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Prediction of Length of Stay After Colorectal Surgery Using Intraoperative Risk Factors

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Objective: The primary objective of this study was to develop a length of stay (LOS) prediction model.

Background: Predicting the LOS is crucial for patient care, planning, managing expectations, and optimizing hospital resources. Prolonged LOS after colorectal surgery is largely influenced by complications, and an accurate prediction model could significantly benefit patient outcomes and healthcare efficiency.

Methods: This study included patients who underwent colorectal surgery in 14 different hospitals between January 2016 and December 2020. Two distinct random forest models were developed: one solely based on preoperative variables (preoperative prediction model [PP model]) and the other incorporating both preoperative and intraoperative variables (intraoperative prediction model [IP model]). Both models underwent validation using 10-fold cross-validation. The discriminative power of the model was assessed using the area under the curve (AUC), and calibration was evaluated using a calibration curve. The 2 developed models were compared using DeLong test.

Results: A total of 2140 patients were included in the analysis. After internal validation, the PP model achieved an AUC of 0.75 (95% confidence interval [CI]: 0.73–0.77), and the IP model achieved an AUC of 0.84 (95% CI: 0.82–0.85). The difference in discrimination between the 2 models was statistically significant (DeLong test, $P < 0.001$). Both models exhibited good calibration.

Conclusions: Incorporating intraoperative parameters enhances the accuracy of the predictive model for LOS after colorectal surgery. Improving LOS prediction can assist in managing the increasing number of patients and optimizing the allocation of healthcare resources.

Keywords: anastomotic bowel leakage, length of stay, prediction, risk factors

INTRODUCTION

With an annual incidence of 14,000 patients, colorectal surgery is common in the Netherlands. The 2018 results from the Dutch Institute for Clinical Auditing (DICA) indicated a decrease in postoperative mortality for colon cancer from 3.4% to 1.8% and for rectal cancer from 2.3% to 1%, alongside a reduction in the length of stay (LOS) from 5 days to 4 days.[1] The DICA publication highlighted that despite an increase in nonsurgical complication rates after colorectal surgery since 2011, the severity of these complications is lower, as evidenced by the decrease in reinterventions, LOS, and postoperative mortality. This trend is possibly due to the increased implementation of Enhanced Recovery after Surgery (ERAS) protocols in the perioperative patient pathway for colorectal surgery, which has been shown to reduce the incidence of perioperative complications, LOS, and overall costs.[2–5]

Colorectal anastomotic leakage (CAL) stands as one of the most severe postoperative complications following colorectal surgery, with a worldwide incidence ranging from 3% to 19%.[6] Our recent study identified multiple potentially modifiable intraoperative risk factors for CAL in a large colorectal surgery cohort.[7] CAL is associated with increased morbidity and mortality, leading to a prolonged LOS.[8,9]

Several factors influence LOS after colorectal surgery, including patient characteristics, postoperative complications, pain management, utilization of ERAS protocols, and hospital discharge planning.[3,4] Prediction of LOS is crucial for patient care, planning, expectation management, and efficient utilization of hospital resources. Extended hospitalization poses an economic burden and can disrupt future planned operations in the operating room. Additionally, poor discharge planning may lead to higher readmission rates and postoperative morbidity.[10,11]

Previous research has identified predictors for prolonged LOS, such as age, American Society of Anesthesiologists (ASA) score, extensive operating time, presence of a stoma, open surgery, and postoperative complications.[12–14] Due to the limited existing research, this study focuses on intraoperative variables and their relationship to LOS. Since intraoperative risk factors are associated with CAL, they may also contribute to a more accurate prediction of LOS.[7] An optimal perioperative condition could potentially support safe early discharge.

This study aims to investigate whether combining intraoperative factors with preoperative factors strengthens the prediction of LOS for colorectal surgery patients.

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The data that support the findings are available from the corresponding author upon reasonable request.

