Article

Identification of Risk Factors for Postoperative Delirium and Targeted Preventive Strategies in Elderly Patients in the Emergency Surgical ICU

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Xiaojiao Liu[1], Feng Pan[1], Liqin Hu[1], Jun Zhao[2]

[1]Department of Critical Care Medicine, Guanghan People's Hospital, 618300 Deyang, Sichuan, China
[2]Department of Critical Care Medicine, Mianyang Third People's Hospital, 621000 Mianyang, Sichuan, China

AIM: Elderly patients admitted to the intensive care unit (ICU) after emergency surgery represent a uniquely high-risk population for postoperative delirium (POD). However, the key risk factors specific to this group have not been comprehensively integrated, and a corresponding clinical prediction tool is lacking. This study aimed to elucidate the clinical features, identify independent risk factors for POD, and develop and validate a prediction model tailored for elderly patients in the emergency surgical ICU.
METHODS: This retrospective study included 496 elderly patients (≥60 years) admitted post-emergency surgery. Delirium was assessed using the Confusion Assessment Method for the Intensive Care Unit (CAM-ICU). Patients were randomly divided in a 7:3 ratio into training (n = 347) and validation (n = 149) sets. Logistic regression identified independent predictors, which were used to construct a nomogram. Model performance was evaluated via receiver operating characteristic (ROC) curves, calibration, and decision curve analysis (DCA).
RESULTS: POD incidence was 33.1%, predominantly the hypoactive subtype (64.6%), with peak onset on postoperative day 2 (57.9%). Five independent risk factors were identified: higher Sequential Organ Failure Assessment (SOFA) score (Odds Ratio [OR] = 3.818), elevated Procalcitonin (PCT) (OR = 1.594), longer mechanical ventilation (OR = 1.283), intraoperative hypotension (OR = 2.666), and physical restraint use (OR = 3.003). A nomogram was developed using these variables, which demonstrated excellent discriminative performance, with area under the curves (AUCs) of 0.937 and 0.913, in the training and validation datasets, respectively. DCA confirmed the clinical utility of our proposed model.
CONCLUSIONS: This study identified five key and modifiable risk factors for POD in elderly emergency surgical ICU patients and successfully developed and validated a high-performance nomogram prediction tool. This model aids in the early identification of high-risk patients, providing a basis for implementing targeted bundled prevention strategies, which holds promise for improving clinical outcomes in this vulnerable population.

Keywords: POD; intensive care unit; elderly; emergency surgery; nomogram

Introduction

Delirium is a common and clinically significant neuropsychiatric syndrome characterized by an acute alteration in mental status, fluctuating levels of consciousness, and impairment in cognition [1]. When developing postoperatively or during admission to the intensive care unit (ICU), it is specifically referred to as postoperative delirium (POD) or ICU delirium [2]. POD typically occurs within the first 2 to 5 days after surgery and is associated with severe adverse outcomes, with a notably high incidence among critically ill older adults, with estimated rates reaching 66.1% [3,4]. Clinically, it is categorized into hyperactive, hypoactive, and mixed subtypes. The hypoactive and mixed presentations are more frequently observed in ICU settings; the hypoactive form, characterized by lethargy and apathy, often remains unrecognized due to its less obvious clinical presentations, resulting in delayed diagnosis and missed opportunities for prompt intervention [5,6]. The occurrence of POD has been linked to prolonged ICU stay, disruption of ongoing treatment protocols, reduced quality of life, and an increased risk of long-term cognitive decline [7,8,9]. Therefore, identification of patients at risk for POD at an early stage remains a crucial clinical priority.

Current evidence is predominantly derived from surgical populations known to have a high baseline POD risk, such as cardiac surgery [10,11], neurosurgery [12], and thoracic procedures [13]. Pathogenesis of POD is multifactorial and likely involves the interplay between patient predisposing characteristics, perioperative physiological stress, and iatrogenic factors. Established risks include iatrogenic exposures such as mechanical ventilation, physical restraints, and the use of benzodiazepines; acute physi-

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Correspondence to: Jun Zhao, Department of Critical Care Medicine, Mianyang Third People's Hospital, 621000 Mianyang, Sichuan, China (e-mail: zhaojunxxxx@163.com).
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ological stressors, including major hemorrhage, hypoxia, systemic inflammatory responses, and high Acute Physiology and Chronic Health Evaluation (APACHE) III scores; and underlying patient vulnerabilities such as advanced age, pre-existing cognitive impairment, and lower Glasgow Coma Scale scores on admission [14,15]. Among these factors, advanced age stands out as one of the most consistent and significant risk factors across ICU populations. Older adults admitted to emergency surgical ICUs often present with more severe and complex clinical conditions, which may further elevate their vulnerability to delirium.

Despite this increased susceptibility, the epidemiological characteristics and independent predictors of POD in older patients undergoing emergency surgical ICU management remain inadequately defined. To address this gap, the present study aims to determine the incidence of POD in this specific population and to identify the key independent risk factors associated with its occurrence. Based on these findings, the study intends to develop a predictive model to support early identification of high-risk patients, guide targeted interventions, and ultimately reduce delirium-related adverse outcomes, thereby improving overall prognosis.

Methods

Recruitment of Study Participants and Inclusion-Exclusion Criteria

This retrospective, single-center observational study enrolled patients admitted to the Surgical Intensive Care Unit (SICU) following emergency surgery between January 2023 and June 2024. The study protocol was approved by the Medical Ethics Committee of Guanghan People's Hospital (Approval No: 2025-018), and due to the retrospective study design and use of routinely collected clinical data, the requirement for informed consent was waived.

