Analysis of Influencing Factors and Construction of Prediction Model for Delirium After Intraspinal Anesthesia in Elderly Patients Undergoing Femoral Neck Fracture Surgery

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AIM: To analyze the influencing factors of postoperative delirium (POD) after intraspinal anesthesia in elderly patients undergoing femoral neck fracture (FNF) surgery and to construct a prediction model for early identification of high-risk patients.
METHODS: This retrospective study included 407 elderly patients who underwent FNF surgery under spinal anesthesia from January 2020 to January 2024 as the modeling cohort; and another 82 patients who underwent similar surgery under spinal anesthesia between February 2024 and February 2025, according to the same inclusion and exclusion criteria, as an independent time-limited external validation cohort. Data were collected from the hospital's electronic medical records. Univariate and multivariate logistic regression analyses were performed to identify independent risk factors for POD. A nomogram prediction model was constructed and validated internally and externally.
RESULTS: The incidence of POD was 16.95% (69/407). Independent risk factors identified were age >80 years (odds ratio (OR) = 2.25, 95% CI: 1.25–4.05, p = 0.007), diabetes (OR = 1.91, 95% CI: 1.03–3.56, p = 0.041), preoperative hemoglobin <90 g/L (OR = 2.11, 95% CI: 1.14–3.90, p = 0.017), preoperative albumin <30 g/L (OR = 3.76, 95% CI: 1.95–7.25, $p < 0.001$), preoperative waiting time ≥3 days (OR = 2.62, 95% CI: 1.40–4.90, p = 0.003), American Society of Anesthesiologists (ASA) grade ≥III (OR = 2.12, 95% CI: 1.08–4.17, p = 0.029), postoperative hypoxemia (OR = 2.22, 95% CI: 1.22–4.05, p = 0.009), and postoperative visual analog scale (VAS) score ≥4 (OR = 2.55, 95% CI: 1.39–4.68, p = 0.002). The nomogram exhibited strong discriminative ability (area under the curve (AUC) = 0.79 for internal, 0.85 for external validation) and satisfactory calibration (Hosmer–Lemeshow $p > 0.05$).
CONCLUSIONS: This study identified independent risk factors for POD after intraspinal anesthesia in elderly FNF patients and established a nomogram with excellent predictive ability, offering a reliable tool for early detection of high-risk cases and facilitating implementation of targeted preventive measures.

Keywords: femoral neck fracture; elderly patients; intraspinal anesthesia; influencing factors; prediction model

Introduction

The accelerated aging of the global population has drawn increasing attention to the health of the elderly demographic [1]. Femoral neck fracture (FNF), one of the most common types of fracture occurring in the elderly, has shown an increasing trend in annual incidence [2]. Due to the decline of physiological functions and comorbidities in elderly patients, the treatment of FNF faces many challenges [3]. At present, surgical operation is an important treatment modality of FNF for the elderly [4]. Intraspinal anesthesia has been widely used in the surgery of FNFs in the elderly due to its advantages such as relatively small impact on the circulatory system and definite postoperative analgesic effect [5]. However, it is worth noting that postoperative delirium is a relatively common complication after intrathecal anaesthesia in elderly patients [6].

Postoperative delirium (POD) is a multifactorial neuropsychiatric syndrome characterized by acute attention deficits and cognitive fluctuation, with neuroinflammation, cerebral hypoperfusion, and neurotransmitter imbalances purportedly constituting the pathogenic mechanism [7]. The incidence of POD after intraspinal anesthesia is relatively high in elderly patients and its occurrence is often closely associated with poor prognosis [8]. POD not only prolongs the patient's hospital stay and increases medical costs, but also substantially affects the patient's postoperative recovery and quality of life, and even increases patient's risk for mortality [9,10]. Previous research has shown that the occurrence of POD in elderly patients with fractures is associated with a variety of factors, including the patient's own physical status, surgical characteristics, and the type and management of anaesthesia [11]. Owing to a limited understanding of the mechanism of POD after intraspinal anesthesia in elderly FNF patients, targeted measures for its prevention and treatment remain relatively scanty. Therefore, in-depth exploration of the influencing factors of POD and