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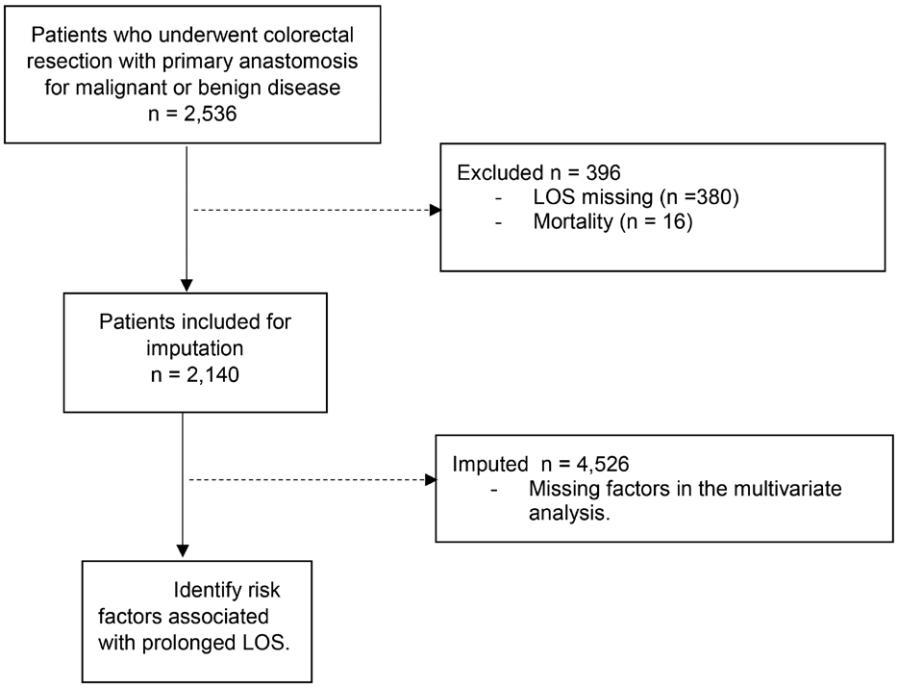

FIGURE 1. Flow diagram of study selection.

METHODS

The study protocol was approved by the Medical Ethics Review Committee of the Amsterdam University Medical Center and conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[15]

Study Design and Patients

This study represents an additional analysis of extended data from the Lekcheck study, recently published by our group.[7] Between January 2016 and December 2020, 14 hospitals (11 in the Netherlands, 1 in Belgium, 1 in Italy, and 1 in Australia) participated in this multicenter, prospective cohort study.

Patients who underwent colorectal resection and primary anastomosis construction were included. Patients with missing LOS registration and deceased patients were excluded from the analysis, as LOS could not be calculated.

Data Collection and Outcome

The following variables were collected preoperatively: age, sex, diabetes mellitus, body mass index, steroid use, intoxications (smoking status and alcohol intake), ASA score, indication for surgery (benign or malignant disease), Tumor Node and Metastasis and American Joint Committee on Cancer (AJCC) stage, neoadjuvant therapy, tumor distance from the anal verge, and preoperative hemoglobin level. Intraoperatively, the following parameters were collected: blood glucose level, use of epidural anesthesia, type and dosage of vasopressors used, volume of blood loss, fluid administration, body temperature in Celsius, mean arterial pressure, oxygen saturation, occurrence of intraoperative events (eg, hypoxic events, hypertension, hypercarbia, bradycardia, hypotension, embolism, reanimation, formation of a stoma and stoma type, more extensive resection than planned, serosa lesions, bladder and ureteral injuries, intraoperative bleeding, splenectomy), and assessment of fecal contamination. The primary outcome of interest in this study was LOS, defined as a prolonged stay of 5 days or more.

Missing Data

Missing data were imputed using predictive mean matching, with 10 iterations. Variables were excluded if they had more than 80% missing data. The dataset consisted of the pooled outcomes from the 10 imputed datasets.