Inclusion criteria for patient selection were: (1) aged 60 years or older; (2) who underwent emergency surgical procedures (such as surgery for major trauma, vascular emergencies, or sepsis) and were admitted directly to the SICU postoperatively; and (3) those with actual SICU stay longer than 24 hours. Participants were excluded if: (1) they were admitted to SICU for non-surgical reasons; (2) had evidence of preoperative delirium or a documented history of dementia or severe cognitive impairment; (3) had history of major psychiatric disorders or severe neurological diseases, such as stroke with significant residual deficit; (4) had severe communication barriers (for example, profound deafness or aphasia) or persistent deep sedation or coma (Richmond Agitation-Sedation Scale [RASS] $\leq$–4) precluding reliable assessment; (5) died or discharge before the first delirium assessment could be completed; and (6) those readmitted to the SICU during the same hospitalization (only the first admission episode was considered for such patients).

During data verification, patients with significant missing information (>20% of key study variables missed) were eliminated to ensure data quality. Patients undergoing isolated neurosurgical procedures (e.g., craniotomy) were not included because they are routinely managed in a dedicated Neurosurgical ICU. All procedures were conducted in accordance with the principles outlined in the Declaration of Helsinki.

Data Sources and Collection Procedures

Data were systematically extracted from the hospital's electronic medical records, including anesthesia charts, surgical reports, nursing documentation, and the laboratory information system. Data were obtained using a pre-designed electronic case report form (eCRF). Two specialized research assistants independently collected data after receiving protocol-specific instructions and were blinded to patients' delirium outcomes. To ensure consistency, a standardized data extraction manual with an explicitly defined procedure was followed throughout the data extraction process. Inter-rater agreement was assessed using a random 10% sample (n = 50), yielding excellent agreement for the Confusion Assessment Method for the Intensive Care Unit (CAM-ICU) classification (Cohen's kappa = 0.92). Any discrepancies were reviewed and resolved by a senior intensivist serving as an independent adjudicator.

Collected variables are categorized as follows:

(1) Demographics and Baseline Characteristics: It includes age, sex, and history of alcohol use. (2) Preoperative Comorbidities and Clinical Status: History of hypertension, diabetes mellitus, cardiovascular disease, and American Society of Anesthesiologists Physical Status (ASA PS). (3) Surgical and Intraoperative Parameters: Surgical category (gastrointestinal, hepatobiliary, vascular, orthopedic/trauma, and others), wound classification (clean, clean-contaminated, contaminated, and dirty-infected) according to National Healthcare Safety Network criteria, duration of surgery, estimated intraoperative blood loss, episodes of intraoperative hypoxia or hypotension, and intraoperative use of propofol, dexmedetomidine, or benzodiazepines. (4) Laboratory Parameters and Biomarkers: White Blood Cell (WBC) count, Neutrophil-to-Lymphocyte Ratio (NLR), C-reactive protein (CRP), Procalcitonin (PCT), Blood Urea Nitrogen (BUN), Creatinine (Cr), Albumin, and Hemoglobin. (5) ICU Severity Scores, Diagnoses, and Management Measures (ICU-Related Clinical Characteristics and Interventions): Sequential Organ Failure Assessment (SOFA) score [16], disease classification (major trauma or acute vascular emergency), presence of sepsis, requirements for reoperation due to postoperative complications, duration of mechanical ventilation, use of physical restraints, number of indwelling catheters, and administration of opioid medications. The SOFA score assesses six organ systems-respiratory, coagulation, hepatic, cardiovascular, central nervous, and renal—each graded from 0 to 4 according to the severity of dysfunction, giving a total score ranging from 0 to 24, with higher scores indicating more severe multi-organ dysfunc-

tion [16]. Use of physical restraints was defined as any documented application of restraint devices during the SICU stay. According to institutional protocol, restraints are routinely applied as a preventive measure upon SICU admission for patients at risk of unplanned removal of medical devices; in most cases, they precede the development of POD. However, due to the retrospective study design, the precise temporal relationship between the restraint used and delirium could not be confirmed for every patient. Duration of mechanical ventilation was defined as the total number of hours of invasive ventilatory support delivered via endotracheal tube or tracheostomy, while non-invasive ventilation was excluded. The PCT level was defined as the first measurement obtained within 24 hours after SICU admission.

Delirium Assessment and Outcome Definition

POD was identified through a structured retrospective review of patient medical records. The primary outcome was defined as the presence of at least one documented positive assessment using the Confusion Assessment Method for the Intensive Care Unit (CAM-ICU) during the postoperative ICU stay.

The CAM-ICU diagnoses delirium based on four core features: (1) acute onset or fluctuating changes in mental status; (2) inattention; (3) altered level of consciousness; and (4) disorganized thinking. A diagnosis requires the presence of both Features 1 and 2, together with either Feature 3 or Feature 4 [17]. In routine clinical practice, interpretation of CAM-ICU findings is usually supported by evaluation of the patient's levels of arousal using the Richmond Agitation-Sedation Scale (RASS) [18]. For this study, all available nursing records and ICU flow sheets were carefully reviewed to identify documented CAM-ICU and RASS scores.

For patients who met criteria for POD, delirium subtypes were retrospectively classified based on RASS scores recorded alongside positive CAM-ICU assessments. Hyperactive (agitated) delirium was defined as a positive CAM-ICU assessment with all daily RASS scores being positive (+1 to +4); hypoactive delirium as a positive CAM-ICU assessment with all daily RASS scores being neutral or negative (0 to –3); and mixed delirium as a positive CAM-ICU assessment with daily RASS scores spanning both positive (+1 to +4) and neutral or negative (0 to –3) values [19]. To minimize ascertainment bias, only patients with at least two documented CAM-ICU assessments per day during the first three postoperative days were included in the analysis. Cases with unclear or incomplete documentation were independently reviewed by a senior intensivist to determine final classification.

