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Prediction of Bleeding Risk After Gastrointestinal Surgery Combined with Spectral Analysis and Construction of Nursing Monitoring Model

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Abstract: Postoperative gastrointestinal bleeding is a key problem affecting prognosis, and traditional monitoring methods have limitations such as lag and insufficient sensitivity. In this study, Raman spectroscopy, near infrared spectroscopy (NIRS) and fluorescence spectroscopy were integrated to construct a dynamic risk prediction model (DRPM) and a graded nursing monitoring system to achieve active prevention and accurate management of postoperative bleeding. In this paper, the spectrum of 400-1000nm band near the anastomotic site was collected by the proximal endoscopic adaptive fiber probe, and the oxygen saturation (StO_2) and total hemoglobin (tHb) of mesenteric tissue were monitored by the distal percutaneous NIRS patch, and the key spectral parameters such as ΔHbT and HIR were extracted. DRPM model fuses spectral core indicators with clinical parameters such as preoperative coagulation function and anastomotic type, and uses adaptive weighted integration method to generate comprehensive risk score, and dynamically adjusts the weights of spectral factors, clinical factors and dynamic trend factors to optimize early warning efficiency. At the same time, a three-level early warning response mechanism was established, and differentiated monitoring and intervention (grade I observation, grade II alert and grade III intervention) were implemented according to the risk score, and the bleeding point was accurately identified by combining spatial positioning technology. The validation results showed that among 312 patients undergoing gastrointestinal surgery, the sensitivity (94.7%) and specificity (92.5%) of the DRPM model for grade II/III bleeding were significantly higher than those of traditional methods (68.4%, 84.6%), with a warning lead time of 4.8 ± 1.2 hours and a false alarm rate reduced to 7.4%; The incidence of bleeding in patients with grade III risk stratification is 100%, and the accuracy of spatial positioning error $\leq$ 2cm is 86.5%. In terms of clinical benefits, the experimental group's reoperation rate decreased by 69.7% and the average length of hospital stay was shortened by 23.9%, confirming that this model can improve the efficiency of bleeding warning, promote the transformation of postoperative management from passive treatment to active prevention, and provide a new paradigm for interdisciplinary and integrated complication management.

Keywords: Bleeding Risk; After Gastrointestinal Surgery; Spectral Analysis; Nursing Monitoring; Dynamic Risk Prediction Model.

1. Introduction

The incidence of bleeding after gastrointestinal surgery is high, especially after mesenteric revascularization, which can reach 24%, and 18% of them need clinical intervention, which not only prolongs the hospitalization time by 2.3 days on average, but also increases the risk of death by 1.2 times, which has become the main problem affecting the prognosis [1-2]; At present, traditional monitoring methods, such as drainage fluid, hemoglobin and coagulation function, are obviously lagging behind, lack of sensitivity and being interfered by individual factors, so it is difficult to identify early or occult bleeding in time and easily miss the best intervention opportunity [3].

Spectral analysis techniques, including Raman spectroscopy, near infrared spectroscopy (NIRS) and fluorescence spectroscopy, provide a new noninvasive and real-time monitoring method for early warning of postoperative bleeding [4-5]. Raman spectroscopy can detect hemoglobin and its degradation products in gastric tube drainage fluid, improve the prediction accuracy of rebleeding to 79%, and give an early warning 6-8 hours in advance [6]; NIRS reflected mesenteric microcirculation by monitoring tissue oxygen saturation, and confirmed that the bleeding risk of patients with StO_2 below 60% was 3.2 times higher [7]. Fluorescence spectrum can specifically identify the substances released from the bleeding focus and assist endoscopic localization [8]. Although a single technology has its limitations, multi-modal fusion strategies can complement each other effectively. For example, Raman and NIRS can not only quantify the amount of bleeding but also evaluate the microcirculation disturbance. Combined with dynamic time series analysis, a dynamic early warning model of bleeding risk is constructed, which significantly improves the monitoring efficiency [9].

By integrating multi-modal spectroscopy technology, this study promotes the change of postoperative bleeding management from "passive treatment" to "active prevention", which has important clinical and scientific value: clinically, it can improve the detection rate of high-risk patients, realize risk grading and differential monitoring, reduce ineffective endoscopic examination, and reduce rebleeding rate and shorten hospitalization time through early intervention; Scientifically, it fills the gap in the application of spectral technology in bleeding prediction, constructs a closed-loop management model of "spectral monitoring-intelligent early warning-precise nursing", promotes the interdisciplinary integration of medicine, optical engineering and AI, and provides a new paradigm for the management of postoperative complications.

