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ABOUT COVER

Peer Review of *World Journal of Gastrointestinal Surgery*, Charalampos M Lampropoulos, MD, MSc, PhD, Consultaunt of General Surgery & Critical Care Medicine, Intensive Care Unit, Saint Andrew's General Hospital, Patras 26504, Greece. x_lamp@hotmail.com

AIMS AND SCOPE

The primary aim of *World Journal of Gastrointestinal Surgery* (*WJGS*, *World J Gastrointest Surg*) is to provide scholars and readers from various fields of gastrointestinal surgery with a platform to publish high-quality basic and clinical research articles and communicate their research findings online.

WJGS mainly publishes articles reporting research results and findings obtained in the field of gastrointestinal surgery and covering a wide range of topics including biliary tract surgical procedures, biliopancreatic diversion, colectomy, esophagectomy, esophagostomy, pancreas transplantation, and pancreatectomy, *etc*.

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ORIGINAL ARTICLE

Retrospective Study

Prediction of parastomal hernia in patients undergoing preventive ostomy after rectal cancer resection using machine learning

Wang-Shuo Yang, Yang Su, Yan-Qi Li, Jun-Bo Hu, Meng-Die Liu, Lu Liu

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Abstract

BACKGROUND

Parastomal hernia (PSH) is a common and challenging complication following preventive ostomy in rectal cancer patients, lacking accurate tools for early risk prediction.

AIM

To explore the application of machine learning algorithms in predicting the occurrence of PSH in patients undergoing preventive ostomy after rectal cancer resection, providing valuable support for clinical decision-making.

METHODS

A retrospective analysis was conducted on the clinical data of 579 patients who underwent rectal cancer resection with preventive ostomy at Tongji Hospital, Huazhong University of Science and Technology, between January 2015 and June 2023. Various machine learning models were constructed and trained using pre-operative and intraoperative clinical variables to assess their predictive performance for PSH risk. SHapley Additive exPlanations (SHAP) were used to analyze the importance of features in the models.

RESULTS

A total of 579 patients were included, with 31 (5.3%) developing PSH. Among the

machine learning models, the random forest (RF) model showed the best performance. In the test set, the RF model achieved an area under the curve of 0.900, sensitivity of 0.900, and specificity of 0.725. SHAP analysis revealed that tumor distance from the anal verge, body mass index, and preoperative hypertension were the key factors influencing the occurrence of PSH.

CONCLUSION

Machine learning, particularly the RF model, demonstrates high accuracy and reliability in predicting PSH after preventive ostomy in rectal cancer patients. This technology supports personalized risk assessment and post-operative management, showing significant potential for clinical application. An online predictive platform based on the RF model (https://yangsu2023.shinyapps.io/parastomal_hernia/) has been developed to assist in early screening and intervention for high-risk patients, further enhancing postoperative management and improving patients' quality of life.

Key Words: Machine learning; Rectal cancer; Parastomal Hernia; SHapley Additive exPlanation algorithms; Predictive model

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Core Tip: This research proposed and validated a predictive model based on machine learning techniques to assess the risk of parastomal hernia following prophylactic ostomy in individuals with rectal cancer. Among multiple algorithms, the random forest (RF) model achieved the best performance. SHapley Additive exPlanations identified tumor distance from the anal verge, body mass index, and preoperative hypertension as key predictors. An online risk prediction tool based on the RF model has been created to support early screening and individualized postoperative management, offering practical value for clinical decision-making.

Citation: Yang WS, Su Y, Li YQ, Hu JB, Liu MD, Liu L. Prediction of parastomal hernia in patients undergoing preventive ostomy after rectal cancer resection using machine learning. *World J Gastrointest Surg* 2025; 17(9): 107977
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INTRODUCTION

Rectal cancer is one of the most common gastrointestinal malignancies, with its incidence rising globally year by year[1]. Particularly in developing countries, changes in lifestyle and diet have led to a trend of increasing incidence, especially among younger populations. With the promotion of total mesorectal excision and advancements in surgical techniques, more and more patients with mid- to low-rectal cancer can undergo sphincter-preserving surgery, significantly improving postoperative quality of life and survival rates[2,3]. However, despite these surgical advancements, post-operative complications remain a significant challenge in the recovery process. Among them, preventive ileostomy is widely recognized for its effectiveness in reducing the incidence of anastomotic leakage or alleviating its symptoms after rectal resection[4,5].