Sample Size Analysis

Sample size was determined using a widely accepted ("Events Per Variable [EPV]" ≥10) principle for prediction model development [20]. Approximately six candidate predictors were anticipated for the final model, encompassing key clinical domains such as severity of organ dysfunction, systemic inflammatory response, intraoperative hemodynamic instability, mechanical ventilation exposure, and iatrogenic interventions based on prior literature examining POD risk factors in ICU populations. Previous studies have reported a PD incidence ranging between 20 and 40% in the emergency surgical ICU settings [21,22]. A conservative incidence of 20% was used in the sample size calculation. Accounting for an estimated 10% data attrition, the minimum required sample size was calculated as follows: $N = (6 \times 10 / 0.2) / 0.9 = 334$ patients.

After applying the pre-defined inclusion and exclusion criteria, the final actual sample size comprised 496 patients who completed CAM-ICU assessments, exceeding the calculated minimum sample size. Patients were randomly divided in a 7:3 ratio into a training set (n = 347) and a validation set (n = 149) using computer-generated randomization (R function sample split, seed = 2024). The training cohort was used for predictive model development, and the validation cohort was used to assess the internal model's clinical performance.

Statistical Analysis

Statistical analyses were conducted using SPSS (version 26.0; IBM Corp., Armonk, NY, USA) and R (version 4.5.1; R Foundation for Statistical Computing, Vienna, Austria). A two-sided p-value below 0.05 defined statistical significance. Normality of the continuous variable was evaluated using the Shapiro-Wilk test. Normally distributed variables were presented as mean ± SD (normal), while non-normally distributed variables were expressed as median with interquartile range (IQR). Categorical variables were reported as counts and percentages. Group comparisons were conducted using the independent samples t-test or Mann-Whitney U test for continuous variables, and the Chi-square or Fisher's exact test for categorical variables. Potential POD risk factors were investigated using univariate logistic regression within the training set. Variables with $p < 0.05$ were included in a subsequent multivariable logistic regression (enter method) to identify independent predictors. Associations were expressed as Odds Ratio (OR) (95% CI). Multicollinearity among the variables included in the final model was examined using tolerance and variance inflation factor (VIF) statistics.

A predictive nomogram was constructed based on the independent predictors identified in the multivariate logistic regression, using the rms package in R. Model calibration was internally validated in the training set using bootstrap resampling (1000 repetitions) to generate calibration plots, together with the Hosmer-Lemeshow goodness-of-fit test. The model's discriminative ability was then evaluated by plotting receiver operating characteristic (ROC) curves and calculating the area under the curve (AUC) for both the training and independent validation datasets. The optimal cutoff probability was determined by maximizing Youden's index. Furthermore, the clinical utility of the nomogram was assessed and compared across both cohorts using Decision Curve Analysis, which quantifies the net benefit over a range of threshold probabilities.

Additionally, a stepwise logistic regression (forward and backward procedures based on the Akaike Information Criterion [AIC]) was performed on the training set to verify variable selection consistency. Stability of variables was further validated using the Least Absolute Shrinkage and Selection Operator (LASSO) regression implemented through the glmnet package in R. The optimal value of the regularization parameter (lambda) was determined using 10-fold cross-validation.

Results

Comparison of Baseline Characteristics Between the Training and Validation Sets

After applying the pre-defined inclusion and exclusion criteria, all eligible patients (n = 496) completed the required assessments. Using computer-generated random numbers, patients were randomly divided in a 7:3 ratio to a training set (n = 347) and a validation set (n = 149). The comparative analysis of baseline demographic and clinical characteristics between the training and validation sets revealed no statistically significant differences ($p > 0.05$ for all comparisons), confirming the comparability of the two groups. As shown in Table 1, the comparative analysis demonstrated a balanced distribution of all baseline characteristics between the training and validation sets.

Incidence POD Subtypes

Among the 496 patients included in the study, 164 developed POD, corresponding to an overall incidence of 33.1%. Based on the clinical presentation, hypoactive POD was the most common subtype, found in 106 (64.6%) patients, followed by mixed POD in 31 (18.9%) patients and hyperactive POD in 27 (16.5%) patients. The probability of delirium was highest on the second day after surgery, when the incidence peaked at 57.9%. However, the rate gradually declined, stabilizing at approximately 20% thereafter (Table 2).

Incidence of POD and Univariate Predictor Analysis in the Training Set

Within the training cohort, 115 patients (33.1%) developed POD, whereas 232 patients (66.9%) did not experience this complication. Univariate analysis revealed that patients in the POD group demonstrated significantly higher Sequential SOFA scores and increased PCT levels ($p < 0.001$). Furthermore, a significantly greater proportion of patients in the POD group experienced intraoperative hypotension, longer duration of mechanical ventilation, and the use of physical restraints ($p < 0.001$). In contrast, no statistically significant differences ($p > 0.05$) were observed between the POD and non-POD groups with respect to other baseline demographic characteristics, comorbidities, intraoperative variables, or laboratory parameters, as detailed in Table 3.

Multivariable Logistic Regression Analysis for Independent Predictors in the Training Set

A multivariate binary logistic regression analysis was performed to identify independent risk factors of POD among emergency surgical ICU patients. The occurrence of delirium was defined as the binary outcome variable (1 = present, 0 = absent). The coding definitions for all categorical variables are detailed in Table 4.