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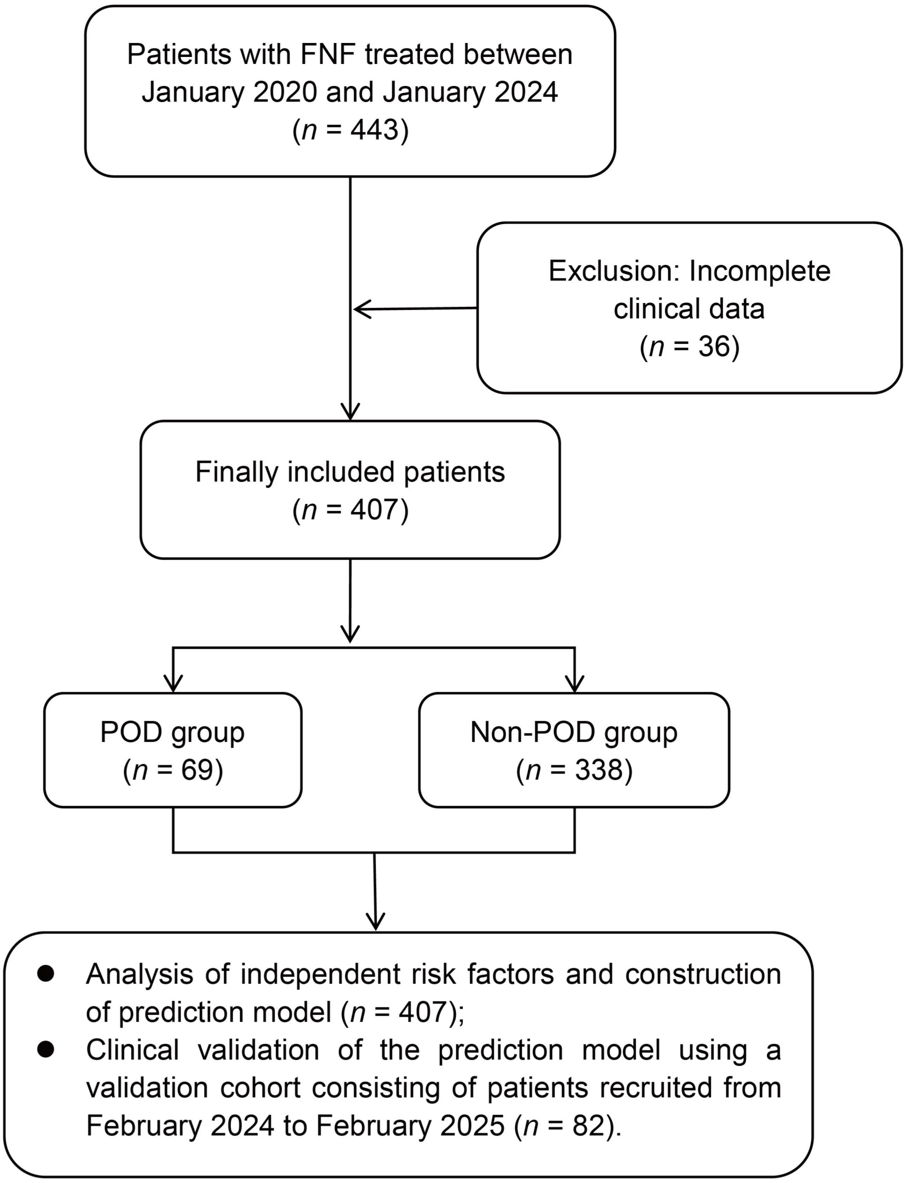

Fig. 1. The flowchart of this study. FNF, femoral neck fracture; POD, postoperative delirium.

construction of an effective prediction model are of great clinical significance for the early identification of high-risk patients, adoption of targeted preventive measures, and improvement of patients' prognosis.

Clinical prediction models, such as nomograms, are statistical tools that integrate multiple predictive factors to quantify the probability of a specific outcome (POD risk), with nomograms, in particular, presenting these relationships visually through a scoring system to facilitate intuitive risk assessment in clinical practice [12]. At present, although there are many studies on POD in elderly patients, existing prediction models for POD either rarely focus on elderly patients with FNF or fail to stratify by anesthetic technique, especially neglecting the specific context of intraspinal anesthesia. The primary objective of this study is to investigate the specific anaesthetic modality of intraspinal anesthesia, to systematically analyze its independent influences on POD, and to construct a proprietary prediction model. The present study aims to provide clinicians with more accurate risk assessment tools and assist in the development of individualized anaesthesia and perioperative management strategies, thereby reducing the incidence of POD and improving the long-term prognosis of elderly patients. In addition, the results of this study may also provide a theoretical basis for future prospective studies to further promote the prevention and treatment of perioperative neurocognitive disorders in elderly patients.