Model Development

Two prediction models were developed: a model using solely preoperative variables (PP model) and a model using both preoperative and intraoperative variables (IP model). The models were developed using a random forest (RF) model. Predictors were chosen using feature selection. The final model was validated using 10-fold cross-validation. The performance of both models was evaluated using the area under the curve (AUC), sensitivity, and specificity.

Statistical Analysis

Statistical analysis was conducted using R-Studio version 2022.07.1. Continuous variables were reported as means with standard deviations or medians with interquartile ranges (IQR) if the distribution was skewed. Dichotomous, ordinal, and nominal variables were presented as numbers and percentages. The AUCs of the models were reported with a 95% confidence interval (95% CI). The AUCs of the PP model and the IP model were compared using DeLong test. Calibration curves were used to compare the observed and estimated probabilities of the models. A P value <0.05 was considered statistically significant. The maximum Youden J value from the area under the receiver operating characteristics (AUROC) was used to identify the cut probability where prediction discrimination was optimized between sensitivity and specificity.

RESULTS

A total of 2536 patients who underwent colorectal surgery with the formation of a primary anastomosis were identified from the database. Of these, 2140 were ultimately included in the analysis

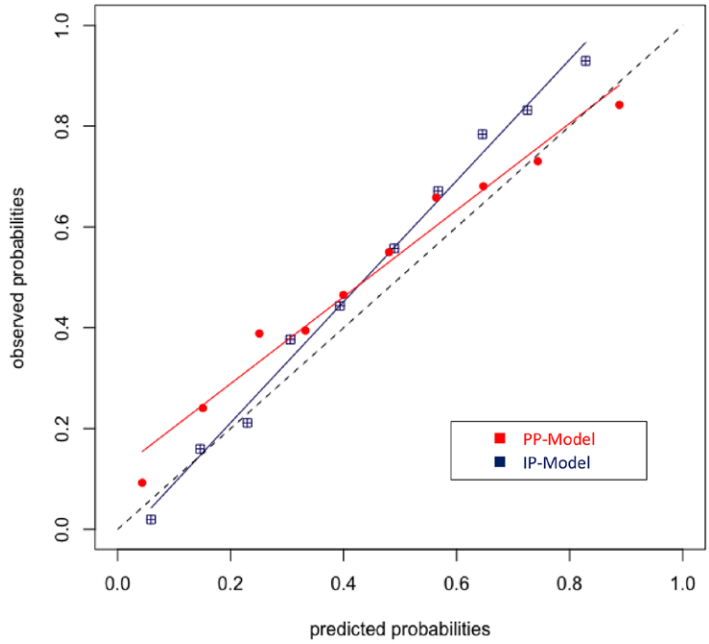

FIGURE 2. The calibration plot of PP model and IP model in predicting PLOS. The red dots represent the deciles of the observed probabilities by deciles of the predicted probabilities of the PP model. The blue squares represent the same for the IP model. The dashed red line represents the ideal performance of the score.

(Fig. 1). The median age was 69 (IQR: 59–76), median body mass index was 26 (IQR: 23–29), 52.2% were male patients (n = 1117), 15% (n = 334) had diabetes, and 28% (n = 599) had an ASA score of 3 or more. While the overall average LOS was 7 days, the median LOS was 4. Based on the median, patients with a LOS of 5 or more days (n = 1063) were classified as having a prolonged LOS (PLOS) and extreme PLOS (above the 75th percentile) was 8 days (n = 560). There were 155 cases of CAL (7.2%) with an average LOS of 20 days (median, 16 days). In the supplemental file, Supplemental Table 1, see http://links.lww.com/AOSO/A398 outlines the preoperative, intraoperative, and postoperative variables for different LOS groups.