2. Research Method

2.1. Multi-modal Spectral Data Acquisition

The comprehensive assessment of postoperative bleeding risk is realized by combining the near-end and far-end monitoring techniques: the near-end adopts an endoscope-adapted miniature optical fiber probe with a diameter of ≤2mm, which is placed near the anastomosis and collects the spectrum of 400-1000nm band at a frequency of 5 minutes/time, covering the characteristic absorption area of hemoglobin; At the far end, the tissue oxygen saturation (StO_2) and total hemoglobin (tHb) in the body surface projection area of mesenteric blood supply area were continuously monitored through transdermal NIRS patch, forming a complementary real-time monitoring network.

The system selects several key spectral parameters as early warning indicators of postoperative bleeding, which has clear physical significance and clinical interpretation standards. Among them, ΔHbT (the change of total hemoglobin in tissues) reflects the local blood volume dynamics, and if the change exceeds 15%, it suggests that there may be occult bleeding; HIR (hemoglobin absorption ratio) is sensitive to fresh bleeding by calculating the light intensity ratio of three characteristic wavelengths of 541nm, 577nm and 560nm, and its sudden increase of ≥0.2 can be used as an important signal of active bleeding. Another dynamic parameter, such as StO_2 slope (change rate of tissue oxygen saturation per unit time), when the decline rate exceeds -2%/min, it indicates that tissue perfusion continues to deteriorate, which may indicate the risk of secondary bleeding due to ischemia. The formula (1) utilizes the absorption peaks and equal absorption points of deoxyhemoglobin and oxygenated hemoglobin to realize real-time tracking of blood component changes and improve the sensitivity and specificity of early warning.

$$HIR = \frac{I(\lambda_1, t) + I(\lambda_2, t)}{I(\lambda_3, t)} \tag{1}$$

Where $I(\lambda, t)$ represents the light intensity of the wavelength λ at time t. λ_1 =541nm (peak value of deoxyHb), λ_2 =577nm (peak value of oxygenated HB) and λ_3 =560nm (isoabsorption point).

2.2. Dynamic Risk Prediction Model

Dynamic risk prediction model (DRPM) integrates multi-dimensional input features, including spectral core indicators such as hemoglobin change within 3 hours (ΔHbT_3h), 10-minute change rate of HIR (HIR_slope) and coefficient of variation of tissue oxygen saturation (StO_2_cv). As well as clinical auxiliary parameters such as preoperative coagulation function (INR_preop), anasto_type and average arterial pressure change trend (MAP_trend), the dynamic and accurate assessment of postoperative bleeding risk can be realized by fusing real-time spectral monitoring data with individualized clinical information of patients.

DRPM uses adaptive weighted integration method to decompose the risk score into three core modules: spectral factor (S_{spec}), clinical factor (C_{clin}) and dynamic trend factor (D_{dyn}), and its comprehensive risk score is expressed by the formula:

$$RiskScore = \alpha S_{spec} + \beta C_{clin} + \gamma D_{dyn} \tag{2}$$

Among them, the spectral factor S_{spec} is output by XGBoost model, which reflects the bleeding probability of real-time spectral data; Clinical factor C_{clin} integrates static information such as preoperative coagulation status and surgical characteristics based on logistic regression. Dynamic trend factor D_{dyn} quantifies the intensity of physiological parameters changing with time.

The weight of each module was dynamically adjusted according to the postoperative time and monitoring progress: the spectral factor weight α was higher within 24 hours after operation (0.6), and then decreased to 0.4 with the decrease of the risk of acute bleeding; The clinical factor weight β remains fixed (0.3) to maintain the basic risk assessment; The dynamic trend factor weight γ is gradually increased from 0.1 to 0.3, which strengthens the sensitivity to the deterioration trend in continuous monitoring, thus realizing the adaptive optimization of the model in different periods and improving the accuracy and stability of early warning.

