

Association Between Preoperative Activities of Daily Living and Postoperative Delirium in Elderly Patients Undergoing Non-Cardiac Surgery: A Prospective Cohort Study

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Background: Postoperative delirium (POD) is a common complication in elderly surgical patients associated with adverse outcomes. However, the relationship between low preoperative Barthel Index (BI) and POD remains unclear.

Purpose: This study investigated the correlation between preoperative BI and POD incidence in elderly patients undergoing non-cardiac surgery.

Patients and Methods: This prospective cohort study enrolled 298 patients (≥ 65 years) undergoing elective non-cardiac surgery under general anesthesia. Preoperative BI assessed activities of daily living (ADL) within 24 hours before surgery. POD was screened twice daily until postoperative day 7 or discharge using the 3-Minute Diagnostic Interview for Confusion Assessment Method–defined Delirium (3D-CAM). Univariate and multivariate logistic regression analyzed associations between BI and POD. Restricted cubic spline (RCS) and two-piecewise linear regression explored non-linearity and identified inflection points. Findings were validated using inverse probability of treatment weighting (IPTW), and BI's incremental predictive value was evaluated by receiver operating characteristic (ROC) curve analysis.

Results: POD incidence was 25.8% (77/298). Multivariate analysis showed lower preoperative BI (OR=0.956, 95% CI: 0.940–0.973, $p < 0.001$), lower BMI (OR=0.860, 95% CI: 0.757–0.977, $p = 0.020$), and advanced age (OR=1.174, 95% CI: 1.102–1.250, $p < 0.001$) independently associated with POD. RCS revealed a nonlinear relationship with inflection at BI=75. Patients with BI<75 had significantly higher POD risk than those with BI \geq 75 (OR=4.615, 95% CI: 2.377–8.963, $p < 0.001$), robust after IPTW adjustment (42.9% vs 14.5%; adjusted OR=4.445, 95% CI: 2.564–7.707, $p < 0.001$). This association was pronounced in patients with fewer comorbidities, shorter anesthesia duration, and shorter preoperative stays. Incorporating the BI score significantly improved the discrimination of the predictive model for POD.

Conclusion: Preoperative ADL impairment (BI<75) independently predicts POD in elderly non-cardiac surgery patients. Preoperative BI assessment is recommended for perioperative risk stratification, identifying low-BI patients as targets for preventive interventions.

Keywords: activities of daily living, barthel index, postoperative delirium, elderly, non-cardiac surgery, 3d-cam, neuropsychological tests

Introduction

Postoperative delirium (POD) is an acute-onset, temporary brain dysfunction occurring primarily within the first week after surgery. Its clinical features include attention deficits, fluctuations in consciousness, and acute changes in cognitive

function.^{1–3} This condition significantly increases the risk of postoperative complications, prolongs hospital stay, exacerbates healthcare burdens, and elevates 30-day readmission rates, thereby adversely affecting patient outcomes.^{4–6}

With the accelerating aging of the population, the number of elderly patients is increasing year by year. Concurrently, alongside advancements in medical technology and the broadening of surgical indications, the rate of non-cardiac surgery in elderly patients is also continuously rising.⁷ Each year, over 310 million surgeries are performed globally, and elderly patients, who constitute about a quarter of these cases, face a heightened risk of POD.⁸ Existing research indicates that preoperative cognitive impairment, reduced physiological reserve, multimorbidity, and frailty are important risk factors for postoperative delirium in elderly patients undergoing non-cardiac surgery.⁹ Simple screening tools such as the GFI, FRAIL scale, or Clinical Frailty Scale can effectively identify high-risk populations,^{10–12} while intraoperative EEG suppression partially mediates the association between frailty and postoperative delirium.¹³ Furthermore, research has confirmed that preoperative administration of corticosteroids can mitigate surgery-induced inflammatory responses, thereby reducing the incidence and severity of postoperative cognitive dysfunction (POCD). This suggests that perioperative inflammatory responses may also constitute a significant shared pathological basis for postoperative neurocognitive complications.¹⁴

Functional status represents a core dimension of geriatric vulnerability. Activities of Daily Living (ADL) reflect an individual's ability to perform basic self-care tasks and serve as an important indicator of fundamental functional reserve.¹⁵ Impaired ADL is often associated with physical frailty, reduced physiological resilience, and underlying cognitive vulnerability, which may increase a patient's susceptibility to the impact of surgical trauma and stress during the perioperative period, thereby elevating the risk of neurocognitive disturbances.¹⁶

Although existing research has explored the relationship between functional status and POD from various perspectives, indicating that improving functional status through multicomponent interventions (such as a tailored program validated in a Chinese population¹⁷) can help reduce the risk of POD, current evidence still has certain limitations. First, in most studies, ADL indicators are typically incorporated into comprehensive geriatric assessments or composite frailty indices,¹⁸ making it difficult to independently clarify the specific association between basic daily living function itself and POD. Second, significant heterogeneity exists across studies in terms of assessment tools, surgical types, and study populations, limiting the comparability and generalizability of findings. The Barthel Index (BI) is currently one of the most widely used and thoroughly validated tools internationally for assessing basic ADL.¹⁹ This scale offers advantages such as a clear structure, ease of administration, objective and quantifiable results, and provides a relatively direct reflection of the basic functional status of elderly patients, thus demonstrating good feasibility and potential for widespread adoption in clinical practice.^{20,21}

Therefore, this study uses the BI score to quantitatively evaluate ADL, aiming to explore the correlation between preoperative BI score and POD in elderly patients undergoing non-cardiac surgery, based on the hypothesis that impaired preoperative basic ADL, as reflected by lower BI scores, is associated with an increased risk of POD. The findings are expected to provide a scientific basis for the early identification of high-risk patients and the development of individualized intervention strategies.

Patients and Methods

Study Design and Participants

This prospective cohort study was approved by the Scientific Research Ethics Review Committee of the First Hospital of Shanxi Medical University (Approval No. KYLL-2025-101) and was conducted in accordance with the ethical principles of the Declaration of Helsinki. The study was registered at <http://www.chictr.org.cn/> (Clinical Trial Registration No. ChiCTR2500101542). A total of 329 elderly patients with complete clinical data who underwent elective non-cardiac surgery under general anesthesia at the First Hospital of Shanxi Medical University between March 2025 and May 2025 were selected.

Patients meeting all the following inclusion criteria were considered for enrollment: 1. age \geq 65 years; 2. scheduled for elective non-cardiac surgery; 3. planned for general anesthesia; 4. American Society of Anesthesiologists (ASA) physical status classification II–III; 5. preoperative Mini-Mental State Examination (MMSE) score \geq 24, Hospital

Anxiety and Depression Scale (HADS) anxiety score ≤ 7 and depression score ≤ 7 ; 6. approved by the hospital ethics committee, and informed consent obtained from the patients. Patients were excluded if they met any of the following criteria: 1. history of traumatic brain injury or severe central nervous system disorders; 2. significant auditory/visual impairment, communication barriers, physical disabilities, or inability to complete assessments; 3. preoperative cognitive impairment, dementia, mental disorders or predisposition, or recent use of antipsychotic medications; 4. undergoing emergency surgery; 5. postoperative Intensive Care Unit (ICU) admission; 6. postoperative hospital stay < 3 days; 7. inability to comprehend informed consent documents or declined study participation.