The analysis revealed that five variables were independently associated with a significantly increased risk of POD ($p < 0.05$ for all) (Table 5). These included a higher Sequential SOFA score (OR = 3.818, 95% CI: 2.621–5.562), elevated PCT levels (OR = 1.594, 95% CI: 1.249–2.034), longer duration of mechanical ventilation (OR = 1.283, 95% CI: 1.180–1.396), the occurrence of intraoperative hypotension defined as mean arterial pressure <65 mmHg (OR = 2.666, 95% CI: 1.295–5.487), and the use of physical restraints (OR = 3.003, 95% CI: 1.409–6.401).

Evaluation of multicollinearity confirmed the robustness of the model, with all tolerance values >0.1 and all VIF values <10, indicating no significant collinearity among the predictors. To validate the robustness of variable selection, stepwise logistic regression based on AIC with bidirectional selection, together with LASSO regression using 10-fold cross-validation (lambda.min = 0.018), were independently performed. Both methods detected the same five predictors as the enter method: SOFA score, PCT, duration of mechanical ventilation, intraoperative hypotension, and the use of physical restraints. The concordance across these three selection approaches supports the reliability and consistency of the final predictive model.

Development of the Prediction Nomogram and Internal Validation in the Training Set

Using the five independent predictors identified in the multivariable logistic regression analysis, a predictive nomogram was constructed within the training set (n = 347). The model incorporates the following variables: SOFA score, PCT level, duration of mechanical ventilation, occurrence of intraoperative hypotension, and use of physical restraints (Fig. 1A). By summing up the points assigned to individual variables, the model provides an individualized predicted risk of ICU-acquired POD.

The model's internal calibration was assessed using bootstrap resampling with 1000 repetitions. The calibration curve demonstrated excellent agreement between predicted and observed probabilities, with a mean absolute error (MAE) of 0.015 (Fig. 1B). The Hosmer-Lemeshow goodness-of-fit test further confirmed satisfactory model calibration ($\chi^2 = 5.586$, $p = 0.705$).

Table 1. Comparison of baseline characteristics between the training and validation sets.

Variable		Total (n = 496)	Training Set (n = 347)	Validation Set (n = 149)	Statistical Value	*p*-value
Age (years)		70.00 (65.00, 76.00)	70.00 (65.00, 75.00)	71.00(66.00, 76.00)	–0.885	0.376
Gender, n (%)					0.111	0.739
	Male	244 (49.2%)	169 (48.7%)	75 (50.3%)		
	Female	252 (50.8%)	178 (51.3%)	74 (49.7%)		
Medical history, n (%)						
	Hypertension	58(11.7%)	40 (11.5%)	18 (12.1%)	0.031	0.860
	Diabetes	99 (20.0%)	77 (22.2%)	22 (14.8%)	3.597	0.058
	Cardiovascular disease	45 (9.1%)	35 (10.1%)	10 (6.7%)	1.439	0.230
SOFA score (points)		5.00(4.00, 6.00)	5.00(4.00, 6.00)	5.00 (4.00, 6.00)	–0.888	0.375
History of alcohol, n (%)					0.088	0.767
	Yes	268 (54.0%)	189 (54.5%)	79 (53.0%)		
	No	228 (46.0%)	158 (45.5%)	70 (47.0%)		
ASA, n (%)					0.777	0.378
	I–II	258 (52.0%)	176 (50.7%)	82 (55.0%)		
	III–IV	238 (48.0%)	171 (49.3%)	67 (45.0%)		
Operation time (min)		127.81 ± 34.50	126.82 ± 34.46	130.11 ± 34.59	–0.973	0.331
Intraoperative blood loss (mL)		326.00 (233.25, 402.75)	325.00 (233.00, 399.00)	332 (240.00, 403.50)	–0.052	0.958
Intraoperative hypoxia, n (%)					0.002	0.969
	Yes	247 (49.8%)	173 (49.9%)	74 (49.7%)		
	No	249 (50.2%)	174 (50.1%)	75 (50.3%)		
Intraoperative hypotension, n (%)					0.260	0.610
	Yes	255 (51.4%)	181 (52.2%)	74 (49.7%)		
	No	241 (48.6%)	166 (47.8%)	75 (50.3%)		
Disease Classification, n (%)					1.722	0.787
	Major trauma	59 (11.9%)	43 (12.4%)	16 (10.7%)		
	Acute vascular emergency	45 (9.1%)	32 (9.2%)	13 (8.7%)		
	Sepsis	27 (5.4%)	17 (4.9%)	10 (6.7%)		
	Postoperative complication re-operation	23 (4.6%)	18 (5.2%)	5 (3.4%)		
	Other acute surgical conditions	342 (69.0%)	237 (68.3%)	105 (70.5%)		
Surgical Category					0.055	1.000
	Gastrointestinal	189 (38.1%)	132 (38.0%)	57 (38.3%)		
	Hepatobiliary-pancreatic	89 (17.9%)	63 (18.2%)	26 (17.4%)		
	Vascular	69 (13.9%)	48 (13.8%)	21 (14.1%)		
	Orthopedic/trauma	84 (16.9%)	59 (17.0%)	25 (16.8%)		
	Others	65 (13.1%)	45 (13.0%)	20 (13.4%)		

Postoperative complication reoperation refers to patients who required a second surgical intervention during the same continuous SICU stay (e.g., re-exploration for hemorrhage), with no discharge occurring between operations. This event is not classified as a readmission.

SOFA, Sequential Organ Failure Assessment; ASA, American Society of Anesthesiologists; SICU, Surgical Intensive Care Unit. Medical history categories are not mutually exclusive.