Methods

Patient Population

The flowchart of this study is shown in Fig. 1, which details the entire process of patient selection, exclusion, and grouping. First, a total of 443 elderly patients who underwent FNF surgery under intraspinal anesthesia at Beijing Chaoyang Hospital, Capital Medical University from January 2020 to January 2024 were initially screened. Among these, 36 patients were excluded due to incomplete clinical data, resulting in 407 patients finally included in the training cohort. This training cohort was used for exploring independent risk factors of POD and constructing the prediction model, and was further divided into a POD group (n = 69) and a non-POD group (n = 338) based on whether POD occurred postoperatively. To verify the generalizability of the model, an external validation cohort was separately established: a total of 82 patients who met the same inclusion and exclusion criteria and underwent FNF surgery under intraspinal anesthesia at our hospital from February 2024 to February 2025 were enrolled, and their data were used for external clinical validation of the constructed model. Data retrieval and extraction for both cohorts were performed through the hospital electronic medical record system. All principles of the Declaration of Helsinki were strictly adhered to in this study. The study was approved by the Medical Ethics Committee of Beijing Chaoyang Hospital, Capital Medical University (CY2024142).

Inclusion and Exclusion Criteria

The patients in this study met the following inclusion criteria: (a) patients aged ≥60 years; (b) patients who were clinically diagnosed with FNF and underwent surgical treatment under intraspinal anesthesia; (c) patients with complete demographic information and medical records. The exclusion criteria for this study are as follows: (a) patients with combined fractures or multiple injuries in other parts of the body; (b) patients with pre-existing severe cognitive dysfunction (e.g., dementia, Alzheimer's disease) or psychiatric disorders (e.g., schizophrenia, major depressive disorder); (c) patients with combined severe failure of vital organs such as the heart, lungs, liver, and kidneys; (d) patients with severe postoperative complications requiring intensive care unit admission or reoperation.

Data Collection

Data were gathered through the hospital's electronic medical record system. The collected data included general demographic information (age, gender, body mass index (BMI), marital status, smoking and drinking history), underlying diseases (hypertension, diabetes, coronary heart disease), preoperative laboratory parameters (hemoglobin (Hb), albumin (ALB) levels), preoperative waiting time, American Society of Anesthesiologists (ASA) physical status classification [13], information related to the surgery (surgical method, duration of the surgery, intraoperative hemorrhage), and postoperative conditions (occurrence of POD, visual analog scale (VAS), hypoxaemia). Hypoxemia is defined as any episode during which SpO_2 <90% persisted for ≥2 min (alarm threshold).

Evaluation of POD

This study used a standardized diagnostic process and assessment tool for the assessment of POD. All patients were screened daily for POD by uniformly trained study staff from postoperative day 1 until discharge or postoperative day 7. The diagnosis of POD was mainly based on the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) criteria, and the internationally accepted Confusion Assessment Method (CAM) was used as the primary assessment tool [14,15]. The CAM tool evaluates four key features: acute onset and fluctuating course of mental status, inattention, disorganized thinking, and altered level of consciousness. A diagnosis of POD was made if the patients exhibited both acute onset/fluctuating course and inattention, along with either disorganized thinking or altered level of consciousness. To ensure accuracy of the assessment, all researchers underwent uniform training and consistency testing (Kappa value >0.85) prior to data collection.

Statistical Analysis

SPSS 27.0 (IBM Corp., Armonk, NY, USA) was used for statistical analysis of the data. Categorical variables are expressed as counts and percentages. The Chi-square test or Fisher's exact test (where appropriate) was used to compare categorical variables between POD and non-POD groups. Univariate logistic regression was performed to determine potential risk factors. Significant variables ($p < 0.05$) were entered into multivariate logistic regression to identify independent risk factors, with odds ratio (OR) and 95% CI calculated. A nomogram model was constructed. Discrimination was assessed using the receiver operating characteristic (ROC) curves and area under the curve (AUC) values, whilst calibration was evaluated through calibration curves and the Hosmer–Lemeshow test. And the clinical utility was evaluated through decision curve analysis (DCA). Internal validation of the nomogram was conducted through 1000-time bootstrap resampling, while external validation was performed in an independent cohort to assess model generalizability using the same indices. A two-sided test with a p value < 0.05 is considered statistically significant.