Data Collection

Demographic and Clinical Characteristics

The baseline characteristics of the enrolled subjects were obtained through a comprehensive review of electronic medical records, including demographic characteristics (eg, sex, age, body mass index [BMI], and smoking status) and clinical laboratory test results.

Preoperative ADL

Within 24 hours before surgery, two assessors trained for consistency used the Chinese version of the BI scale to assess the patients' ADL. The assessment included 10 functions such as feeding, dressing, and toileting, with a total score range of 0–100 (higher scores indicate greater independence).²²

Other Potential Risk Factors of POD

Based on current state-of-the-art evidence and clinical guidelines,² the following data were collected: ASA physical status classification, Charlson Comorbidity Index (CCI), and preoperative length of stay. In addition, ten intraoperative and postoperative variables were recorded: type of surgery (gastrointestinal, urologic, orthopedic, gynecologic, neurosurgical, otorhinolaryngologic [ear, nose, and throat; ENT], thoracic, hernia, oral, and hepatobiliary surgery), type of anesthesia (total intravenous anesthesia or combined intravenous–inhalational anesthesia), duration of anesthesia (from induction to extubation), duration of surgery (from skin incision to skin closure), mean arterial pressure difference (highest minus lowest intraoperative value), oxygen saturation difference (highest minus lowest intraoperative value), intraoperative blood loss, total fluid input, use of patient-controlled intravenous analgesia (PCIA), and administration of postoperative nerve block. All variables were obtained through a review of surgical records, anesthesia records, and intraoperative monitoring data.

Observation Indicators

The primary outcome of this study was the occurrence of POD within 7 days after surgery or before hospital discharge, whichever occurred first. Trained researchers assessed patients twice daily (08:00–10:00 and 18:00–20:00)²³ using the validated Chinese version²⁴ of the 3-Minute Diagnostic Interview for Confusion Assessment Method–defined Delirium (3D-CAM) from postoperative day 1 until day 7 or discharge.^{25,26} The 3D-CAM, whose diagnostic algorithm operationalizes the core domains of the DSM-5 criteria,²⁷ was used as the primary instrument for delirium diagnosis. In cases of complex or ambiguous clinical presentations where scale item interpretation was uncertain, final diagnostic judgment was made with direct reference to the original DSM-5 diagnostic domains. Delirium occurrence was recorded as a binary variable (yes/no).

The secondary outcome was postoperative agitation, assessed using the Riker Sedation–Agitation Scale (SAS)²⁸ immediately after emergence from anesthesia and at 1, 2, 4, and 6 hours thereafter. An SAS score ≥ 5 was defined as agitation and recorded as a binary outcome. All data were collected using standardized case report forms and independently verified by two researchers to ensure data accuracy.²⁹

Perioperative Management

All patients received standardized monitoring upon entry into the operating room, including electrocardiography, invasive or noninvasive blood pressure monitoring, and pulse oximetry. All surgeries were performed under general anesthesia, either alone or in combination with regional anesthesia, at the discretion of the attending anesthesiologist

based on the type of surgery. General anesthesia was induced using sufentanil and etomidate. After tracheal intubation, mechanical ventilation was initiated to maintain an end-tidal carbon dioxide partial pressure of 35–45 mmHg. Anesthesia was maintained with continuous intravenous infusions of propofol and remifentanyl, with or without sevoflurane inhalation, and neuromuscular blockade was routinely achieved using muscle relaxants such as cisatracurium. The depth of anesthesia was adjusted to maintain the bispectral index (BIS) between 40 and 60 throughout the procedure. Hemodynamic stability was maintained using vasoactive agents (vasopressors and/or inotropes), fluid administration, and red blood cell transfusion when clinically indicated.

Sample Size Calculation

According to the Chinese Expert Consensus on Prevention and Treatment of Postoperative Delirium in Elderly Patients (2022 Edition), data from China show that the incidence of POD in patients over 65 years undergoing non-cardiac surgery ranges from 6.1% to 57.1%, with an overall incidence of 11.1%.³⁰ Assuming an incidence rate of 11.1% in our study, an AUC of no less than 80%, and 4 candidate predictor variables, calculation using the R software `pmsampsize` package yielded a sample size of 279, requiring at least 31 outcome events. Considering a 15% loss to follow-up rate, the final required sample size was 329 patients.

Statistical Analysis

The distribution of continuous variables was visually assessed using histograms to determine normality. Normally distributed continuous variables are expressed as mean \pm standard deviation (Mean \pm SD), and compared between groups using the independent samples *T*-test. Non-normally distributed continuous variables are expressed as median and interquartile range [M (P25, P75)], and compared between groups using the Mann–Whitney *U*-test. Categorical variables are described using counts (percentages), and compared between groups using the Chi-square (χ^2) test or Fisher's exact test (when the number of cells with expected count <5 exceeds 20% or the total number of cases is <40).

First, univariate logistic regression analysis was performed. Then, preoperative BI score and variables with $P < 0.05$ in the univariate analysis were simultaneously entered into a multivariate logistic regression model using the enter method to analyze the association between preoperative BI score and the risk of POD, calculating the odds ratio (OR) and its 95% confidence interval (CI).

Furthermore, restricted cubic spline (RCS) nested within a multivariate logistic regression model was employed to visualize and analyze the dose-response relationship between preoperative BI scores and the risk of POD. To achieve a balance between model fit and smoothness, four knots were pre-specified for the BI score distribution, as recommended by Harrell.³¹ The model was adjusted for potential confounders. A likelihood ratio test was performed to test the null hypothesis of linearity (P for nonlinear). If a significant non-linear association was identified, a two-piecewise linear regression model was subsequently applied to determine the threshold effect (inflection point) using the maximum likelihood method. Based on the identified inflection point, patients were stratified into High BI and Low BI groups. Subsequently, univariate and multivariate logistic regression analyses were repeated to further validate the association between BI categories and POD risk, with ORs and 95% CIs calculated.

To enhance the reliability of the results, this study further employed Inverse Probability of Treatment Weighting (IPTW) analysis. To reduce confounding effects due to the non-randomized nature of this study, the preoperative BI score group (High BI group/Low BI group) was used as the outcome variable, and the demographic and clinical characteristics listed in Table 1 (excluding preoperative BI score) were used as predictor variables to construct a Logistic regression model for calculating the propensity score. The stabilized weight for each patient was calculated based on their marginal probability and the propensity score. Furthermore, we trimmed the top and bottom 1% of the stabilized weights to reduce the influence of outliers.^{32,33} The Absolute Standardized Difference (ASD) was used to assess the balance between the two groups before and after weighting. An ASD less than 0.10 was considered indicative of good balance between the two groups. Variables with ASD still ≥ 0.10 after IPTW adjustment were considered insufficiently balanced and were included as covariates in the outcome analysis to control for residual confounding. Specifically, relevant variables were included as additional covariates in the weighted Logistic regression models for POD and postoperative agitation, respectively. Results are presented as ORs and their 95% CIs.