However, preventive ileostomy is associated with a range of complications, one of the most common and challenging being parastomal hernia (PSH). PSH not only can lead to bowel obstruction, severely affecting the patient's quality of life, but in some cases, it can even be life-threatening[6-8]. Furthermore, PSH can cause changes in the patient's body image, increase psychological burden, and complicate nursing care, ultimately leading to higher healthcare costs. While known risk factors such as body mass index (BMI), age, sex, and surgical duration have been suggested to be associated with PSH development[9,10], the precise mechanisms behind its occurrence remain unclear. Traditional statistical methods have limitations when analyzing the influence of multiple factors, making it difficult to predict individual risk accurately [11].

With the rapid development of artificial intelligence and big data technologies, machine learning has become increasingly applied in the medical field for disease risk prediction and decision-making support[12]. Machine learning can uncover complex patterns within large clinical datasets, providing more accurate risk assessment tools for clinicians, thereby optimizing individualized treatment plans. This study aims to leverage machine learning techniques to develop a predictive model for PSH occurrence in patients undergoing preventive ileostomy following rectal cancer surgery. The goal is to provide new theoretical foundations and practical guidance for postoperative management, individualized treatment, and preventive interventions.

MATERIALS AND METHODS

Study design and patient data

This retrospective study included patients who underwent rectal cancer resection with preventive ostomy at Tongji Hospital, Huazhong University of Science and Technology, from January 2015 to June 2023. The inclusion criteria were as follows: (1) Patients aged ≥ 18 years; (2) Preoperative diagnosis of rectal cancer with planned resection; (3) preventive ostomy performed during surgery; and (4) Availability of postoperative follow-up data for at least 18 months. The exclusion criteria were: (1) Presence of distant metastasis at the time of diagnosis; (2) Incomplete or insufficient follow-up data; (3) Patients with a history of abdominal radiation therapy prior to surgery; and (4) Patients with severe comorbidities that might interfere with postoperative recovery (*e.g.*, advanced heart failure, active infection). Ultimately, 579 patients met the inclusion criteria and were included in the final analysis.

Diagnosis criteria

PSH after rectal cancer resection was diagnosed according to the guidelines recommended by the European Hernia Society. PSH is defined as an abnormal protrusion of abdominal contents through a defect in the abdominal wall caused by an ostomy[13]. Diagnosis was based on clinical presentation (*e.g.*, abdominal bulge), physical examination (palpation of the abdominal defect), and imaging studies (*e.g.*, computed tomography, ultrasound).

Variable and feature selection

Preoperative and intraoperative variables were collected, including gender, age, American Society of Anesthesiologists score, BMI, smoking history, alcohol use, abdominal surgery history, comorbidities (*e.g.*, diabetes, hypertension), preoperative tumor markers (carcinoembryonic antigen), hemoglobin, albumin, electrolytes, intraoperative blood loss, surgical approach, surgical duration, tumor stage, tumor size, tumor distance from the anal verge, and neoadjuvant treatment. All data were retrieved from the hospital's electronic medical record system and verified by three independent researchers for accuracy and completeness. To identify key predictors of PSH risk, the Boruta algorithm was employed. This algorithm evaluates the relative importance of each feature by comparing the original features with random shadow features, allowing for the identification of variables significantly associated with the risk of PSH[14].

Machine learning model construction and evaluation

Based on the selected features, several machine learning models were built to predict the risk of PSH in patients undergoing preventive ostomy after rectal cancer resection. Due to the complexity and variability in predicting this outcome, models including eXtreme gradient boosting (XGBoost), logistic regression (LR), random forest (RF), support vector machine (SVM), and k-nearest neighbors (KNN) were evaluated. The dataset was randomly split into training and testing sets in an 80:20 ratio, with 10-fold cross-validation used for model parameter optimization, and grid search applied to find the best parameters. Evaluation metrics included the area under the curve (AUC) from receiver operating characteristic analysis, sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV). Decision curve analysis (DCA) and calibration curves were used to assess the clinical utility of the models. The contribution of each feature to the prediction results was analyzed using SHapley Additive exPlanation (SHAP).