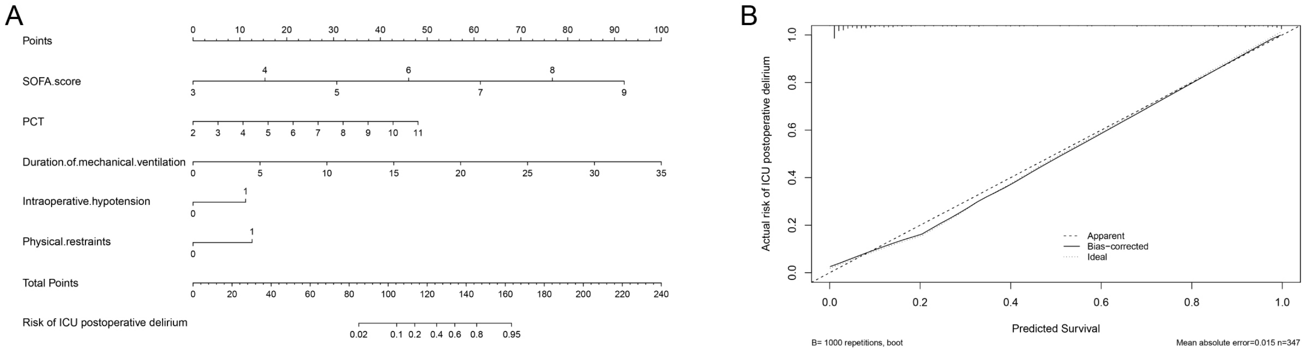

Fig. 1. Predictive nomogram and its calibration curve were developed from the training set. (A) The nomogram for predicting ICU-acquired POD. For each patient, a points value is assigned based on their SOFA score, PCT level, duration of mechanical ventilation, presence of intraoperative hypotension, and application of physical restraints. Summing these points yields a total points value, which corresponds to an individualized risk of POD on the bottom axis. (B) Calibration curve of the nomogram. The 'Apparent' line represents the performance of the original model on the training set. The 'Bias-corrected' line reflects the performance after optimism correction via bootstrap internal validation (1000 repetitions). The 'Ideal' line indicates perfect prediction. The mean absolute error (MAE) is 0.015.

Table 2. The incidence of POD subtype throughout the observation period.

Variable	N = 164	Percentage (%)
POD subtypes		
Hypoactive type	106	64.6
Hyperactive type	27	16.5
Mixed type	31	18.9
The first occurrence of delirium[a]		
The second day after surgery	95	57.9
The third day after surgery	36	22.0
Later than the third day after surgery	33	20.1

Notes: [a]Delirium onset is demarcated by the initial time a positive result is recorded on the CAM-ICU. POD duration encompasses the interval beginning at the first positive CAM-ICU evaluation and ending with the immediately following first negative assessment.
CAM-ICU, Confusion Assessment Method for the Intensive Care Unit; POD, postoperative delirium.

Discriminative Performance of the Nomogram in the Training and Validation Sets

The discriminative performance of the model was quantified using receiver operating characteristic (ROC) curve analysis in both the training and independent validation sets. As shown in Fig. 2, the nomogram demonstrated robust predictive performance. In the training set, the area under the curve (AUC) reached 0.937 (95% CI: 0.910–0.964), with a sensitivity of 86.1%, a specificity of 89.2%, and a Youden index of 0.753 (Fig. 2A). When applied to the independent validation set, the model maintained strong discriminatory power, yielding an AUC of 0.913 (95% CI: 0.860–0.965), a sensitivity of 83.7%, a specificity of 90.0%, and a Youden index of 0.737 (Fig. 2B).

Clinical Utility of the Nomogram in the Training and Validation Sets: Decision Curve Analysis

The clinical utility of the nomogram was further assessed using decision curve analysis (DCA). As presented in Fig. 3, applying the nomogram in clinical decision-making provided a superior net benefit compared to the "intervene-all" or "intervene-none" strategies across a wide range of threshold probabilities (0.01–0.99) in both cohorts. In the training set, the model achieved a maximum net benefit of 0.326 (Fig. 3A). A similar clinical value was observed in the independent validation set, where the maximum net benefit reached 0.323 (Fig. 3B). The consistency of net benefits across both datasets supports the reliability of the model and underscores its potential in routine clinical practice.

Discussion

This retrospective analysis of 496 older patients admitted to the ICU after emergency surgery provides a comprehensive overview of the epidemiology of POD, detects key independent risk factors, and presents a clinically applicable predictive model for this high-risk cohort. The overall incidence of POD was 33.1%, with a predominance of the hypoactive subtype (64.6%), and the highest occurrence was observed on the second postoperative day. Multivariable analysis identified five independent predictors for POD: SOFA score, PCT level, duration of mechanical ventilation, intraoperative hypotension, and use of physical restraints. These factors collectively represent a dimension of risk, encompassing baseline physiological susceptibility, systemic inflammatory burden, and potentially modifiable iatrogenic interventions. The resulting nomogram demonstrated excellent discriminatory performance, with AUC values of 0.937 and 0.913 in the training and validation sets, respectively, offering good potential for early clinical risk stratification.

Table 3. Univariate analysis of baseline and clinical variables between the POD and non-POD groups.