Table 1 Comparison of Variables Between High and Low BI Groups Before and After IPTW Adjustment

Variables	Entire Cohort			IPTW Cohort		
	High BI Group (n=179)	Low BI Group (n=119)	ASD	High BI Group (n=179)	Low BI Group (n=120)	ASD
Barthel Index	95(85,100)	55(50,65)	3.700			
Patient characteristics						
Sex: M	117(65.4%)	78(65.5%)	0.002	116(64.8%)	81(67.5%)	0.057
Age (year)	75(69,79)	76(71,80)	0.289	76(69,79)	75(70,78)	0.043
Body mass index (kg/m ²)	25.51±2.58	25.31±2.58	0.079	25.41±2.54	25.44±2.60	0.011
ASA-PS			0.210			0.034
II	99(55.3%)	78(65.5%)		106(59.2%)	69(57.5%)	
III	80(44.7%)	41(34.5%)		73(40.8%)	51(42.5%)	
Patient history						
Smoking status			0.110			0.093
Never	97(54.2%)	60(50.4%)		100(55.6%)	62(51.7%)	
Occasional	7(3.9%)	10(8.4%)		6(3.3%)	13(10.8%)	
Former (>1year)	20(11.2%)	17(14.3%)		21(11.7%)	14(11.7%)	
Current	55(30.7%)	32(26.9%)		53(29.4%)	31(25.8%)	
Charlson Comorbidity Index≥3	54(30.2%)	42(35.3%)	0.109	59(33.0%)	35(29.4%)	0.078
Preoperative variables						
Preoperative hemoglobin (g/dl)	12.55±1.55	12.29±1.22	0.189	12.45±1.53	12.52±1.35	0.047
Preoperative albumin (g/L)	38.69±4.24	39.01±4.25	0.077	38.95±4.34	39.05±4.25	0.021
Preoperative LOS (days)	6(3,7)	4(3,7)	0.151	5(3,7)	5(3,7)	0.069
Surgical variables						
Surgical sites			0.121			0.096
Gastrointestinal	30(16.8%)	15(12.6%)		29(16.1%)	20(16.7%)	
Urology	48(26.8%)	46(38.7%)		53(29.4%)	37(30.8%)	
Orthopedics	22(12.3%)	15(12.6%)		20(11.1%)	18(15.0%)	
Gynecology	8(4.5%)	3(2.5%)		9(5.0%)	3(2.5%)	
Neurosurgery	10(5.6%)	4(3.4%)		10(5.6%)	5(4.2%)	
ENT	17(9.5%)	6(5.0%)		19(10.6%)	8(6.7%)	
Thoracic	6(3.4%)	3(2.5%)		6(3.3%)	2(1.7%)	
Hernia	8(4.5%)	9(7.6%)		8(4.4%)	8(6.7%)	
Oral	15(8.4%)	5(4.2%)		14(7.8%)	6(5.0%)	
Hepatobiliary	15(8.4%)	13(10.9%)		12(6.7%)	13(10.8%)	
Anesthesia types			0.008			0.004
Total intravenous anesthesia	165(92.2%)	110(92.4%)		164(91.6%)	110(91.7%)	
Combined intravenous-inhalational	14(7.8%)	9(7.6%)		15(8.4%)	10(8.3%)	
Operation time (min)	116(74,157)	106(67,187)	0.182	113(72,154)	116(69,200)	0.067
Anesthesia time (min)	118(83,206)	109(80,195)	0.153	115(80,197)	125(81,237)	0.072
Mean arterial pressure difference (mmHg)	36.07±9.99	38.06±8.65	0.213	37.07±10.57	37.39±8.61	0.033
Oxygen saturation difference (%)	1(1,2)	1(1,2)	0.303	1(1,2)	1(1,2)	0.013
Blood loss (mL)	200(100,300)	150(50,200)	0.271	150(100,262)	200(100,300)	0.096
Total intraoperative input (mL)	1000(750,1500)	1000(500,1500)	0.196	1000(500,1500)	1000(518,1750)	0.066
Patient-controlled intravenous analgesia	112(62.6%)	65(54.6%)	0.163	108(60.0%)	73(60.8%)	0.016
Postoperative nerve block	7(3.9%)	4(3.4%)	0.027	6(3.4%)	4(3.3%)	0.006

Notes: Categorical variables are presented as number (%) and continuous variables are presented as mean ± standard deviation or median (interquartile range).

Abbreviations: IPTW, inverse probability treatment weighting; ASD, absolute standardized difference; BI, Barthel Index; ASA-PS, American Society of Anesthesiologists physical status; LOS, length of stay; ENT, Ear, Nose, and Throat.

Additionally, to explore potential effect modifiers, subgroup analyses were performed stratified by age (≥75 years vs <75 years), gender (male vs female), CCI (≥3 points vs <3 points), anesthesia duration (≥120 min vs <120 min), and preoperative hospital stay (≥5 days vs <5 days). The presence of interaction between each stratification factor and

preoperative BI score in influencing the risk of POD was tested by constructing a single Logistic regression model containing the treatment-covariate interaction term. The interaction was tested using the likelihood ratio test, with $P < 0.05$ indicating a statistically significant interaction. We estimated stratum-specific ORs.

To assess the incremental predictive value of the BI score for POD, four logistic regression models were developed: Model 1 included variables expect BI score that were significant in univariate analysis; Model 2 incorporated the BI score along with those univariate-significant variables; Model 3 included variables expect BI score that were significant in multivariate analysis; and Model 4 incorporated the BI score alongside those multivariate-significant variables. The predictive performance of these models was evaluated using receiver operating characteristic (ROC) curve analysis, and the improvement attributed to the BI score was quantified by comparing the area under the curve (AUC) with its corresponding 95% confidence interval (CI).

This study used professional statistical analysis software SPSS 25.0 and Zstats for data processing and analysis. A two-sided P -value < 0.05 was considered statistically significant. The calculation of inverse probability weights was achieved by obtaining propensity scores and performing calculations using SPSS 25.0 software.

Results

Patient Characteristics

A total of 329 patients voluntarily participated in this study and provided written informed consent. After excluding 31 individuals based on the exclusion criteria, 298 patients were ultimately included for analysis (Figure 1). The baseline characteristics and perioperative data of the patients are detailed in Table 2. Among the preoperative indicators, compared to the non-delirium group, the delirium group had a significantly lower preoperative BI score ($Z = -5.673$, $P < 0.001$), lower BMI ($t = 3.149$, $P = 0.002$), older age ($Z = -6.757$, $P < 0.001$), and longer preoperative hospital stay ($Z = -3.086$, $P = 0.002$). Among the intraoperative variables, delirium patients had a greater mean arterial pressure difference ($t = -2.000$, $P = 0.046$) and greater fluctuation in oxygen saturation difference ($Z = -2.253$, $P = 0.024$) compared to non-delirium patients. The differences in the remaining variables between the two groups did not reach statistical significance.