Statistical analysis

Data analysis and model construction were performed using R software (version 4.3.0) and Python software (version 3.11.6). Categorical data were presented as frequencies and percentages, and intergroup comparisons were performed using the χ^2 test or Fisher's exact test. Continuous variables were expressed as mean ± SD, with comparisons between groups made using *t*-tests or Mann-Whitney *U* tests. A *P*-value < 0.05 was considered statistically significant.

RESULTS

Baseline clinical characteristics

A total of 579 patients were included in this study, with a 5.3% incidence of PSH. The patients were randomly assigned to either the training group (n = 405) or the testing group (n = 174) at a 7:3 ratio. Comparative analysis revealed no significant differences in baseline clinical characteristics between the two groups (P > 0.05), indicating that the datasets were representative and balanced (Table 1).

Feature selection using the Boruta algorithm

In the model-building phase, we utilized the Boruta method to perform feature selection and assess the importance of individual variables. Figure 1A illustrates the ranking and statistical distribution of variable importance. A total of nine key predictors were identified, including BMI, preoperative albumin levels, tumor distance from the anal verge, preoperative hemoglobin levels, clinical staging, gender, hypertension, electrolyte disturbances, and age. These factors were determined to be crucial in predicting surgical-related risks in the machine learning model.

Model construction and comparison of machine learning algorithms

Using the selected nine predictors, we constructed five different machine learning models: RF, LR, KNN, XGBoost, and SVM. Table 2 summarizes the performance of each model in the training cohort.

Table 1 Comparison of baseline characteristics in training and test cohorts, *n* (%)

Characteristic	All (*n* = 579)	Training cohort (*n* = 405)	Testing cohort (*n* = 174)	*P* value
Female	207 (35.7)	139 (34.3)	68 (39.1)	0.27
Age (≥ 65 years)	190 (32.8)	132 (32.6)	58 (333.3)	0.86
BMI, kg/m^2	23.1 (3.0)	23.0 (3.0)	23.1 (3.0)	0.80
Smoking	141 (24.4)	102 (25.2)	39 (22.4)	0.48
Alcohol use	86 (14.9)	58 (14.3)	28 (16.1)	0.49
Hypertension	154 (26.6)	105 (25.9)	49 (28.1)	0.58
Diabetes	72 (12.4)	49 (12.1)	23 (13.2)	0.71
Previous abdominal surgery	89 (15.3)	62 (15.3)	27 (15.5)	0.95
Tumorous obstruction	27 (4.7)	19 (4.7)	8 (4.6)	0.96
Neoadjuvant therapy	89 (15.3)	65 (16.1)	24 (13.8)	0.49
Electrolyte disorders	89 (15.4)	62 (15.3)	27 (15.5)	0.95
Albumin, g/L	40.1 (4.0)	40.1 (3.9)	40.1 (4.1)	0.97
CEA (> 5 ng/mL)	143 (24.7)	95 (23.5)	48 (27.6)	0.29
Tumor size, cm	3.4 (1.3)	3.4 (1.2)	3.5 (1.3)	0.76
Tumor distance, cm	6.4 (2.4)	6.4 (2.3)	6.5 (2.5)	0.57
Laparoscopic surgery	563 (97.2)	394 (97.2)	169 (97.1)	0.96
Operative time, minutes	219.1 (57.1)	220.4 (57.4)	215.9 (56.4)	0.39
Intraoperative bleeding, ml	75.8 (122.6)	79.1 (122.5)	68.3 (123.1)	0.34
ASA				0.97
I, II	507 (91.0)	354 (91.8)	153 (91.5)	
III, IV	72 (9.0)	51 (8.1)	21 (8.5)	
Clinical stages				0.38
1	158 (27.2)	113 (27.9)	45 (25.9)	
2	189 (32.6)	1255 (30.8)	64 (36.8)	
3	232 (40.1)	167 (41.2)	65 (37.3)	
PSF	31 (5.3)	21 (5.1)	10 (5.7)	0.42

ASA: American Society of Anesthesiologists; BMI: Body mass index; PSH: Parastomal hernia; CEA: Carcinoembryonic antigen.