Variable		Postoperative Delirium (n = 115)	No postoperative Delirium (n = 232)	Statistical Value	*p*-value
Age (years)	-	70.00 (66.00, 75.00)	70.00 (65.00, 75.75)	–0.406	0.685
Gender, n (%)				1.297	0.255
	Male	61 (53.0%)	108 (46.6%)		
	Female	54 (47.0%)	124 (53.4%)		
Medical history, n (%)					
	Hypertension	42 (36.5%)	98 (42.2%)	1.045	0.307
	Diabetes	23 (20.0%)	54 (23.3%)	0.478	0.489
	Cardiovascular disease	15 (13.0%)	20 (8.6%)	1.658	0.198
History of alcohol, n (%)				0.998	0.318
	Yes	67 (58.3%)	122 (52.6%)		
	No	48 (41.7%)	110 (47.4%)		
ASA PS, n (%)				2.084	0.149
	I–II	52 (45.2%)	124 (53.4%)		
	III–IV	63 (54.8%)	108 (46.6%)		
SOFA score (points)		6.00 (5.00, 7.00)	5.00 (4.00, 5.00)	–10.900	<0.001
Operation time (min)	-	131.05 ± 34.52	124.72 ± 34.31	1.614	0.107
Intraoperative blood loss (mL)	-	326.00 (222.00, 406.00)	320.50 (238.25, 398.50)	–0.145	0.885
Intraoperative hypoxia, n (%)				0.370	0.543
	Yes	60 (52.2%)	113 (48.7%)		
	No	55 (47.8%)	119 (51.3%)		
Intraoperative hypotension, n (%)				32.613	<0.001
	Yes	85 (73.9%)	96 (41.4%)		
	No	30 (26.1%)	136 (58.6%)		
WBC ($\times 10^9$/L)	-	12.45 ± 3.58	12.61 ± 3.91	–0.368	0.713
NLR	-	8.74 ± 3.52	8.41 ± 3.38	0.832	0.406
CRP (mg/L)	-	13.26 ± 3.10	13.28 ± 2.93	–0.062	0.951
PCT (ng/mL)	-	6.93 ± 1.45	5.64 ± 1.52	7.564	<0.001
BUN (mmol/L)	-	9.20 ± 2.12	8.97 ± 2.24	0.914	0.361
Cr (umol/L)	-	84.20 ± 12.07	84.63 ± 11.43	–0.323	0.747
Albumin level (g/L)	-	32.88 ± 3.40	32.56 ± 3.86	0.752	0.452
Hemoglobin level (g/L)	-	109.95 ± 19.51	107.54 ± 20.93	1.032	0.303
Propofol, n (%)	-	28 (24.3%)	63 (27.2%)	0.313	0.576
Dexmedetomidine, n (%)	-	32 (27.8%)	56 (24.1%)	0.553	0.457
Benzodiazepines, n (%)	-	40 (34.8%)	76 (32.8%)	0.142	0.707
Disease Classification, n (%)					
	Major Trauma	51 (44.3%)	92 (39.7%)	0.699	0.403
	Acute vascular emergency	17 (14.8%)	45 (19.4%)	1.115	0.291
	Sepsis	44 (38.3%)	73 (31.5%)	1.589	0.208
	Postoperative complication re-operation	8 (7.0%)	10 (4.3%)	1.095	0.295
Duration of mechanical ventilation (h)	-	19.35 ± 5.20	14.30 ± 4.84	8.916	<0.001
Physical restraints, n (%)				25.589	<0.001
	Yes	86 (74.8%)	107 (46.1%)		
	No	29 (25.2%)	125 (53.9%)		
Number of catheters	-	6.00 (5.00, 9.00)	7.00 (5.00, 9.00)	–0.710	0.478
Opioid, n (%)				0.972	0.324
	Yes	59 (51.3%)	132 (56.9%)		
	No	56 (48.7%)	100 (43.1%)		
Surgical category				0.535	0.971
	Gastrointestinal	45 (39.1%)	87 (37.5%)		
	Hepatobiliary-pancreatic	22 (19.1%)	41 (17.7%)		
	Vascular	16 (13.9%)	32 (13.8%)		
	Orthopedic/trauma	19 (16.5%)	40 (17.2%)		
	Others	13 (11.3%)	32 (13.8%)		

WBC, White Blood Cell; CRP, C-reactive protein; NLR, Neutrophil-to-Lymphocyte Ratio; PCT, Procalcitonin; BUN, Blood Urea Nitrogen; Cr, Creatinine; ASA PS, American Society of Anesthesiologists Physical Status; SOFA, Sequential Organ Failure Assessment.

Table 4. Assignment of Independent Variables.

Independent variable	Variable description	Assignment
SOFA score (points)	Continuous variable	–
Intraoperative hypotension	Categorical variable	Yes = "1", No= "0"
PCT	Continuous variable	–
Duration of mechanical ventilation	Continuous variable	–
Physical restraints	Categorical variable	Yes = "1", No= "0"

Table 5. Multivariable logistic regression analysis of independent predictors for POD in the training set.

	β	SE	Wald χ^2	*p*-value	OR	95% CI	Tolerance	VIF
SOFA score	1.340	0.192	48.744	<0.001	3.818	2.621–5.562	0.861	1.161
PCT	0.466	0.124	14.040	<0.001	1.594	1.249–2.034	0.919	1.088
Duration of mechanical ventilation	0.249	0.043	33.935	<0.001	1.283	1.180–1.396	0.951	1.051
Intraoperative hypotension	0.981	0.368	7.089	0.008	2.666	1.295–5.487	0.927	1.079
Physical restraints	1.100	0.386	8.107	0.004	3.003	1.409–6.401	0.945	1.058
Constant	–16.260	1.736	87.690	<0.001	0.000			

OR, Odds Ratio; VIF, variance inflation factor.