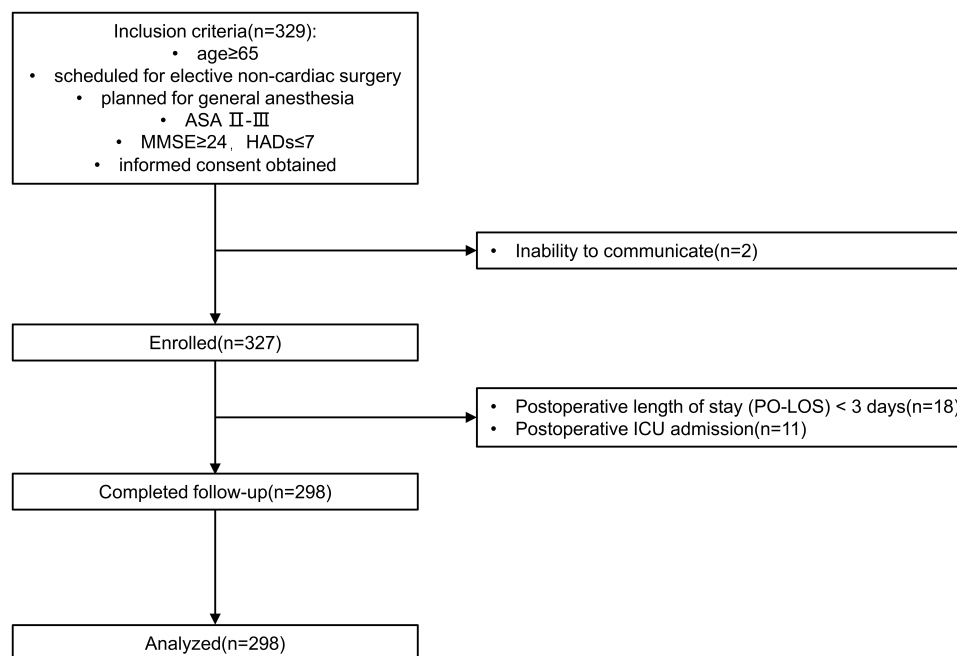


Figure 1 Flow chart of patient selection.

Table 2 Comparison of Variables Between the Two Patient Groups

Variables	Delirium (n=77)	Non-Delirium (n=221)	t/Z/ χ^2	p
Barthel Index	60(50,80)	85(65,95)	-5.673	<0.001
Patient characteristics				
Sex: M	24(31.2%)	79(35.7%)	0.529	0.467
Age (year)	79(76,83)	75(69,78)	-6.757	<0.001
Body mass index (kg/m ²)	24.64±2.63	25.70±2.51	3.149	0.002
ASA-PS			1.013	0.314
II	42(54.5%)	135(61.1%)		
III	35(45.5%)	86(38.9%)		
Patient history				
Smoking status			7.098	0.069
Never	37(48.1%)	120(54.3%)		
Occasional	9(11.7%)	8(3.6%)		
Former (>1 year)	10(13.0%)	27(12.2%)		
Current	21(27.3%)	66(29.9%)		
Charlson Comorbidity Index≥3	25(32.5%)	71(32.1%)	0.003	0.956
Preoperative variables				
Preoperative hemoglobin (g/dl)	12.49±1.36	12.43±1.46	-0.332	0.740
Preoperative albumin (g/L)	38.63±4.20	38.88±4.26	0.440	0.660
Preoperative LOS (days)	6(4,10)	5(3,7)	-3.086	0.002
Surgical variables				
Surgical sites			11.138	0.266
Gastrointestinal	14(18.2%)	31(14.0%)		
Urology	28(36.4%)	66(29.9%)		
Orthopedics	11(14.3%)	26(11.8%)		
Gynecology	0(0.0%)	11(5.0%)		
Neurosurgery	2(2.6%)	12(5.4%)		
ENT	6(7.8%)	17(7.7%)		
Thoracic	4(5.2%)	5(2.3%)		
Hernia	2(2.6%)	15(6.8%)		
Oral	3(3.9%)	17(7.7%)		
Hepatobiliary	7(9.1%)	21(9.5%)		
Anesthesia types			0.219	0.640
Total intravenous anesthesia	72(93.5%)	203(91.9%)		
Combined intravenous-inhalational	5(6.5%)	18(8.1%)		
Operation time (min)	116(87,205)	108(69,155)	-1.386	0.166
Anesthesia time (min)	120(89,230)	113(80,191)	-1.507	0.132
Mean arterial pressure difference (mmHg)	38.72±7.98	36.22±9.93	-2.000	0.046
Oxygen saturation difference (%)	1(1,3)	1(1,2)	-2.253	0.024
Blood loss (mL)	150(50,275)	150(100,250)	-0.315	0.753
Total intraoperative input (mL)	1000(500,1750)	1000(500,1500)	-0.796	0.426
Patient-controlled intravenous analgesia	48(62.3%)	129(58.4%)	0.373	0.542
Postoperative nerve block	4(5.2%)	7(3.2%)	0.660	0.416

Notes: Categorical variables are presented as number (%) and continuous variables are presented as mean ± standard deviation or median (interquartile range).

Abbreviations: ASA, American Society of Anesthesiologists; IQR, interquartile range; ENT, Ear, Nose, and Throat; Preoperative LOS, Preoperative length of stay.

Analysis Results of Influencing Factors for POD in Elderly Non-Cardiac Surgery Patients

The results showed that several variables were significantly associated with POD ($P < 0.05$): Preoperative BI score (OR=0.959, 95% CI: 0.946–0.973) and BMI (OR=0.852, 95% CI: 0.769–0.944) were significantly negatively correlated

with the outcome. Age (OR=1.196, 95% CI: 1.131–1.264), preoperative hospital stays (OR=1.179, 95% CI: 1.072–1.297), and mean arterial pressure difference (OR=1.027, 95% CI: 1.001–1.055) were significantly positively correlated with the outcome. The associations of variables such as hemoglobin and albumin with the outcome did not reach significant statistical significance. For categorical variables, taking smoking as an example, the association with the outcome varied by smoking status; “occasional smoking” (OR=3.649, 95% CI: 1.314–10.131) was significantly associated with the outcome, while other categories were not, as shown in Table 3. These results provided a preliminary basis for subsequent multivariate analysis.

Table 3 Univariate and Multivariate Logistic Regression Analysis of Factors Influencing POD

Variables	Univariate			Multivariate		
	OR	95% CI	p	OR	95% CI	p
Barthel Index	0.959	0.946–0.973	<0.001	0.956	0.940–0.973	<0.001
Patient characteristics						
Sex						
Male	1.000	Reference				
Female	0.814	0.467–1.418	0.467			
Age	1.196	1.131–1.264	<0.001	1.174	1.102–1.250	<0.001
BMI	0.852	0.769–0.944	0.002	0.860	0.757–0.977	0.020
ASA-PS						
II	1.000	Reference				
III	1.308	0.775–2.209	0.315			
Patient history						
Smoking status						
Never	1.000	Reference		1.000	Reference	
Occasional	3.649	1.314–10.131	0.013	3.048	0.778–11.948	0.110
Former (>1year)	1.201	0.532–2.710	0.659	1.382	0.516–3.701	0.519
Current	1.032	0.558–1.907	0.920	1.522	0.722–3.208	0.269
CCI						
<3	1.000	Reference				
≥3	1.016	0.583–1.768	0.956			
Preoperative variables						
Preoperative hemoglobin	1.031	0.860–1.237	0.740			
Preoperative albumin	0.986	0.927–1.049	0.659			
Preop LOS	1.179	1.072–1.297	<0.001	1.109	0.983–1.250	0.092
Surgical variables						
Surgical sites						
Gastrointestinal	1.000	Reference				
Urology	0.939	0.435–2.030	0.874			
Orthopedics	0.937	0.364–2.413	0.892			
Gynecology	0.000	0.000–Inf	0.983			
Neurosurgery	0.369	0.073–1.873	0.229			
ENT	0.782	0.254–2.406	0.667			
Thoracic	1.771	0.412–7.616	0.442			
Hernia	0.295	0.059–1.469	0.136			
Oral	0.391	0.098–1.553	0.182			
Hepatobiliary	0.738	0.255–2.137	0.576			
Anesthesia types						
Total intravenous anesthesia	1.000	Reference				
Combined intravenous-inhalational	0.783	0.281–2.186	0.641			
Operation time	1.002	0.999–1.004	0.174			

(Continued)

Table 3 (Continued).