Table 2 Performance metrics for five different models in the training cohort

Model	AUC (95%CI)	Accuracy	Sensitivity	Specificity	PPV	NPV
RF	0.909 (0.844-0.974)	0.891	0.857	0.893	0.305	0.991
LR	0.876 (0.800-0.953)	0.785	0.809	0.783	0.170	0.986
KNN	0.884 (0.825-0.954)	0.920	0.714	0.932	0.365	0.983
XGBoost	0.879 (0.812-0.945)	0.829	0.761	0.833	0.200	0.984
SVM	0.870 (0.786-0.955)	0.859	0.857	0.859	0.250	0.990

SVM: Support vector machine; LR: Logistic regression; KNN: K-nearest neighbors; RF: Random forest; XGBoost: EXtreme gradient boosting; NPV: Negative predictive value; PPV: Positive predictive value; AUC: Area under the curve.

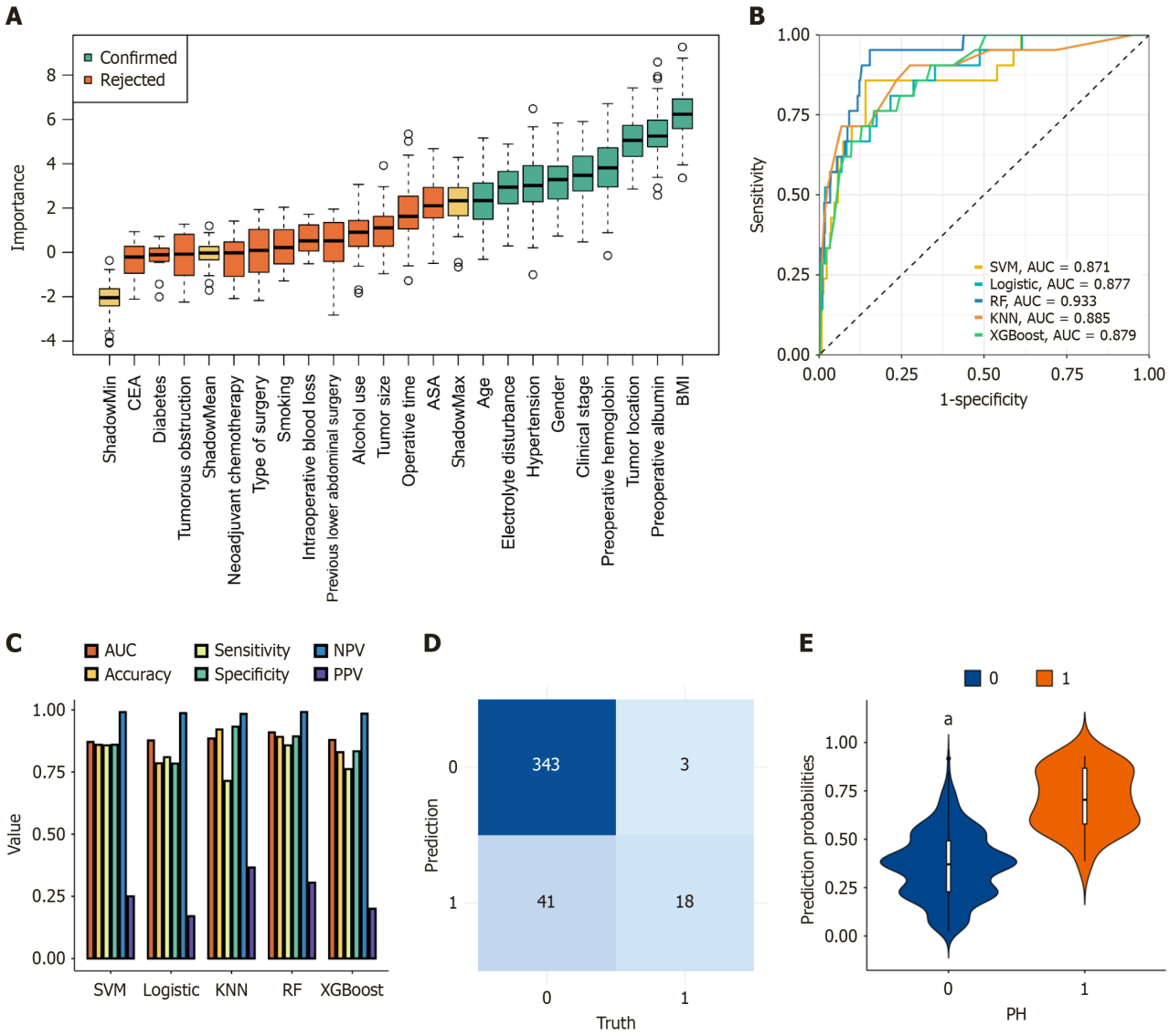

Figure 1 Features selection and model performance in the training cohort. A: Relevant features identified by the Boruta algorithm; B: Receiver operating characteristic curves and area under the curve values for the five models; C: Comparison of performance metrics across all five models; D: Confusion matrix of the random forest (RF) model; E: Comparison of predicted probabilities from the RF model for patients with and without parastomal hernia in the training cohort. [a]$P < 0.001$ *vs* control group. SVM: Support vector machine; LR: Logistic regression; KNN: K-nearest neighbors; RF: Random forest; XGBoost: EXtreme gradient boosting; ASA: American Society of Anesthesiologists.

Among all models, the RF model achieved the best performance with an AUC of 0.909 (95%CI: 0.844-0.974), accuracy of 0.891, specificity of 0.893, and NPV of 0.991. KNN exhibited the highest overall accuracy (0.920) but had lower sensitivity (0.714). LR and XGBoost showed relatively balanced