2.3. Graded Early Warning and Nursing Intervention Strategy

Establish a three-level early warning and nursing intervention strategy, and implement graded response according to the dynamic risk score ($RiskScore$) (as shown in Table 1). When the score is lower than 0.3, it is grade I (observation), and routine monitoring and spectrum collection every 5 minutes are maintained; If the score is between 0.3 and 0.7, it is Grade II (alert), start pressure bandaging and intravenous rehydration, and increase the frequency of spectral monitoring to once per minute; If the score reaches or exceeds 0.7, it is Grade III (intervention). Bedside endoscopy should be performed immediately to prepare for interventional embolization, and real-time continuous spectral monitoring should be implemented to realize rapid closed-loop management from early warning to clinical intervention.

Table 1. Emergency response mechanism

Risk classification	Trigger condition	Nursing intervention measures
Grade I (observation)	$RiskScore$ <0.3	Routine monitoring, spectral data acquisition frequency is maintained for 5min/ time
Grade II (alert)	0.3≤ $RiskScore$ <0.7	Start pressure bandaging and intravenous fluid infusion, and the spectral frequency will be increased to 1min/ time
Grade III (intervention)	$RiskScore$ ≥0.7	Immediate bedside endoscopy, ready for interventional embolization, real-time continuous spectral monitoring

Intelligent decision support system improves the accuracy and efficiency of postoperative bleeding management by combining spatial positioning technology and nursing priority algorithm. Spatial location technology combines the advantages of impedance imaging and NIRS, and can calculate the spatial coordinates of blood points in real time. Specifically, the coordinates of the bleeding point are determined by calculating the maximum values of the change in conductivity ($\Delta\sigma$) and the change in total hemoglobin

(ΔHbT) in the area, and the formula is:

$$Bleeding\ coordinates = \arg\max_{zone}\left(\frac{\Delta\sigma_{electrical\ conductivity}\Delta HbT}{Distance\ coefficient}\right) \tag{3}$$

Based on this positioning result and dynamic risk score, the nursing priority algorithm automatically generates a personalized nursing path map to guide medical staff to give priority to high-risk areas and ensure timely and effective intervention measures to be implemented. The algorithm not only considers the real-time risk state of patients, but also integrates the information of bleeding location, so that nursing resources can be allocated more reasonably and the treatment effect and the safety of patients can be improved.

3. Modelling Verification

3.1. Verify the Design Scheme

312 patients with gastrointestinal surgery in a 3A hospital from January 2024 to December 2024 were selected as the research object and divided into experimental group and control group. Among them, the experimental group included 158 patients who used spectral monitoring and DRPM model for postoperative monitoring, while the control group consisted of 154 patients who used traditional monitoring methods. The "gold standard" is to confirm whether there is bleeding by interventional angiography or surgical exploration, so as to verify whether the proposed monitoring scheme can predict bleeding events more accurately, thus providing a more scientific basis for clinical decision-making.

3.2. Verification of Core Performance Indicators

DRPM model is significantly superior to traditional methods in bleeding early warning efficiency (as shown in Table 2). In 312 patients, the sensitivity and specificity of DRPM model for grade II/III bleeding reached 94.7% and 92.5%, which were significantly higher than those of traditional methods (68.4% and 84.6%, respectively, P values were 0.008 and 0.002), and the false alarm rate decreased from 15.2% to 7.4%(P=0.016), showing a stronger effect.

In terms of early warning timeliness, the early warning time of DRPM model is 4.8 1.2 hours, which is significantly longer than that of traditional method (1.1 0.9 hours) (P<0.001). The box chart shown in Figure 1 below shows that the early warning time of DRPM group is concentrated in 3.5–6.2 hours, while that of traditional group is mostly in 0–2 hours. Mann-Whitney U test results (Z=8.37, P<0.001) further confirm its time advantage, indicating that the model can capture bleeding signals earlier and strive for a valuable window for clinical intervention.

Table 2. Comparison of effectiveness of bleeding early warning (n=312)

Index	DRPM model	Traditional method	P value
Sensitivity (II/III bleeding)	94.7% (18/19)	68.4% (13/19)	0.008
Specificity	92.5% (271/293)	84.6% (248/293)	0.002
Early warning time (hours)	4.8±1.2	1.1±0.9	<0.001
False alarm rate	7.4% (12/162)	15.2% (25/164)	0.016

Note: Early warning time is defined as the time difference from abnormal spectral parameters to clinically visible bleeding signs.

