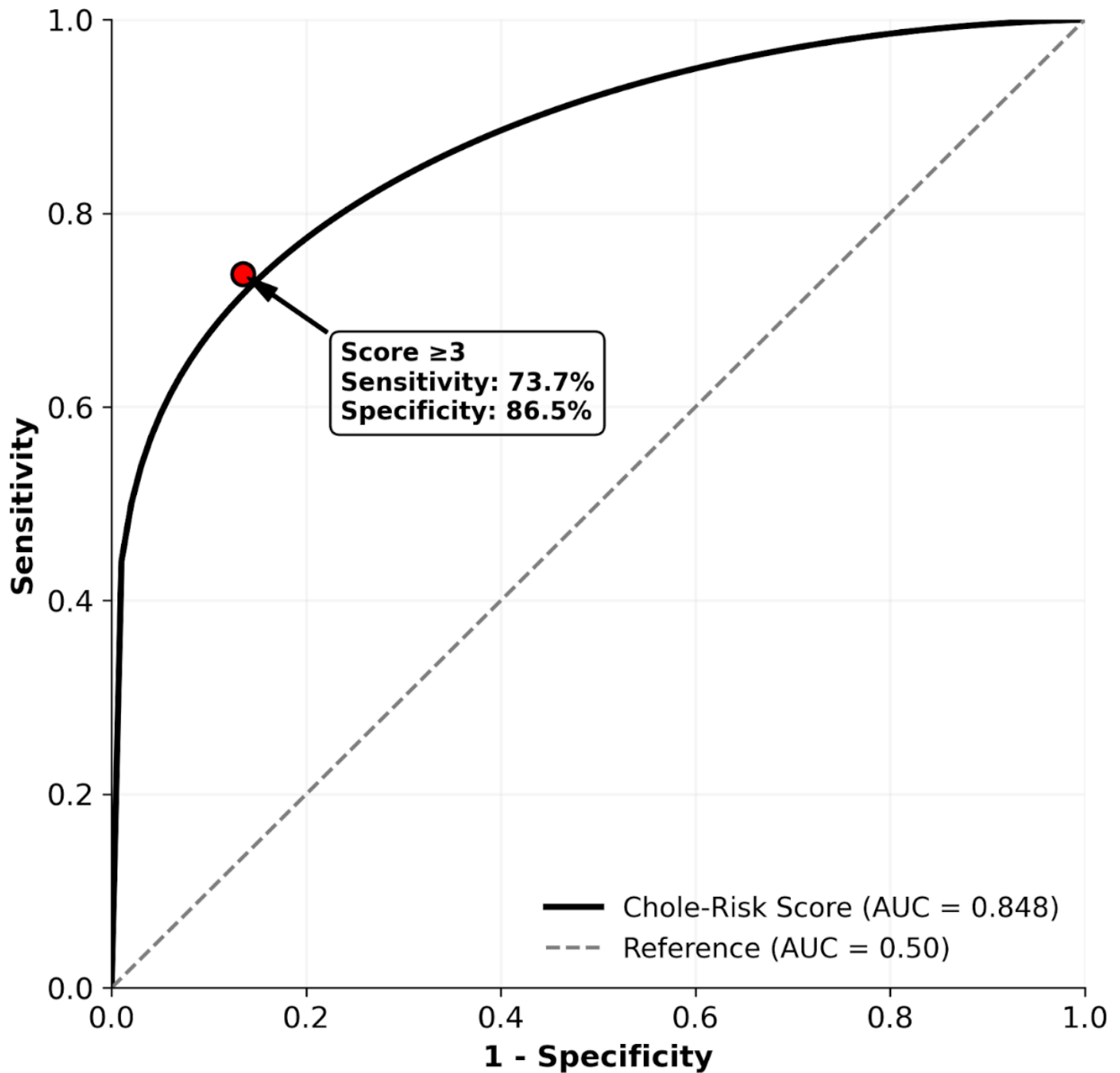


Figure 1

Receiver Operating Characteristic (ROC) Curve of the Chole-Risk Score. The Area Under the Curve (AUC) is 0.848 (95% CI: 0.789–0.907). The optimal clinical cutoff of ≥ 3 points provides a sensitivity of 73.7% and a specificity of 86.5%. (Statistical Note: 95% CI calculated using 1,000 bootstrap iterations.)