sensitivity and specificity, while SVM delivered consistent classification with slightly lower AUC (0.870) (Figure 1B and C; Table 2). The confusion matrix of the RF model in the training set is shown in Figure 1D. Figure 1E demonstrates strong calibration between predicted and observed PSH probabilities.

The RF performance in test model and application

To assess the effectiveness of the RF model in predicting the risk of PSH, we employed an independent testing cohort. The RF model demonstrated excellent discriminatory ability in identifying PSH. Key performance indicators derived from the confusion matrix revealed an AUC of 0.900, a specificity of 0.725, a sensitivity of 0.900, a PPV of 0.166, and a NPV of 0.991 (Figure 2A and B). Furthermore, the distribution of predicted probabilities differed significantly between patients with and without PSH ($P < 0.001$) (Figure 2C). Calibration curve analysis further confirmed that the model's predictions closely aligned with the actual incidence of PSH (Figure 2D). DCA revealed substantial net benefit across a broad range of threshold probabilities, indicating that the RF model can serve as a valuable tool for clinicians in assessing PSH risk, thereby facilitating more informed decision-making across diverse clinical thresholds (Figure 2E). Given the excellent performance of the RF model, we developed a user-friendly online prediction platform to assist clinicians with an accessible and intuitive interface (https://yangsu2023.shinyapps.io/parastomal_hernia/). By entering patient-specific predictive factors, physicians can quickly assess the likelihood of PSH, aiding in clinical decision-making.