Preoperative Model and Intraoperative Model Predicting LOS ≥ 5 Days

The following preoperative factors were associated with an LOS of 5 days or more: ASA (odds ratio [OR]: 1.38, CI: 1.2–1.6, $P < 0.001$), hemoglobin (OR: 0.7, CI: 0.7–0.9. $P < 0.001$), alcohol >3 units/wk (OR: 1.02, CI: 1.0–1.03, $P = 0.023$). The following perioperative factors were associated with a LOS of 5 days or more: body temperature (OR: 0.83, CI: 0.7–0.9, $P = 0.029$), use of vasopressor agents (OR: 1.3, CI: 1–1.6, $P = 0.005$), mean arterial pressure (OR: 1, CI: 1–1.02, $P = 0.012$), contamination (OR: 2.5, CI: 1.4–4.4, $P = 0.001$), epidural (OR: 1.5, CI: 1.2–1.9, $P < 0.001$), fluid administration (OR: 1, CI: 1–1, $P = 0.026$), approach (OR: 0.3, CI: 0.2–0.4, $P < 0.001$), conversion from laparoscopic to open (OR: 2.8, CI: 1.8–2.4, $P < 0.001$), formation of a stoma (OR: 2.7, CI: 1.8–4.2, $P < 0.001$), resection type (OR: 0.9, CI: 0.9–0.97, $P < 0.001$), operating room duration time (OR: 1, CI: 1–1, $P < 0.001$), emergency procedure (OR: 0.7, CI: 0.4–1, $P = 0.083$), goal directed therapy (OR: 0.8, CI: 0.6–1, $P = 0.074$), and prophylactic antibiotics administered on time (OR: 0.5, CI: 0.4–0.7, $P < 0.001$).

Preoperative Prediction Model (PP Model) LOS ≥ 5 Days

The PP model using RF performed better with an AUROC of 0.75 (95% CI: 0.73–0.77), sensitivity 0.72, and specificity 0.65 after internal validation. For the calibration curve of the validation cohort, see Figure 2. For the preoperative prediction formula (PP model), see Supplemental Table 2, see http://links.lww.com/AOSO/A398.

Intraoperative Prediction Model (IP Model) LOS ≥ 5 Days

The IP model using RF performed better with an AUROC of 0.84 (95% CI: 0.82–0.86), sensitivity 0.80, and specificity 0.70 after internal validation. For the calibration curve of the validation cohort, see Figure 2. For the Intraoperative prediction formula (IP model), see Supplemental Table 3, see http://links.lww.com/AOSO/A398.

Comparison of the PP Model and IP Model

The AUC of the IP model in predicting LOS ≥ 5 days was significantly better than the AUC of the PP model (DeLongs test, $P < 0.001$) (Fig. 3). For the calibration curve comparison tables, see Supplemental Table 4, see http://links.lww.com/AOSO/A398.

DISCUSSION

This prospective multicenter study shows that a predictive model using both pre- and intraoperative risk factors can more accurately predict PLOS after colorectal surgery than a model based solely on preoperative risk factors.

The study reveals that the incorporation of intraoperative parameters within the IP model significantly enhances the prediction of LOS in patients undergoing colorectal resection. In comparison to previous literature focused on preoperative factors, the IP model exhibits an improved AUC.[16,17] Therefore, it is crucial to consider intraoperative contributing factors when planning hospitalization to determine the likelihood of a PLOS. In the baseline characteristics, the incidence of certain intraoperative risk factors is higher in patients with a PLOS (see Supplemental Table 1, see http://links.lww.com/AOSO/A398).