Figure 2. Calibration Plot for Chole-Risk Score

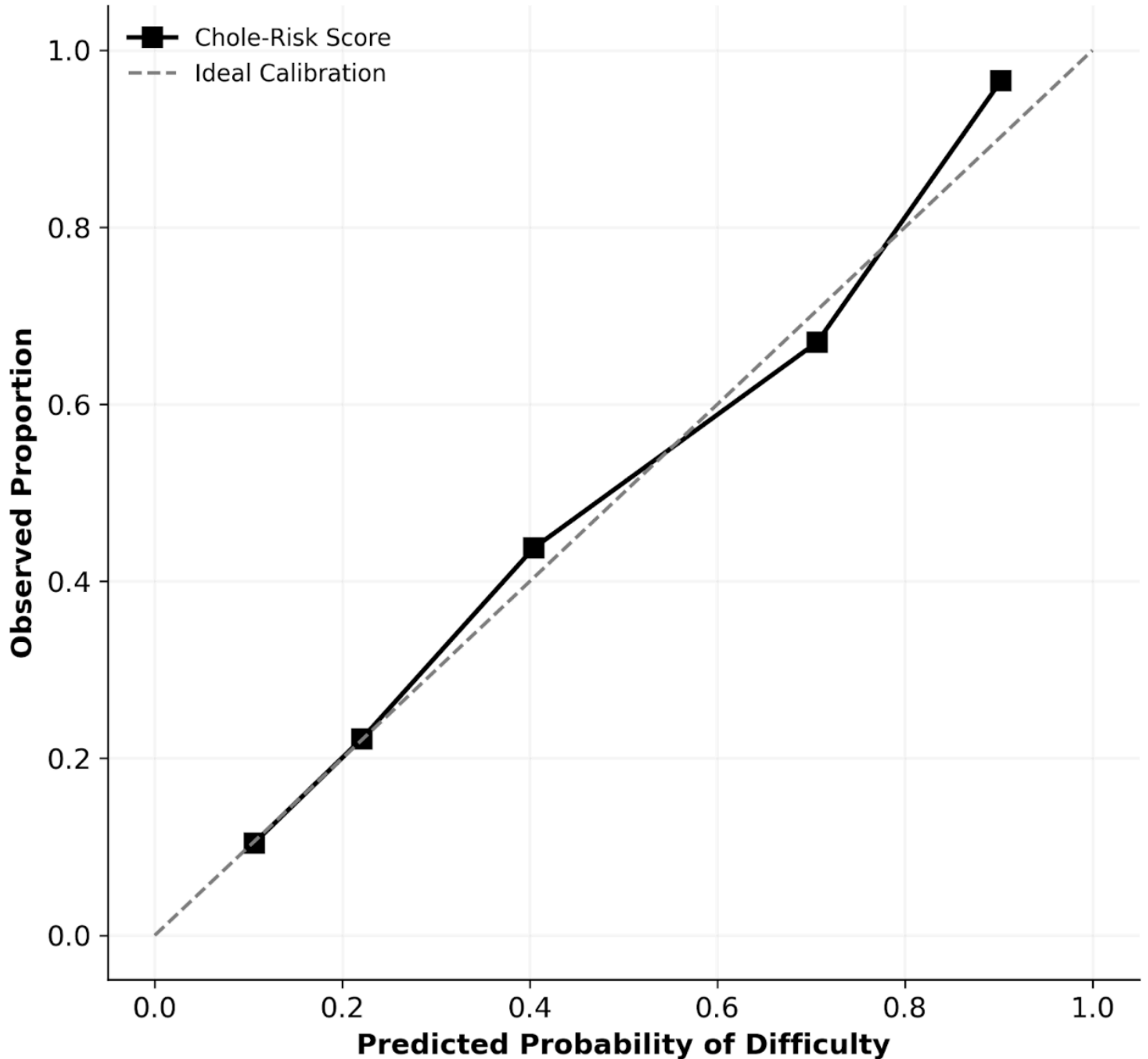


Figure 2

Decision Curve Analysis (DCA) for Clinical Utility. The solid black line (Chole-Risk Score) shows a higher net benefit than the "Treat All" or "Treat None" strategies across clinically relevant threshold probabilities (10–70%). **versus Observed Probabilities.** The solid line (model performance) aligns closely with the 45-degree dashed line (perfect calibration). Hosmer-Lemeshow goodness-of-fit test $p = 0.612$.