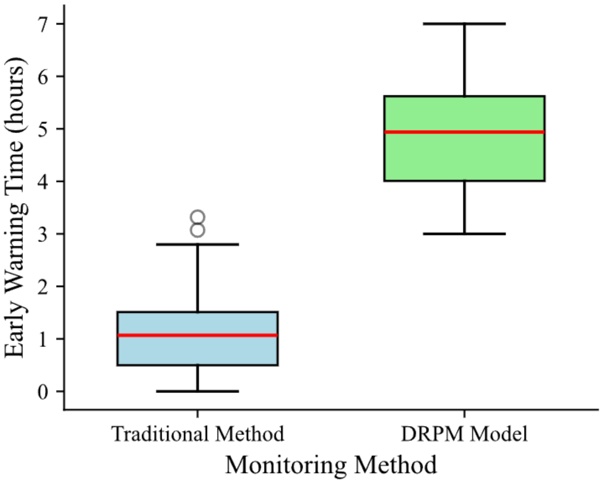

Figure 1. Early warning timeliness

3.3. Risk Stratification Verification

In 312 patients, the risk stratification ability of DRPM model has been fully verified. The bleeding incidence of grade I (low risk) patients was 1.9%, grade II (medium risk) increased to 19.5% (OR = 12.7, 95% CI: 4.1–39.2), while the bleeding incidence of grade III (high risk) patients reached 100%(OR=∞), which indicated that the model could effectively distinguish different bleeding risk levels. See Table 3.

Table 3. The risk level was related to the actual bleeding event (n=312)

The model predicts the risk level	Number of patients	Actual bleeding rate	OR value (95%CI)
Grade I (low risk)	207	1.9% (4/207)	Refer to
Grade II (medium risk)	82	19.5% (16/82)	12.7(4.1-39.2)
Grade III (high risk)	23	100% (23/23)	∞

3.4. Verification of Spatial Positioning Accuracy

Using receiver operation characteristic curve to evaluate bleeding point localization capability: localization accuracy=(real bleeding point coordinates/predicted bleeding area) × 100%. The verification results of spatial positioning accuracy show that the positioning method based on the fusion of spectral and impedance imaging has high accuracy. As shown in Figure 2, among the 37 confirmed bleeding points, the average positioning error is 0.6 ± 0.74cm, with a precision positioning rate (error $\leq$ 2 cm) of 86.5% (32/37) and a depth recognition accuracy rate of 78.4% (29/37). The Euclidean distance between the actual and predicted coordinates is highly correlated (r=0.98, P<0.001), indicating that the system can reliably achieve spatial positioning of bleeding points and provide technical support for subsequent precise interventions.

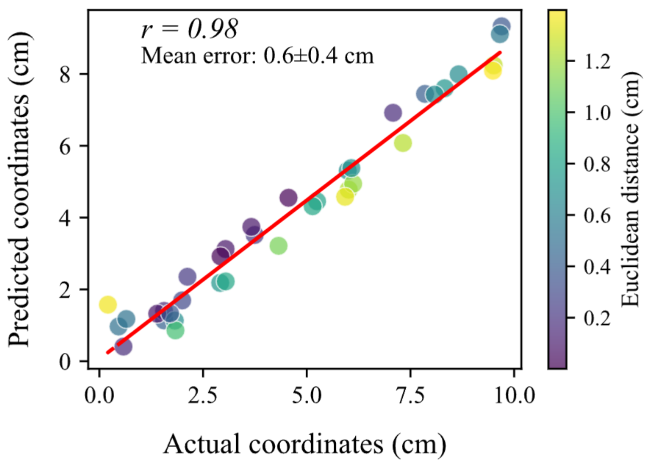

Figure 2. Euclidean distance distribution between actual bleeding point and predicted coordinates

3.5. Clinical Benefit Verification

The clinical benefit verification in Table 4 shows that the experimental group with DRPM model is significantly superior to the traditional group in many outcome indicators. The reoperation rate decreased by 69.7%, the average length of stay shortened by 23.9%, the length of stay in ICU decreased by 26.1%, and the amount of blood transfusion decreased by 52.9%, indicating that this model can not only effectively reduce invasive intervention and resource consumption, significantly improve the prognosis of patients, but also reflect good clinical application value and cost-effectiveness potential.