Variables	Univariate			Multivariate		
	OR	95% CI	p	OR	95% CI	p
Anesthesia time	1.002	1.000–1.004	0.105	1.013	0.980–1.047	0.448
Mean arterial pressure difference	1.027	1.001–1.055	0.049			
Oxygen saturation difference	1.102	0.991–1.226	0.072			
Blood loss	1.001	0.999–1.002	0.257			
Total intraoperative input	1.000	1.000–1.001	0.241			
Patient-controlled intravenous analgesia						
Yes	1.000	Reference				
No	0.847	0.497–1.443	0.542			
Postoperative nerve block						
Yes	1.000	Reference				
No	0.597	0.170–2.098	0.421			

Abbreviations: POD, postoperative delirium; OR, odds ratio; CI, confidence interval; BMI, body mass index; ASA-PS, American Society of Anesthesiologists physical status; CCI, Charlson Comorbidity Index; Preop LOS, preoperative length of stay; ENT: Ear, Nose, and Throat.

Using POD as the dependent variable (assignment: 1=occurred, 0=not occurred) and the 6 variables with $P < 0.05$ from the univariate logistic regression analysis as independent variables, multivariate logistic regression analysis was performed. No significant multicollinearity was detected among the variables ([Supplementary Table 1](#)), and the model showed good fit ([Supplementary Table 2](#)). The final results showed that 3 variables were significantly associated with POD ($P < 0.05$). Among them, a higher preoperative BI score (OR=0.956, 95% CI: 0.940–0.973) and a higher BMI (OR=0.860, 95% CI: 0.757–0.977) were protective factors for POD in elderly patients undergoing non-cardiac surgery under general anesthesia, while older age (OR=1.174, 95% CI: 1.102–1.250) was an independent risk factor, as shown in [Table 3](#).

Dose-Response Relationship Between Preoperative BI Score and POD Risk and Threshold Identification

We performed RCS analysis to examine the nonlinear dose–response relationship between preoperative BI score and the risk of POD in elderly non-cardiac surgery patients. The RCS curve revealed a significant negative nonlinear association: as the BI score increased, POD risk gradually decreased. Notably, in the range below a BI score of 70, the risk declined more steeply, indicating greater sensitivity of POD risk to BI score changes among patients with lower functional status. Beyond a specific threshold, the decline in risk slowed and the curve flattened, suggesting a diminished protective effect of further increasing the BI score ([Figure 2](#)).

To quantitatively identify the threshold, a two-piecewise linear regression model was applied. The analysis indicated an inflection point at 74.795 for the BI score ([Supplementary Table 3](#)). A likelihood ratio test comparing the two-piecewise model with a simple linear model yielded $P = 0.034$, supporting the presence of a threshold effect. On either side of this value, the association between BI score and POD risk differed substantially: at BI scores < 74.795 , each 1-point increase was associated with a 7.5% reduction in POD risk (OR = 0.925, 95% CI: 0.885–0.966, $P < 0.001$), whereas above this point, the association was not statistically significant (OR = 1.003, 95% CI: 0.956–1.052, $P = 0.903$).

POD Risk Analysis Based on Preoperative BI Score Grouping

To enhance clinical applicability and validate the observed threshold effect, this study categorized patients into two groups using a cutoff value of 75 points based on the calculated threshold and BI score characteristics: the High BI group (BI ≥ 75 points, $n = 179$, 60.1%) and the Low BI group (BI < 75 points, $n = 119$, 39.9%). Detailed baseline characteristics and perioperative data are presented in [Supplementary Table 4](#). Overall, the median preoperative BI scores were 95 in the High BI group and 55 in the Low BI group. Compared with the High BI group, patients in the Low

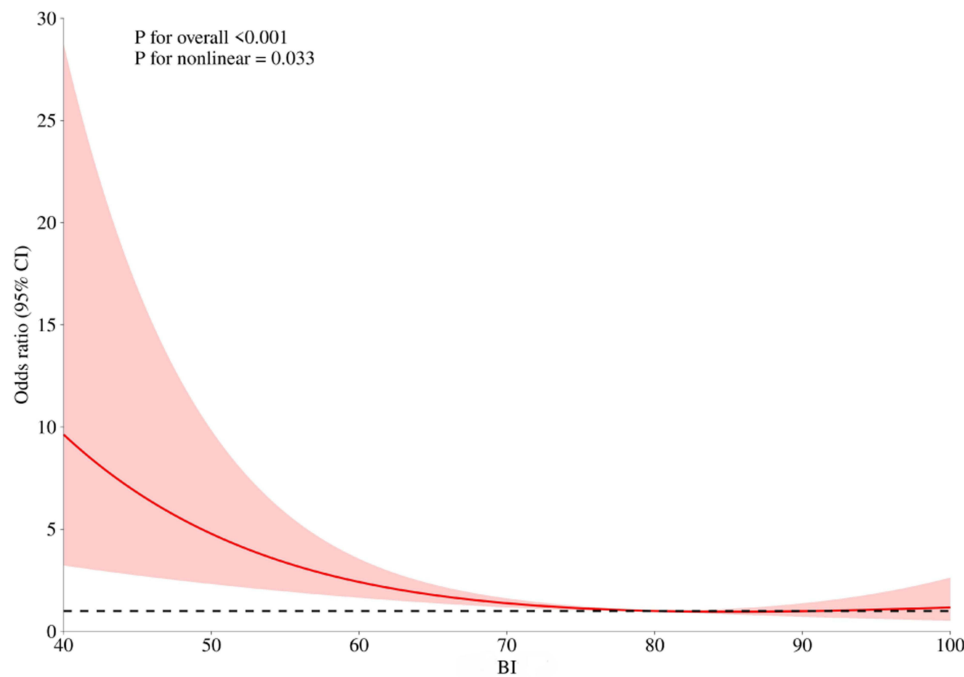


Figure 2 RCS curve depicting the relationship between BI and the risk of POD. The solid red line represents the trend of the OR for POD as the BI increases, the red shaded area indicates the 95% confidence interval, and the black dashed line represents the line of null effect (OR = 1). The plot was derived from a multivariable logistic regression model incorporating restricted cubic splines with four knots, adjusted for covariates. The reference point was set at the median BI value.
Abbreviations: RCS, restricted cubic spline; BI, Barthel Index; POD, postoperative delirium; OR, odds ratio.

BI group were significantly older ($P = 0.033$), while no statistically significant differences were observed in the remaining variables between the two groups.