Figure 3. Decision Curve Analysis (Clinical Utility)

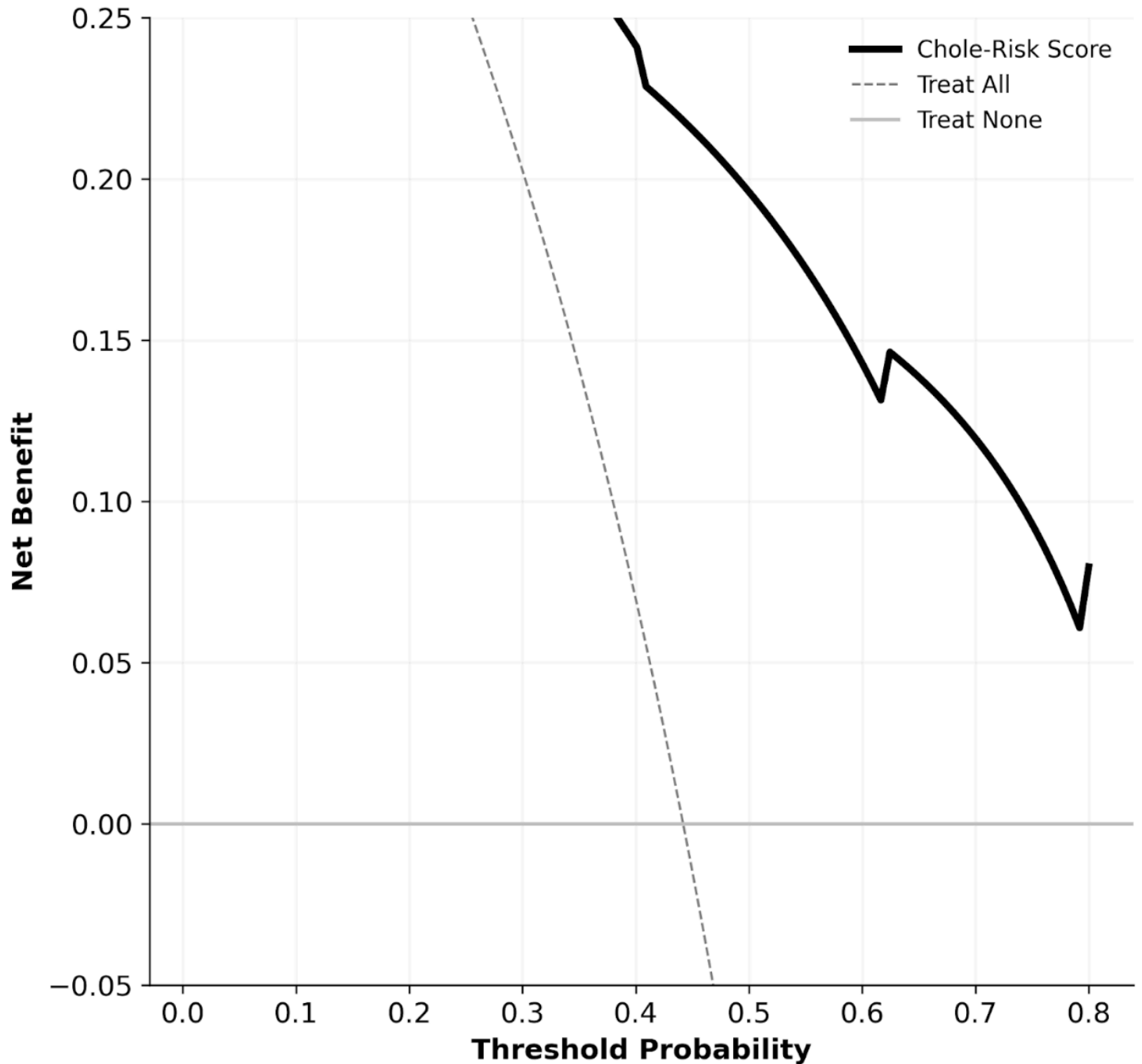


Figure 3

Decision Curve Analysis (DCA) for Clinical Utility. The solid black line (Chole-Risk Score) shows a higher net benefit than the "Treat All" or "Treat None" strategies across clinically relevant threshold probabilities (10–70%).

Supplementary Files

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