Results

General Information of the Patients

Among the 407 patients, a total of 69 cases were diagnosed with POD, with an incidence rate of 16.95%. Among the patients in the POD group, the proportions of those aged >80 years (p = 0.007), diabetes (p = 0.007), preoperative Hb <90 g/L (p = 0.024), preoperative ALB <30 g/L (p < 0.001), preoperative waiting time ≥3 days (p = 0.002), ASA grade ≥III (p = 0.004), VAS score ≥4 (p = 0.002), and presence of postoperative hypoxemia (p = 0.010) were significantly higher than those in the non-POD group (Ta-

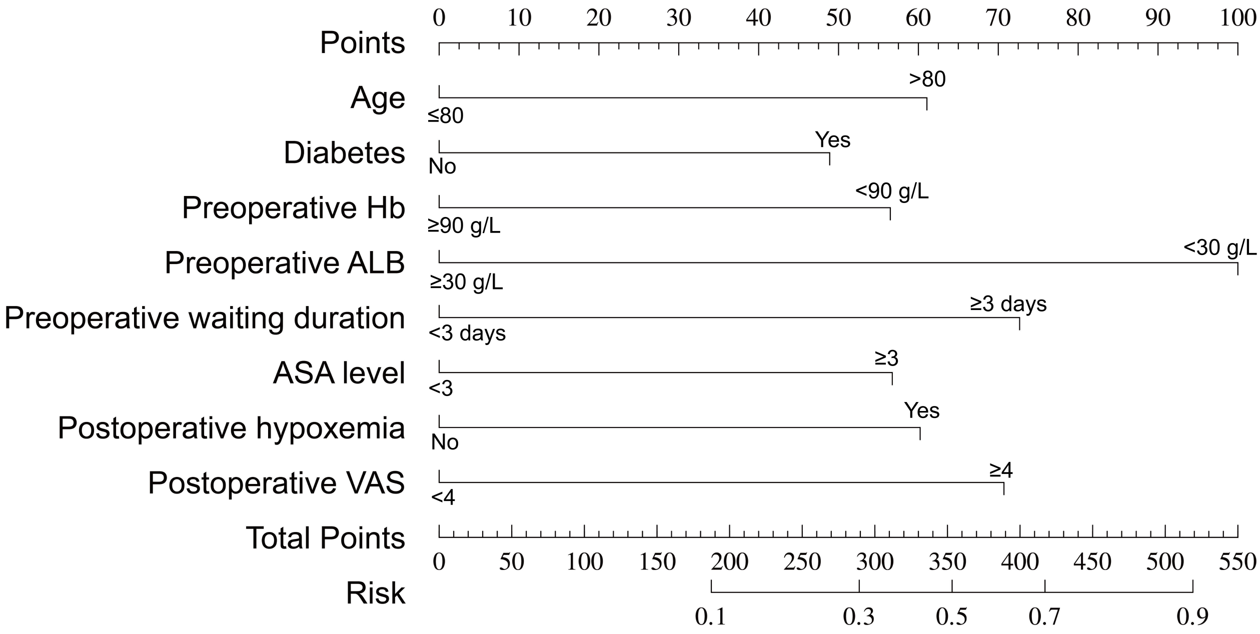

Fig. 2. Nomogram prediction model. ALB, albumin; ASA, American Society of Anesthesiologists; Hb, hemoglobin; VAS, visual analog scale.

ble 1). Furthermore, no statistical differences in other variables were found between groups.

Univariate Logistic Regression Analysis

Univariate logistic regression analysis showed that age >80 years (OR = 2.04, 95% CI: 1.21–3.44, p = 0.008), diabetes (OR = 2.06, 95% CI: 1.20–3.52, p = 0.008), preoperative Hb <90 g/L (OR = 1.85, 95% CI: 1.08–3.19, p = 0.025), preoperative ALB <30 g/L (OR = 3.90, 95% CI: 2.17–7.00, $p < 0.001$), preoperative waiting time ≥3 days (OR = 2.45, 95% CI: 1.39–4.33, p = 0.002), ASA grade ≥III (OR = 2.49, 95% CI: 1.33–4.65, p = 0.004), postoperative VAS score ≥4 (OR = 2.00, 95% CI: 1.18–3.39, p = 0.010), and presence of postoperative hypoxemia (OR = 2.36, 95% CI: 1.37–4.07, p = 0.002) were associated with an increased risk of POD (Table 2).