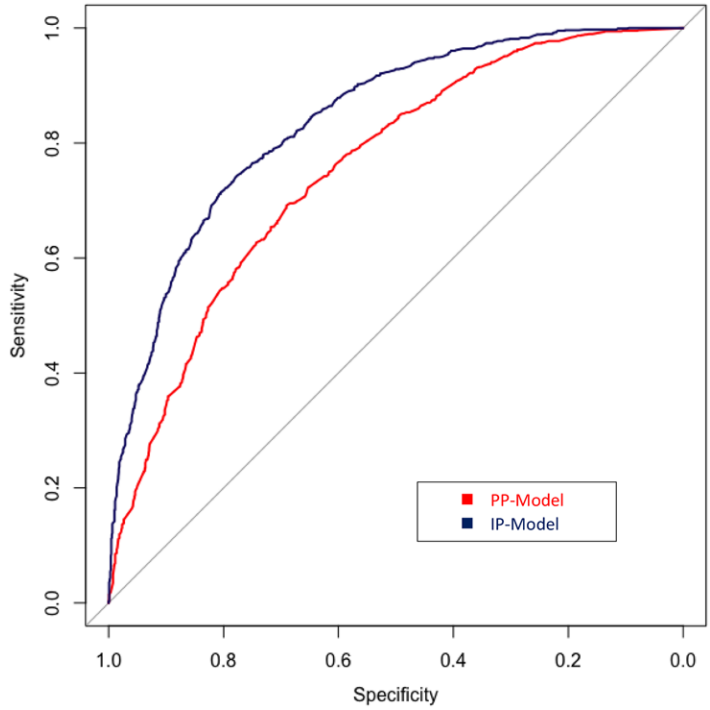

FIGURE 3. Comparison of the receiver operating characteristics (ROC) curves for the PP model and IP model in predicting PLOS after internal validation. The reference line (gray) represents the performance of a random guess.

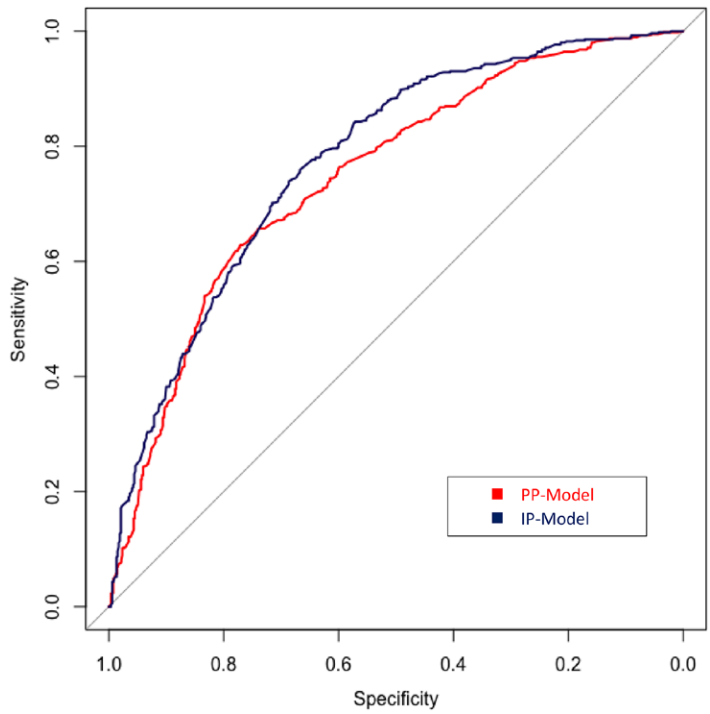

FIGURE 4. Comparison of the receiver operating characteristics (ROC) curves for the PP model and IP model in predicting extreme PLOS after internal validation. The reference line (gray) represents the performance of a random guess.

Raising awareness of these risk factors among surgical and anesthesiology teams to optimize patients' perioperative condition could potentially lead to a decrease in postoperative complications, thus reducing PLOS. The current study highlights that LOS exceeding 4 days is more likely to be influenced by intraoperative patient factors. The ERAS program has significantly improved postoperative outcomes and LOS in colorectal surgery.[5,18] Moreover, improved intraoperative factors are becoming more common in updated ERAS programs, further supporting the notion that intraoperative factors play a significant role in LOS ≥ 5 days. A successful CHASE cohort involving colorectal patients discharged within 23 hours of surgery was published by Tweed et al,[19] and while the complication rates were comparable, the readmission rate was higher