The overall incidence of POD within 7 days after surgery was 25.8% (77/298), with distinct rates between the High BI and Low BI groups (14.5% vs 42.9%, respectively). Both univariate and multivariate logistic regression analyses were conducted on the grouped data, with results shown in Table 4. The multivariate model confirmed that the low BI group was independently associated with an increased risk of POD (OR = 4.615, 95% CI: 2.377–8.963, $P < 0.001$). To enhance

Table 4 Univariate and Multivariate Logistic Regression Analysis of the Impact of BI-Based Grouping on POD

Variables	Univariate			Multivariate		
	OR	95% CI	<i>p</i>	OR	95% CI	<i>p</i>
BI group						
High BI group	1.000	Reference		1.000	Reference	
Low BI group	4.434	2.506–7.845	<0.001	4.615	2.377–8.963	<0.001
Patient characteristics						
Sex						
Male	1.000	Reference				
Female	0.814	0.467–1.418	0.467			
Age	1.196	1.131–1.264	<0.001	1.173	1.102–1.249	<0.001
BMI	0.852	0.769–0.944	0.002	0.869	0.767–0.985	0.028
ASA-PS						
II	1.000	Reference				
III	1.308	0.775–2.209	0.315			

(Continued)

Table 4 (Continued).

Variables	Univariate			Multivariate		
	OR	95% CI	p	OR	95% CI	p
Patient history						
Smoking status						
Never	1.000	Reference		1.000	Reference	
Occasional	3.649	1.314~10.131	0.013	3.352	0.924~12.162	0.066
Former (>1 year)	1.201	0.532~2.710	0.659	1.459	0.552~3.857	0.446
Current	1.032	0.558~1.907	0.920	1.442	0.691~3.008	0.329
CCI						
<3	1.000	Reference				
≥3	1.016	0.583~1.768	0.956			
Preoperative variables						
Preoperative hemoglobin	1.031	0.860~1.237	0.740			
Preoperative albumin	0.986	0.927~1.049	0.659			
Preop LOS	1.179	1.072~1.297	<0.001	1.099	0.975~1.238	0.122
Surgical variables						
Surgical sites						
Gastrointestinal	1.000	Reference				
Urology	0.939	0.435~2.030	0.874			
Orthopedics	0.937	0.364~2.413	0.892			
Gynecology	0.000	0.000~Inf	0.983			
Neurosurgery	0.369	0.073~1.873	0.229			
ENT	0.782	0.254~2.406	0.667			
Thoracic	1.771	0.412~7.616	0.442			
Hernia	0.295	0.059~1.469	0.136			
Oral	0.391	0.098~1.553	0.182			
Hepatobiliary	0.738	0.255~2.137	0.576			
Anesthesia types						
Total intravenous anesthesia	1.000	Reference				
Combined intravenous-inhalational	0.783	0.281~2.186	0.641			
Operation time	1.002	0.999~1.004	0.174			
Anesthesia time	1.002	1.000~1.004	0.105			
Mean arterial pressure difference	1.027	1.001~1.055	0.049	1.009	0.976~1.042	0.596
Oxygen saturation difference	1.102	0.991~1.226	0.072			
Blood loss	1.001	0.999~1.002	0.257			
Total intraoperative input	1.000	1.000~1.001	0.241			
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Abbreviations: BI, Barthel Index; POD, postoperative delirium; BMI, body mass index; ASA-PS, American Society of Anesthesiologists physical status; CCI, Charlson Comorbidity Index; Preop LOS, preoperative length of stay; ENT, Ear, Nose, and Throat; OR, odds ratio; CI, confidence interval.

the reliability of the findings, IPTW was further employed as a supplementary analysis. After IPTW adjustment, all variables achieved good balance between the two groups (ASD < 0.10; Table 1). The IPTW-adjusted analysis corroborated the primary results, demonstrating a persistently elevated risk of POD in the Low BI group (adjusted OR = 4.445, 95% CI: 2.564–7.707, P < 0.001). However, no significant differences were observed between the two groups in secondary outcomes such as agitation (Table 5).

Table 5 Comparison of Postoperative Outcomes Based on BI Before and After IPTW Adjustment

	Entire Cohort				IPTW Cohort	
	High BI Group (n=179)	Low BI Group (n=119)	OR (95% CI)	p	OR (95%)	p
Primary outcome POD	26(14.5%)	51(42.9%)	4.413(2.541,7.665)	<0.001	4.445(2.564,7.707)	<0.001
Secondary outcomes Postoperative agitation	5(2.8%)	5(4.2%)	0.807(0.441,1.477)	0.487	0.893(0.490,1.629)	0.713

Notes: Data are presented as number (%).

Abbreviations: BI, Barthel Index; IPTW, inverse probability of treatment weighting; OR, odds ratio.; POD, postoperative delirium.

Subgroup Analysis

Subgroup analysis showed that the association between preoperative BI score and POD had significant interaction effects with three variables: CCI (interaction $P < 0.001$), anesthesia duration (interaction $P = 0.004$), and preoperative hospital stay (interaction $P < 0.001$). The significant association between preoperative BI score and POD was more prominent in patients with shorter anesthesia duration (OR=0.938; 95% CI: 0.917–0.960; $P < 0.001$), and was only applicable to patient groups with a low CCI (OR=0.931; 95% CI: 0.911–0.952; $P < 0.001$) and shorter preoperative hospital stay (OR=0.919; 95% CI: 0.894–0.946; $P < 0.001$) (Figure 3).

The Incremental Predictive Value of BI Score on POD

ROC curve analysis was performed to evaluate the incremental predictive value of the preoperative BI score for POD in elderly patients undergoing non-cardiac surgery. To assess the specific contribution of the BI score, models were developed and evaluated separately, with and without it. Incorporating the BI score into the model with univariable-significant predictors increased the AUC from 0.779 (95% CI: 0.723–0.835) to 0.840 (95% CI: 0.790–0.890) (Figure 4A and B). Similarly, when the