Analysis of Independent Risk Factors for POD

Variables found to be statistically significant ($p < 0.05$) in the univariate logistic regression were included in the multivariate logistic regression model. The results showed that age >80 years (OR = 2.25, 95% CI: 1.25–4.05, p = 0.007), diabetes (OR = 1.91, 95% CI: 1.03–3.56, p = 0.041), preoperative Hb <90 g/L (OR = 2.11, 95% CI: 1.14–3.90, p = 0.017), preoperative ALB <30 g/L (OR = 3.76, 95% CI: 1.95–7.25, $p < 0.001$), preoperative waiting time ≥3 days (OR = 2.62, 95% CI: 1.40–4.90, p = 0.003), ASA grade ≥III (OR = 2.12, 95% CI: 1.08–4.17, p = 0.029), presence of postoperative hypoxemia (OR = 2.22, 95% CI: 1.22–4.05, p = 0.009), and postoperative VAS score ≥4 (OR = 2.55, 95% CI: 1.39–4.68, p = 0.002) were independent risk factors for POD in patients with FNF (Table 3).

Construction and Evaluation of Nomogram

Based on the results of multivariate logistic regression, a nomogram model for predicting the risk of POD was constructed (Fig. 2). The ROC curve of the nomogram model is shown in Fig. 3A, with an area under the curve (AUC) of 0.78, indicating that the model has a good discriminatory ability for POD. The calibration curve is shown in Fig. 3B, indicating that the model has a good calibration capability (Hosmer–Lemeshow p = 0.963). The DCA of this model, presented in Fig. 3C, demonstrates that the model provides a positive net benefit across a wide range of risk thresholds.

Internal Validation of the Model

Internal validation employed 1000 times of repeated sampling (bootstrap) to ensure model robustness. The internally verified ROC curve is shown in Fig. 4A, with an AUC of 0.79, indicating a good discriminatory ability. The calibration curve is shown in Fig. 4B, and there is no significant difference between the predicted values and the observed values (Hosmer–Lemeshow p = 0.487). DCA is shown in Fig. 4C, indicating that the model has good clinical utility.

External Validation of the Model

The external validation cohort consisted of a total of 82 patients, among whom 20 cases were diagnosed with POD, with an incidence rate of 24.39%. Comparison of the basic characteristics of the training cohort and the external validation cohort is shown in Table 4. There were no significant differences in basic characteristics such as age (p = 0.618) and gender (p = 0.998) between the two groups of patients, indicating that the two groups of patients were compara-

Table 1. Comparison of the general information of the patients.