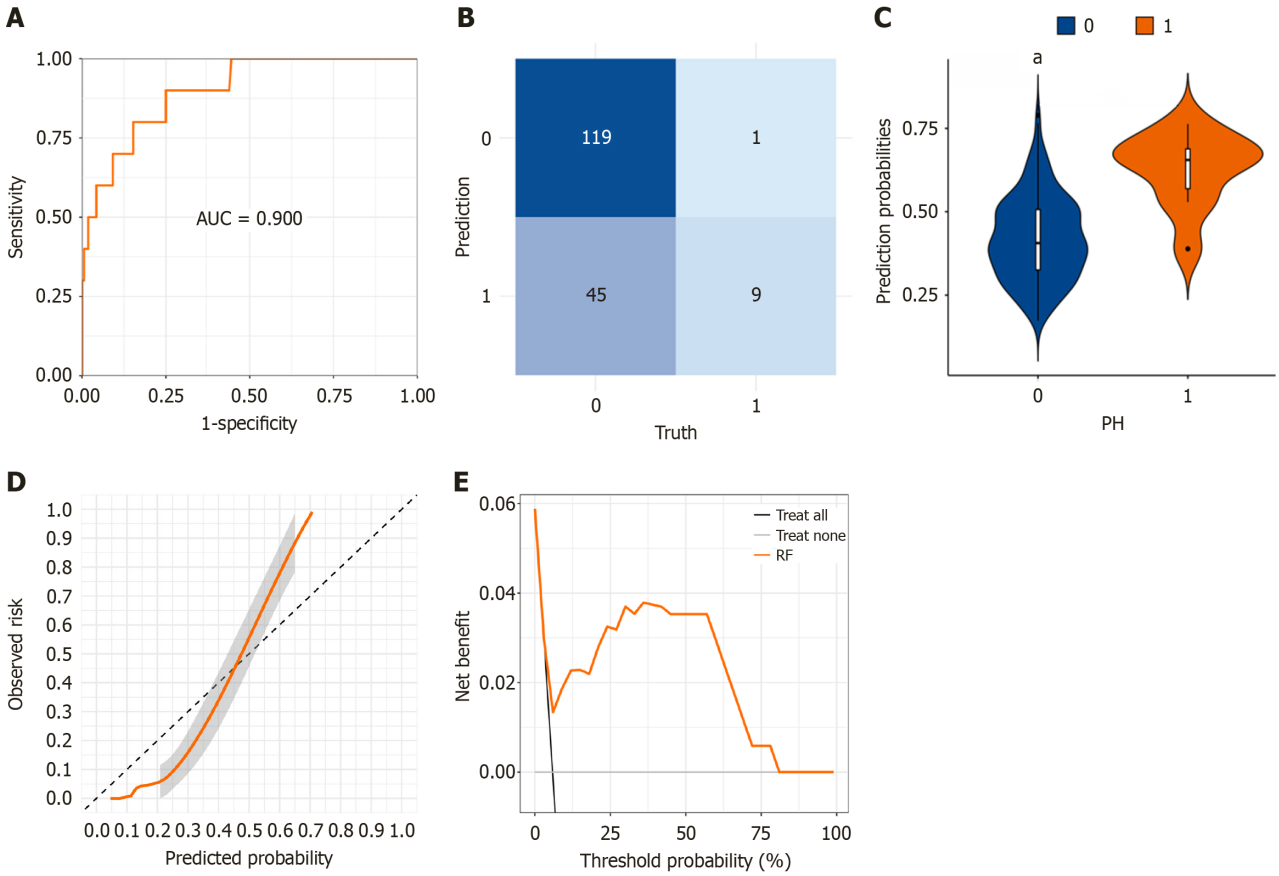

Figure 2 Evaluation of the random forest model in the test cohort. A: Receiver operating characteristic curves and area under the curve values for the testing set; B: Confusion matrix for the random forest (RF) model applied to the testing set; C: Comparison of predicted probabilities by the RF model for patients with and without parastomal hernia in the test cohort; D: Decision curve analysis for the test group; E: Calibration curve of the testing set. $^{a}P < 0.001$ *vs* control group. AUC: Area under the curve.

Model interpretation analysis

To quantify the contribution of each feature to the RF model's predictions, we performed an explanation analysis using the SHAP algorithm. The analysis identified three key factors influencing the prediction of PSH risk: Tumor distance from the anal verge, BMI and hypertension (Figure 3A). Additionally, BMI, hypertension, and longer surgery duration were associated with an increased likelihood of PSH. In contrast, tumor height from the anus and preoperative albumin levels appeared to have a protective effect, reducing the risk of PSH occurrence (Figure 3B).

DISCUSSION

PSH is one of the most common and severe complications in patients undergoing preventive ostomy after rectal cancer resection. It can cause symptoms such as abdominal deformity, swelling, and, in severe cases, lead to ostomy dysfunction, bowel obstruction, or hernia content incarceration[15,16]. These complications not only increase the patient's life risk and economic burden but also significantly prolong recovery time and impair quality of life. Therefore, early prediction of PSH occurrence is of great clinical significance. However, effective predictive methods remain scarce in current clinical practice. Traditional risk assessment methods mainly rely on statistical models, which often consider only a few variables and fail to capture the complexity of individual patient differences and multifactorial interactions, limiting their predictive accuracy and ability to support personalized medical decisions[17]. Thus, developing a model that integrates multiple clinical factors and demonstrates high predictive accuracy is of considerable clinical value for early identification of high-risk PSH patients.