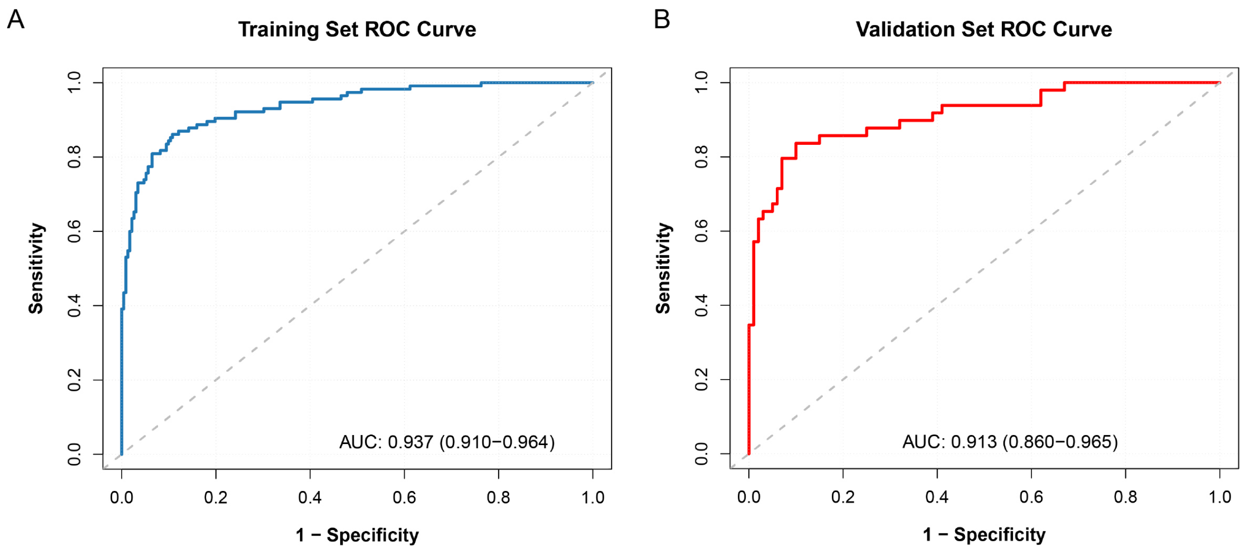

Fig. 2. Receiver operating characteristic (ROC) curves assessing the discriminative performance of the nomogram both in the training and independent validation sets. (A) Performance metrics derived from the application of the nomogram to the training set (n = 347). The area under the curve (AUC) is 0.937 (95% CI: 0.910–0.964). (B) Performance metrics resulting from the application of the nomogram to the independent validation set (n = 149). The AUC in this cohort was 0.913 (95% CI: 0.860–0.965). For both plots, the horizontal axis represents 1 – Specificity, and the vertical axis represents Sensitivity.

The observed POD incidence of 33.1% is consistent with the high rates reported in critically ill elderly populations [1,23]. The predominance of the hypoactive subtype (64.6%) aligns with prior reports [22] and underscores a significant clinical challenge. Hypoactive delirium often manifests as apathy and drowsiness, making it more challenging to identify than agitated clinical presentations. Consequently, it is frequently underdiagnosed in the ICU setting, leading to potential delays in management and adversely affecting clinical outcomes [6,24,25]. While the development of subtype-specific prediction models would be clinically promising, the relatively small sample size of hyperactive (n = 27) and mixed (n = 31) subgroups in this cohort limited the feasibility of reliable multivariate analysis for these subgroups. Future larger, multicenter studies are warranted to develop and validate subtype-specific prediction tools, which would clarify whether risk profiles differ meaningfully between delirium phenotypes. Therefore, prevention strategies for older emergency surgical patients must prioritize careful monitoring for non-agitated symptoms. Regular screening with standardized, validated tools such as the CAM-ICU, ideally conducted twice daily, together with multicomponent non-pharmacological interventions, including orientation approaches, early mobilization, and sleep optimization [5].

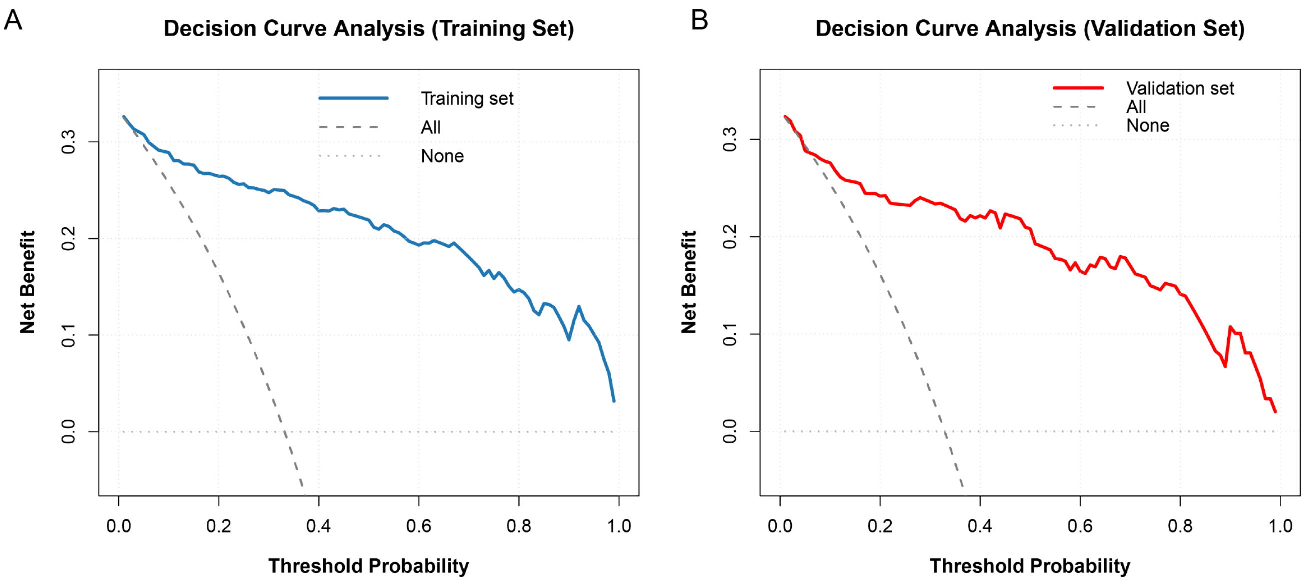

Fig. 3. Decision curve analysis of the nomogram in the training and validation sets. (A) decision curve analysis (DCA) evaluates the clinical utility of the nomogram within the training set. The solid line (nomogram) shows a greater net benefit than the “intervene-all” (dashed line) or “intervene-none” (dotted line) strategies across most threshold probabilities, with a maximum net benefit of 0.326. (B) DCA validates the clinical utility of the nomogram in the independent validation set. The model demonstrates a robust and comparable net benefit (maximum: 0.323), confirming its generalizability. For both panels, the horizontal axis represents the threshold probability for clinical intervention, and the vertical axis denotes the net benefit.