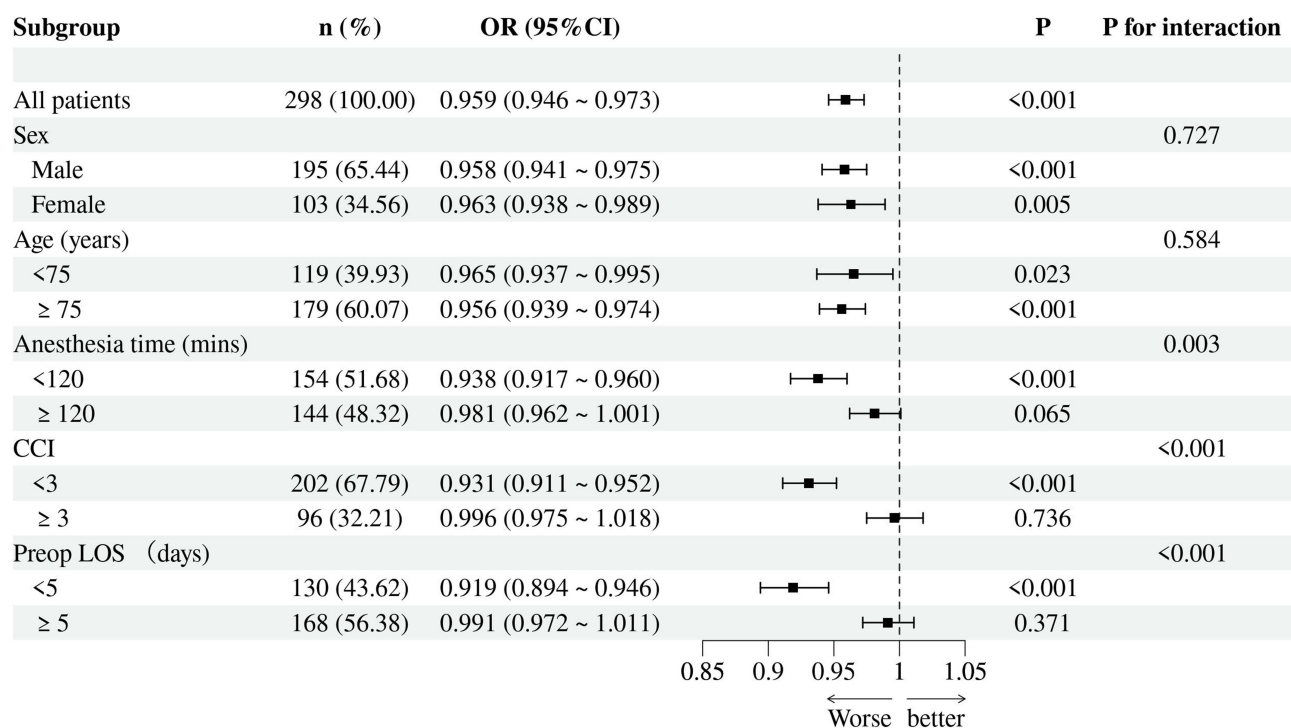


Figure 3 Forest plot of ORs by patient subgroups.

Abbreviations: OR, odds ratio; CCI, Charlson Comorbidity Index; Preop LOS, preoperative length of stay.

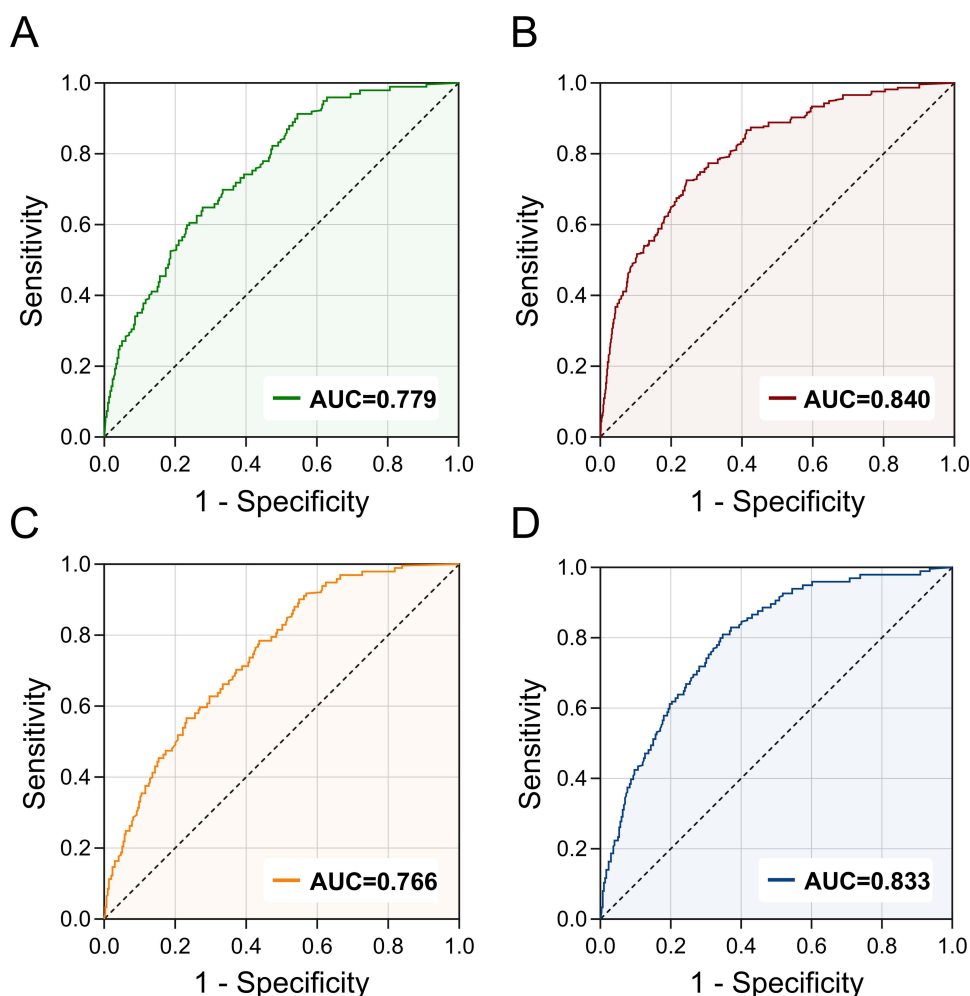


Figure 4 (A) ROC curve analysis of Model 1 for predicting POD; (B) ROC curve analysis of Model 2 for predicting POD; (C) ROC curve analysis of Model 3 for predicting POD; (D) ROC curve analysis of Model 4 for predicting POD. Model 1 included variables other than the BI score that were significant in univariate analysis; Model 2 added the BI score to Model 1; Model 3 included variables other than the BI score that were significant in multivariate analysis; Model 4 added the BI score to Model 3. The incremental predictive value of the BI score was assessed by comparing the area under the curve (AUC) among these models.

Abbreviations: ROC, receiver operating characteristic; POD, postoperative delirium; BI, Barthel Index; AUC, area under the curve.

score was added to the multivariate-significant predictors, the AUC improved from 0.766 (95% CI: 0.710–0.823) to 0.833 (95% CI: 0.782–0.884) (Figures 4C and D). Furthermore, integrating the BI score markedly improved model specificity, positive predictive value, and overall diagnostic accuracy, as detailed in Table 6. These findings underscore the BI score's role as a robust, continuous measure of functional status that provides critical incremental information, thereby optimizing the identification of high-risk patients.

Table 6 Comparison of Predictive Performance for POD Between Models with and without the BI Score

Indicators	Sensitivity (95% CI)	Specificity (95% CI)	AUC (95% CI)	PPV (95% CI)	NPV (95% CI)	Accuracy (95% CI)
Model 1	0.883(0.811–0.955)	0.570(0.505–0.635)	0.779(0.723–0.835)	0.417(0.341–0.493)	0.933(0.891–0.975)	0.651(0.594–0.705)
Model 2	0.844(0.763–0.925)	0.715(0.655–0.774)	0.840(0.790–0.890)	0.508(0.421–0.594)	0.929(0.891–0.968)	0.748(0.695–0.797)
Model 3	0.896(0.828–0.964)	0.529(0.464–0.595)	0.766(0.710–0.823)	0.399(0.326–0.472)	0.936(0.893–0.979)	0.624(0.566–0.679)
Model 4	0.779(0.687–0.872)	0.769(0.714–0.825)	0.833(0.782–0.884)	0.541(0.448–0.633)	0.909(0.868–0.950)	0.772(0.720–0.818)

Notes: Model 1 included other variables identified as significant in univariate analysis; Model 2 incorporated the BI score in addition to the univariate-significant variables; Model 3 included other variables identified as significant in multivariate analysis; Model 4 incorporated the BI score in addition to the multivariate-significant variables.