With the development of big data and artificial intelligence, machine learning offers a new approach to solving this issue. The RF model, as an ensemble learning method, has shown excellent performance in various medical prediction tasks due to its ability to handle nonlinear relationships and its robustness and interpretability[18].

In our study, the incidence of PSH was 5.3%, which is within the range of 3.1% to 16.5% reported in the literature[17,19,20]. This difference may be attributed to variations in diagnostic criteria, follow-up duration, and study populations. By utilizing preoperative and intraoperative clinical data, our study constructed a machine learning model that effectively predicted the risk of PSH following preventive ostomy in rectal cancer patients. The results indicate that the RF model performs well with an AUC of 0.900 on the test set, demonstrating its high accuracy and robustness. Additionally, SHAP

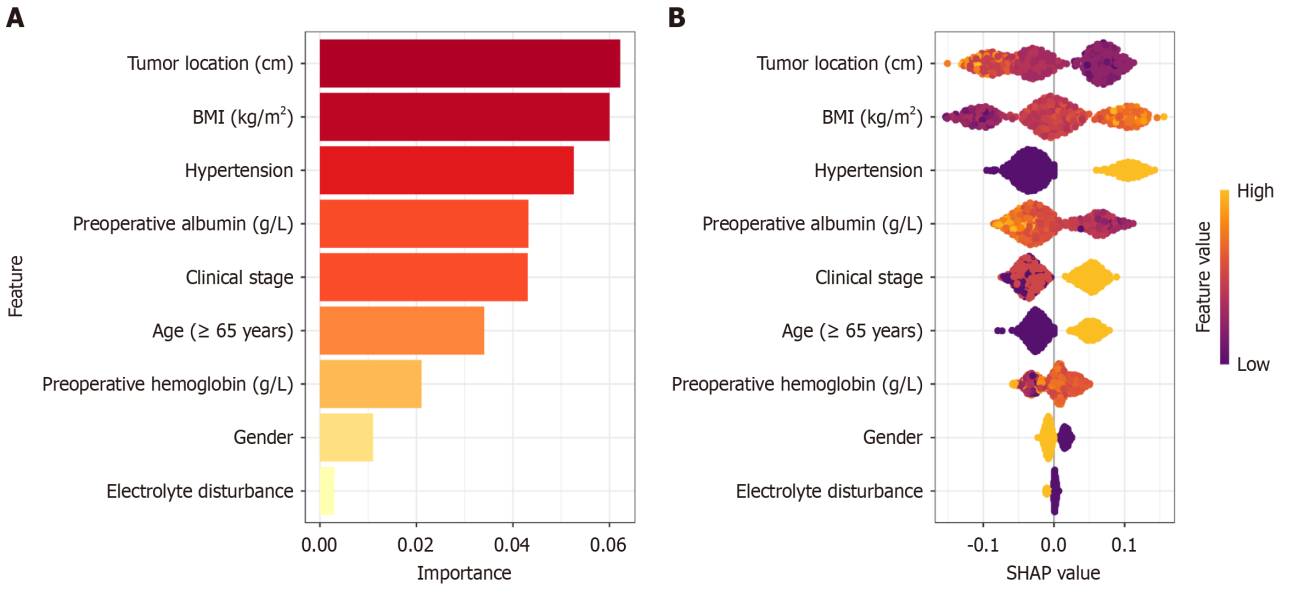

Figure 3 SHapley Additive exPlanation analysis of the random forest model. A: Average absolute SHapley Additive exPlanation (SHAP) values for various clinical features; B: SHAP values illustrating the influence of different clinical features on the model's predictions. SHAP: SHapley Additive exPlanation; BMI: Body mass index.

analysis identified tumor distance from the anal verge, BMI, preoperative hypertension, and hypoalbuminemia as key factors influencing the occurrence of PSH. These findings are consistent with previous studies[17,21], suggesting that patients with a closer tumor to the anal verge, higher BMI, preoperative hypertension, and hypoalbuminemia are at significantly increased risk for developing PSH postoperatively. For example, Zhu *et al*[22] found that overweight (BMI ≥ 25 kg/m²) is significantly associated with PSH formation after abdominoperineal resection for rectal cancer. A shorter tumor distance from the anal verge may increase the risk of permanent ostomy due to postoperative complications, such as anastomotic leaks and stenosis, leading to a higher likelihood of PSH[4,12,22]. Hypertension could increase the risk of postoperative thrombosis, reduce tissue oxygenation, and impair wound healing, thereby promoting the development of PSH. Hypoalbuminemia, through its impact on collagen synthesis and granulation tissue formation, may also increase the risk of hernia formation[23]. Additionally, factors such as longer surgical time, older age, clinical staging, and female sex were found to contribute positively to PSH occurrence, which aligns with previous research findings[22,24-26].