Table 4. Comparison of clinical outcomes between the two groups

Index	DRPM model group	Traditional group	Reduce the range
Reoperation rate	5.7% (9/158)	18.8% (29/154)	69.7%
Average length of stay (days)	8.3±2.1	10.9±3.4	23.9%
ICU stay time (hours)	38.5±12.7	52.1±18.3	26.1%
Blood transfusion volume (ml)	320±150	680±240	52.9%

4. Conclusion

(1) The DRPM model significantly outperforms traditional methods in terms of bleeding warning effectiveness, with sensitivity and specificity reaching 94.7% and 92.5%, respectively. The false positive rate is reduced to 7.4%, and the warning lead time is 4.8 ± 1.2 hours, which is significantly longer than traditional methods. In addition, the DRPM model can effectively distinguish different levels of bleeding risk, with bleeding incidence rates of 1.9%, 19.5%, and 100% for patients with level I (low risk), level II (medium risk), and level III (high risk), respectively.

(2) The verification of spatial positioning accuracy shows that the positioning method based on the fusion of spectral and impedance imaging has high accuracy, with an average positioning error of 0.6 ± 0.74cm and an accurate positioning rate of 86.5%.

(3) The verification of clinical benefits shows that the experimental group with DRPM model is significantly superior to the traditional group in the reoperation rate, average length of stay in ICU and blood transfusion, with the reoperation rate reduced by 69.7%, the average length of stay in ICU shortened by 23.9%, the length of stay in ICU decreased by 26.1% and the blood transfusion decreased by 52.9%.

References

[1] Li Zijia,Zhao Yingyin,Shi Jiankun,Liang Chujun,Zhang Shimin,Zheng Jiayi... & Zhao Yang.(2025).Association of Intraoperative Hypotension with Postoperative Nausea and Vomiting in Laparoscopic Gastrointestinal Surgery: A Secondary Analysis of a Randomized Trial.Anesthesiology, 143(3), 582-592.

[2] Yinchao Zhang,Chao Li,Linze Xu,Jin Zhang,Dandan Wu,Yu Bai & Huikai Li.(2025).The safety and efficacy of NEPA in preventing postoperative nausea and vomiting after general anesthesia during gastrointestinal cancer surgery: a single-center retrospective study..Translational cancer research,14 (7), 4369-4380.

[3] Andrei Gurau,Olivia Monton,Jonathan B Greer,Norman G Nicolson & Fabian M Johnston.(2024).Racial Disparities in the Use of Minimally Invasive Surgery for Gastrointestinal Cancer.. Journal of surgical oncology,131(6),1118-1124.

[4] Ling Zhu,Jun Cheng,Fei Xiao & Yan Yan Mao.(2024).Effects of comprehensive nutrition support on immune function, wound healing, hospital stay, and mental health in gastrointestinal surgery..World journal of gastrointestinal surgery, 16(12),3737-3744.

[5] Odysseas P. Chatzipanagiotou & Timothy M. Pawlik.(2024). ASO Author Reflections: Impact of Area Deprivation on Days at Home Following Gastrointestinal Cancer Surgery.Annals of Surgical Oncology,32(4),1-2.

[6] Kei Harada,Yusuke Uemoto,Keiji Nagata,Taisuke Matsuoka, Ippei Yamana,Toshifumi Watanabe... & Takahisa Fujikawa. (2024). The effect of anticoagulation therapy on the surgical outcomes of minimally invasive major gastrointestinal surgery..Surgical endoscopy,39(2),1-9.

[7] Nanako Kawata,Mitsuyoshi Yoshida,Ayu Sakai,Tsuyoshi Tanaka,Gaku Inaguma,Koichi Suda & Akitsugu Ohuchi. (2024). Relationship between the number of remaining teeth and postoperative delirium in patients after gastrointestinal surgery..Geriatrics & gerontology international, 25(1), 90-95.

[8] Michael G Fadel,Josephine Walshaw,Francesca Pecchini, Marina Yiasemidou,Matthew Boal,Muhammed Elhadi... & European Robotic Surgery Consensus (ERSC) study group. (2024).A pan-European survey of robotic training for gastrointestinal surgery: European Robotic Surgery Consensus (ERSC) initiative.. Surgical endoscopy,39(2),1-15.

[9] Taishi Hata,Hiroyuki Yamamoto,Masataka Ikeda,Hiroaki Nagano, Ichiro Takemasa,Takeshi Naitoh... & Yuichiro Doki. (2024). Status of perioperative venous thromboembolism (VTE) prophylaxis in gastrointestinal surgery based on national clinical database (NCD) data in Japan..Surgery today,55(6),1-9.