Abbreviations: POD, postoperative delirium; BI, Barthel Index; CI, confidence interval; AUC, area under the curve; PPV, positive predictive value; NPV, negative predictive value.

Discussion

This study focused on the intrinsic relationship between the preoperative BI score and POD in elderly patients undergoing non-cardiac surgery. Through systematic analysis of prospectively collected single-center data, we found that a lower preoperative BI score was associated with a higher risk of POD, and there was a significant nonlinear relationship between the BI score and POD risk, with an optimal critical value of 75 points. Using this value as a cutoff, a low BI score status was a strong independent risk factor for POD. Furthermore, ROC curve analysis demonstrated that the inclusion of the BI score significantly improved the model's discrimination and diagnostic performance. This confirms that the BI captures a dimension of patient vulnerability distinct from traditional risk factors, providing quantitative evidence to support its integration into routine perioperative risk stratification.

In recent years, exercise interventions have emerged as a promising non-pharmacological approach to enhance functional and cognitive outcomes in elderly patients. Accumulating evidence demonstrates that tailored exercise regimens not only effectively counteract hospitalization-associated functional decline³⁴ but also confer multidomain benefits in patients with Alzheimer's disease.³⁵ Notably, exercise has shown potential in delirium management, with studies reporting improved delirium trajectory and preserved functional capacity after hospital discharge.³⁶ These consistent observations underscore the importance of maintained physical function in preventing neurocognitive complications. Nevertheless, existing research has primarily addressed post-delirium interventions or focused on specific clinical populations, whereas the relationship between preoperative functional status and POD risk during the elective surgical period remains inadequately explored.

Against this background, the current study systematically examines the association between preoperative ADL, as quantified by the BI, and POD risk in elderly non-cardiac surgical patients. Our analysis identifies a preoperative BI score <75 as a strong independent predictor for POD development. This observation extends the established connection between physical function and cognitive preservation into the preoperative context, while simultaneously supporting the integration of BI assessment into routine preoperative evaluation. Such implementation could facilitate early identification of high-risk patients and inform targeted prehabilitation strategies aimed at POD prevention.

Patients with low preoperative BI scores often exhibit insufficient compensatory reserve of organ function, impaired integrity of neuroregulatory networks, and are frequently accompanied by nutritional and metabolic imbalances and immune dysfunction.³⁷ This frail physical state leaves them lacking the effective capacity to resist surgical trauma stress, anesthetic drug effects, and postoperative environmental disturbances. The brain, as an organ with extremely high demands for energy metabolism and internal homeostasis, is more prone to functional disorders during this process, manifesting as delirium.³⁸ From a clinical practice perspective, traditional POD prediction indicators mostly focus on physiological parameters (such as age, BMI, hemoglobin) or disease states (such as comorbidity index, ASA classification).^{39,40} These indicators can only reflect the patient's current pathophysiological state but cannot quantify their potential compensatory capacity to cope with surgical trauma and anesthetic stress. In contrast, the BI score, which uses ADL (such as eating, dressing, toileting, walking, transferring) as its core assessment dimension, essentially quantifies the patient's physical functional reserve. This scoring system integrates multiple dimensions reflecting physical functional status, including muscle strength, balance ability, and neural coordination function, providing a relatively comprehensive assessment of the patient's overall functional reserve.⁴¹ Moreover, the BI score can be obtained through a simple assessment, offering the advantages of easy operation, strong repeatability, and freedom from medical facility limitations, making it particularly suitable for primary hospitals or rapid perioperative risk screening scenarios.

Through RCS curve analysis, we revealed a significant nonlinear correlation between the preoperative BI score and POD risk and identified BI=75 as the risk threshold. For elderly non-cardiac surgery patients with a BI score <75 points, close attention should be paid to the high POD risk associated with their deficits in ADL. Interventions such as preoperative rehabilitation training can be implemented to improve the BI score and reduce the incidence of POD. For patients with a BI score \geq 75 points, the focus of POD risk prevention and control should shift to other risk factors (such as age, underlying diseases, et).^{9,42-44} This conclusion provides an important reference for clinical individualized risk stratification and precise intervention.

Simultaneously, the subgroup analysis in this study showed that the association between preoperative BI score and POD had significant interaction effects in patients with different CCI scores, anesthesia durations, and preoperative hospital stays, indicating that the impact of patient characteristics on POD varies. Furthermore, this association was only significant in patients with a lower CCI, shorter anesthesia duration, and shorter preoperative hospital stay. This suggests that in patients with fewer comorbidities, the predictive value of physical functional reserve (BI score) for POD is more prominent, whereas in patients with more comorbidities, POD risk is more dominated by organ function damage,⁴⁵ diminishing the relative predictive performance of the BI score. Shorter anesthesia duration causes less interference with neurological function, making the patient's functional reserve (BI score) a key indicator for identifying POD risk; whereas prolonged anesthesia itself increases neuronal stress,^{46,47} thereby weakening the predictive ability of the BI score for POD risk. Patients with short preoperative stays experience less negative impact of the hospital environment (eg, noise, disrupted routines) on cognitive function, making their POD risk more dependent on assessment of their preoperative functional status; patients with long preoperative stays may already have hospital-acquired frailty or cognitive decline,⁴⁸ reducing the predictive value of the BI score. These results suggest that when assessing POD risk and formulating perioperative strategies to improve activity capacity, individual patient characteristics should be fully considered.

Despite the rigorous design and analytical methods employed in this study, several limitations remain: First, the study was single-center with a relatively limited sample size, potentially introducing selection bias, and the generalizability of the results requires validation through multi-center, large-sample prospective studies. Second, the specific molecular mechanisms through which the BI score is associated with POD (eg, whether by modulating neuroinflammatory factors or cholinergic neurotransmitter levels) were not explored, preventing a complete pathophysiological explanation for their association. Third, the effects of targeted preoperative interventions (such as preoperative functional rehabilitation training, individualized nutritional support, preoperative cognitive enhancement training) on improving the BI score were not assessed. This precludes determining specific intervention protocols for improving the BI score and their effectiveness, meaning the study conclusions can only reflect the predictive value of the preoperative BI score but cannot provide evidence for BI score-based preoperative targeted interventions. Future research should further investigate the preventive effects of these interventions on POD in elderly non-cardiac surgery patients.

Conclusion

This study demonstrates that a low preoperative BI score is an independent risk factor for POD in elderly patients undergoing non-cardiac surgery. RCS analysis revealed a significant nonlinear association between BI scores and POD risk, identifying a critical inflection point around 75 points, below which the risk of POD increases substantially. Furthermore, incorporating the BI score into clinical prediction models significantly enhances their discriminative performance for high-risk individuals. These findings suggest that preoperative BI assessment serves as a valuable tool for risk stratification. Future multicenter prospective studies are warranted to evaluate whether targeted interventions to optimize preoperative functional status can effectively reduce POD incidence, thereby improving long-term cognitive outcomes and quality of life in the elderly surgical population.

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An unauthorized version of the Chinese MMSE was used by the study team without permission, however this has now been rectified with PAR. The MMSE is a copyrighted instrument and may not be used or reproduced in whole or in part, in any form or language, or by any means without written permission of PAR (www.parinc.com).

Data Sharing Statement

All data relevant to the study are included in the article or uploaded as [Supplementary Information](#).

Disclosure

The authors have no conflict of interest to declare.

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