The elevated SOFA score, a marker of organ dysfunction and physiological reserve depletion, was a significant predictor of POD, corroborating previous research [26,27]. Mechanistically, elevated SOFA scores reflect multi-organ dysfunction, which promotes blood-brain barrier disruption through systemic endothelial activation and facilitates the entry of peripheral inflammatory mediators into the central nervous system, ultimately contributing to microglial activation and neuronal dysfunction [28]. This pathological cascade aligns with the “systemic inflammation–neuroinflammation” hypothesis of delirium, in which cholinergic deficiency and dopaminergic excess play central roles [16,29]. Concurrently, elevated PCT levels, a biomarker of systemic inflammation [30,31], were independently associated with delirium risk. The inflammatory cascade is a central pathophysiological mechanism in delirium [4,32,33], suggesting that monitoring PCT may help identify patients at heightened neuroinflammatory risk.

Among the modifiable iatrogenic factors, prolonged duration of mechanical ventilation was strongly associated with POD, consistent with findings across ICU and cardiac surgery populations [34,35,36,37,38]. Prolonged ventilatory support is accompanied by elevated sedative exposure, immobilization, sleep disruption, and respiratory distress, all of which may contribute to cognitive dysfunction. Therefore, efforts to minimize ventilator duration through refined weaning strategies and careful sedation management may help reduce delirium risk. Furthermore, intraoperative hypotension was also identified as a significant contributor, likely reflecting transient impairment in cerebral perfusion and subsequent postoperative cognitive dysfunctions [39,40]. These observations highlight the importance of maintaining stable intraoperative hemodynamics through individualized, goal-oriented blood pressure management.

The use of physical restraints was identified as a potent modifiable risk factor. While sometimes deemed necessary for patient safety, restraint use can initiate a vicious cycle by inducing fear, discomfort, and sensory deprivation, which may exacerbate or precipitate delirium [4,41,42]. This complex, bidirectional relationship has been particularly observed in surgical ICU settings [43,44,45,46]. Therefore, a rigorous protocol to minimize restraint use—employing alternatives such as enhanced communication, family presence, and optimized sedation—is essential. When restraint is unavoidable, it must be coupled with intensified delirium monitoring. Although advanced age is well-established as a predisposing factor for POD in a heterogeneous population, our study exclusively enrolled patients aged ≥60 years. Within this relatively homogeneous, age-restricted cohort, the narrower between-group variation in age was insufficient to demonstrate independent predictive power after adjusting for more proximal clinical risk factors. This phenomenon—where a universally recognized risk factor loses significance within a homogeneous high-risk subgroup—is consistent with restriction of range effects.

This study has several limitations. First, its single-center, retrospective design may affect the generalizability of the findings and introduce potential biases from unmeasured confounders, such as medication exposure and environmental factors. Moreover, the retrospective design precluded definitive establishment of the temporal relationship between restraint application and POD onset, and cumulative sedative dose was not quantified as a separate covariate, which may represent residual confounding. Additionally, the surgeon's experience level was also not analyzed and thus could not be evaluated as a potential confounder. Second, a fixed daily assessment schedule might not have captured all fluctuating delirium episodes, potentially leading to an underestimation of incidence, particularly for the hypoactive subtype. To mitigate retrospective ascertainment bias, we employed dual-investigator blinded extraction with high inter-rater reliability (kappa = 0.92) and independent adjudication of discrepancies. Finally, while the nomogram showed excellent internal validation performance, its clinical utility and impact on long-term patient outcomes require external validation in prospective, multicenter settings.

Conclusions

In conclusion, this single-center retrospective study characterizes the occurrence and determinants of POD in elderly patients admitted to the ICU following emergency surgery. We found a high incidence of POD, with the hypoactive subtype representing the most frequent clinical presentation. Five independent and clinically relevant risk factors were identified: SOFA score, PCT level, duration of mechanical ventilation, intraoperative hypotension, and physical restraint. A nomogram prediction model integrating these variables demonstrated excellent discriminative ability and a favorable net clinical benefit during internal validation. This model provides a practical, evidence-based tool for the early stratification of high-risk patients. We therefore recommend that patients identified as high-risk by this model promptly receive a bundled, multidisciplinary prevention strategy. This strategy should be centered on intensified neurological monitoring, optimization of analgesia-sedation and respiratory weaning protocols, promotion of early mobilization, and a strict minimization of physical restraints. Implementation of such approaches may help minimize the clinical burden of POD and enhance recovery outcomes in this particularly high-risk population.

Availability of Data and Materials

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

Author Contributions

XL and JZ conceived and designed the study; XL, FP and LH acquired and analyzed the data; XL and JZ drafted the manuscript. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The research protocol was reviewed and approved by the Medical Ethics Committee of Guanghan People's Hospital (Approval Number: 2025-018) and is in line with the ethical standards for medical research involving human subjects as set out in the Declaration of Helsinki and its subsequent amendments. Participants provided written informed consent prior to taking part in the study.

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Conflict of Interest

The authors declare no conflict of interest.

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