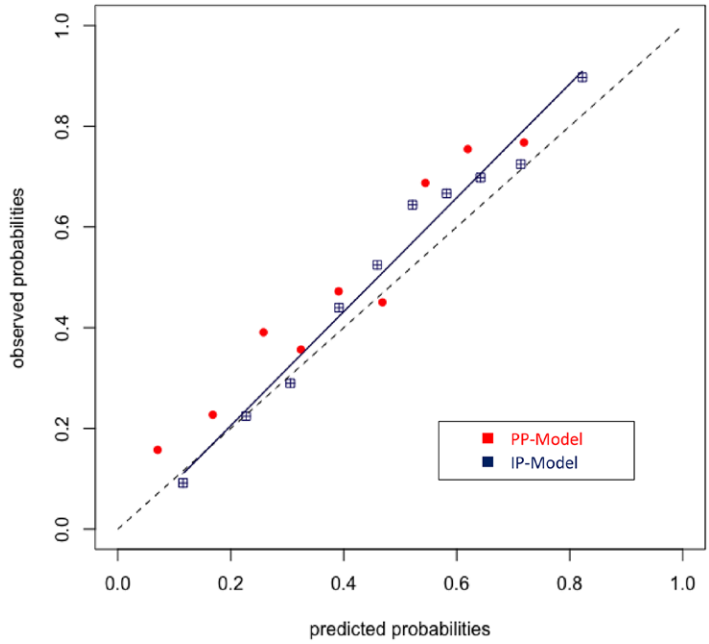

FIGURE 5. Calibration plot of PP model and IP model in predicting extreme PLOS. The red dots represent the deciles of the observed probabilities by deciles of the predicted probabilities of the PP model. The blue squares represent the same for the IP model. The dashed red line represents the ideal performance of the score.

(17.1% vs. 5.3%, $P = 0.051$), with all readmissions occurring within 2 days of discharge.[16] Potentially incorporating intraoperative prognostic variables into the discharge criteria could help lower this readmission rate. The next step should involve an interventional cohort study to observe the evolving trend of a shorter hospital stay, to create a model predicting the safest discharge day.

In cases of extreme PLOS, that is, more than 7 days, the additional analysis demonstrated that the AUC of the IP model in predicting LOS ≥ 8 days was comparable to the AUC of the PP model (DeLong test, $P = 0.176$), suggesting that intraoperative factors have a lesser impact on a LOS of 8 days or more (Fig. 4 and 5).

It is conceivable that preoperative patient characteristics play a more determinative and dominant role in extreme PLOS. This patient group might be particularly suitable for prehabilitation, as suggested by previous literature.[18] Preoperative factors for PLOS have also been identified in previous studies. Masum et al used variables such as age, ASA, open surgery, resection type, stoma placement, and AJCC staging to predict LOS.[12] The preoperative prediction model by Chan et al included age over 65 years, neoadjuvant therapy, an open approach, smoking history, and a white blood cell count.[16] Furthermore, Achilonu et al demonstrated that patient-related variables such as anemia, hypertension, and ASA were predominantly responsible for prolonged hospital LOS. They found that having a stoma formation increased the odds of PLOS by 2.5 times.[17] In the current study, predictors such as ASA, AJCC, anemia, surgical approach, stoma, type of resection, emergency surgery, and operating room duration time also emerged.

A limitation of the current study is that it is a retrospective analysis of a prospective study, using a dataset that was not originally created with LOS as the primary outcome. The database was initially designed to identify risk factors for CAL, hence some predictors may be missing. Additionally, the model has not yet undergone external validation. Further research will be necessary to determine its applicability in colorectal surgery patients, as well as other patient populations. Despite these limitations, the current LOS prediction model underscores the added value of including intraoperative risk factors alongside the traditionally used preoperative risk factors. A prospective trial in the future would be recommended to verify if intraoperatively optimized patients indeed experience shorter LOS.

CONCLUSIONS

The inclusion of intraoperative parameters improves the accuracy of predicting LOS after colorectal surgery. Enhancing LOS predictions can aid in discharge planning, particularly with rising healthcare need, while optimizing the utilization of scarce healthcare funds.

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