Despite the valuable findings obtained in this study, several limitations should be acknowledged. First, this is a single-center retrospective study, with patient data derived from a single institution. This may introduce selection bias due to institutional-specific surgical techniques, perioperative management protocols, and regional demographic characteristics. Such homogeneity could limit the generalizability of our findings to more diverse clinical settings. Second, although the sample size of 579 patients is sufficient for initial model development and internal validation, it may not fully capture the heterogeneity present in broader populations. Subgroups with rare complications or unique demographic traits may be underrepresented, potentially affecting the robustness and external applicability of the predictive model. In particular, performance metrics such as sensitivity and PPV may vary in real-world multicenter use. Third, while we employed well-established machine learning techniques including feature selection with the Boruta algorithm and cross-validation, emerging methods such as deep learning, ensemble hybrid frameworks, and temporal modeling could be explored in future studies to further enhance predictive performance and adaptability. To address these limitations, we have already initiated a prospective, multicenter validation study involving three independent institutions. This ongoing effort aims to assess the reproducibility and clinical utility of our model in varied healthcare environments. Furthermore, we plan to incorporate patient-reported outcome measures, such as ostomy-related discomfort and quality of life scores, into the predictive framework to better capture patient-centered dimensions of postoperative recovery. These future directions will not only refine the predictive capacity of the model but also support its integration into clinical workflows, enabling personalized postoperative risk stratification and more informed decision-making in rectal cancer management.

CONCLUSION

This study developed an online predictive tool (https://yangsu2023.shinyapps.io/parastomal_hernia/) based on the RF model to assess the risk of PSH after preventive ostomy in rectal cancer patients. By integrating preoperative and intraoperative clinical data, the RF model effectively identifies high-risk patients with excellent predictive performance. Key factors such as tumor distance from the anal verge, BMI, preoperative hypertension, and hypoalbuminemia significantly influence the development of PSH. This online platform provides clinicians with a convenient, personalized tool for early risk assessment, helping to optimize postoperative management, reduce complication rates, and improve patients' quality of life. As technology continues to evolve, machine learning models are expected to further improve and become more

widely applicable in clinical practice.

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FOOTNOTES

Author contributions: Yang WS wrote the first draft, developed the main ideas, curated the data, designed the methodology, created visualizations, and contributed to review and editing; Su Y developed the main ideas, designed the methodology, performed formal analysis, and contributed to review and editing; Li YQ curated the data and performed formal analysis; Hu JB acquired the funding; Liu L acquired the funding and contributed to review and editing; Liu MD curated the data and supervised the project. This study is a multidisciplinary collaborative project involving clinical surgery, artificial intelligence algorithms, and data analysis. Professor Su Y was responsible for the clinical design and acquisition of patient data, ensuring the clinical relevance and feasibility of the research. Liu MD led the development and optimization of the machine learning models, playing a key role in model selection and performance evaluation. All two authors played indispensable roles in the study and are required to communicate externally to address academic inquiries and technical details. Therefore, designating all three as corresponding authors allows for more comprehensive responses to peer reviews and post-publication queries, ultimately enhancing the quality and impact of the paper.

Institutional review board statement: The study was conducted in strict accordance with the principles outlined in the Declaration of Helsinki and received ethical approval from the local Ethics Committee at Tongji Hospital, Huazhong University of Science and Technology. All procedures adhered to relevant regulations and guidelines. The study was approved under protocol number 202410039, with ethical clearance granted on October 8, 2024.

Informed consent statement: Given the retrospective nature of the study, the requirement for informed consent was waived. To ensure patient confidentiality, all datasets were de-identified.

Conflict-of-interest statement: The authors declare no conflict of interest.

Data sharing statement: The data utilized in this study can be obtained from the corresponding author upon reasonable request.

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