Variables	Total (n = 407)	Non-POD group (n = 338)	POD group (n = 69)	Statistic	p
Age				χ^2 = 7.28	**0.007**
≤80 years	242 (59.46)	211 (62.43)	31 (44.93)		
>80 years	165 (40.54)	127 (37.57)	38 (55.07)		
Gender				χ^2 = 0.44	0.505
Female	144 (35.38)	122 (36.09)	22 (31.88)		
Male	263 (64.62)	216 (63.91)	47 (68.12)		
BMI				χ^2 = 0.03	0.863
≤28 kg/m^2	310 (76.17)	258 (76.33)	52 (75.36)		
>28 kg/m^2	97 (23.83)	80 (23.67)	17 (24.64)		
Marital status				χ^2 = 0.61	0.436
Married	332 (81.57)	278 (82.25)	54 (78.26)		
Divorced/widowed	75 (18.43)	60 (17.75)	15 (21.74)		
Smoking				χ^2 = 0.15	0.696
No	262 (64.37)	219 (64.79)	43 (62.32)		
Yes	145 (35.63)	119 (35.21)	26 (37.68)		
Drinking				χ^2 = 0.10	0.755
No	272 (66.83)	227 (67.16)	45 (65.22)		
Yes	135 (33.17)	111 (32.84)	24 (34.78)		
Hypertension				χ^2 = 2.08	0.149
No	215 (52.83)	184 (54.44)	31 (44.93)		
Yes	192 (47.17)	154 (45.56)	38 (55.07)		
Diabetes				χ^2 = 7.16	**0.007**
No	290 (71.25)	250 (73.96)	40 (57.97)		
Yes	117 (28.75)	88 (26.04)	29 (42.03)		
Coronary heart disease				χ^2 = 0.33	0.566
No	323 (79.36)	270 (79.88)	53 (76.81)		
Yes	84 (20.64)	68 (20.12)	16 (23.19)		
Preoperative Hb				χ^2 = 5.10	**0.024**
≥90 g/L	293 (71.99)	251 (74.26)	42 (60.87)		
<90 g/L	114 (28.01)	87 (25.74)	27 (39.13)		
Preoperative ALB				χ^2 = 22.76	**<0.001**
≥30 g/L	339 (83.29)	295 (87.28)	44 (63.77)		
<30 g/L	68 (16.71)	43 (12.72)	25 (36.23)		
Preoperative waiting time				χ^2 = 9.92	**0.002**
<3 days	182 (44.72)	163 (48.22)	19 (27.54)		
≥3 days	225 (55.28)	175 (51.78)	50 (72.46)		
ASA grade				χ^2 = 8.52	**0.004**
<III	145 (35.63)	131 (38.76)	14 (20.29)		
≥III	262 (64.37)	207 (61.24)	55 (79.71)		
Surgical method				χ^2 = 3.02	0.082
Replacement surgery	168 (41.28)	146 (43.20)	22 (31.88)		
Internal fixation	239 (58.72)	192 (56.80)	47 (68.12)		
Surgical duration				χ^2 = 0.34	0.559
<3 hours	340 (83.54)	284 (84.02)	56 (81.16)		
≥3 hours	67 (16.46)	54 (15.98)	13 (18.84)		
Intraoperative hemorrhage				χ^2 = 0.29	0.589
<200 mL	356 (87.47)	297 (87.87)	59 (85.51)		
≥200 mL	51 (12.53)	41 (12.13)	10 (14.49)		
Postoperative VAS score				χ^2 = 9.93	**0.002**
<4	206 (50.61)	183 (54.14)	23 (33.33)		
≥4	201 (49.39)	155 (45.86)	46 (66.67)		
Postoperative hypoxemia				χ^2 = 6.72	**0.010**
No	278 (68.30)	240 (71.01)	38 (55.07)		
Yes	129 (31.70)	98 (28.99)	31 (44.93)		

Notes: Categorical variables are expressed as count (percentage). $p < 0.05$ was shown in bold.

ALB, albumin; ASA, American Society of Anesthesiologists; BMI, body mass index; Hb, hemoglobin; VAS, visual analog scale; POD, postoperative delirium.

Table 2. Univariate logistic regression analysis.

Variables	β	S.E.	Z	p	OR (95% CI)
Age					
$\leq$80 years					1.00 (Reference)
>80 years	0.71	0.27	2.67	**0.008**	2.04 (1.21–3.44)
Gender					
Female					1.00 (Reference)
Male	0.19	0.28	0.67	0.505	1.21 (0.69–2.10)
BMI					
$\leq$28 kg/m^2					1.00 (Reference)
>28 kg/m^2	0.05	0.31	0.17	0.863	1.05 (0.58–1.93)
Marital status					
Married					1.00 (Reference)
Divorced/widowed	0.25	0.32	0.78	0.437	1.29 (0.68–2.43)
Smoking					
No					1.00 (Reference)
Yes	0.11	0.27	0.39	0.696	1.11 (0.65–1.90)
Drinking					
No					1.00 (Reference)
Yes	0.09	0.28	0.31	0.755	1.09 (0.63–1.88)
Hypertension					
No					1.00 (Reference)
Yes	0.38	0.27	1.44	0.151	1.46 (0.87–2.46)
Diabetes					
No					1.00 (Reference)
Yes	0.72	0.27	2.64	**0.008**	2.06 (1.20–3.52)
Coronary heart disease					
No					1.00 (Reference)
Yes	0.18	0.32	0.57	0.566	1.20 (0.65–2.23)
Preoperative Hb					
$\geq$90 g/L					1.00 (Reference)
<90 g/L	0.62	0.28	2.24	**0.025**	1.85 (1.08–3.19)
Preoperative ALB					
$\geq$30 g/L					1.00 (Reference)
<30 g/L	1.36	0.30	4.55	**<0.001**	3.90 (2.17–7.00)
Preoperative waiting time					
<3 days					1.00 (Reference)
$\geq$3 days	0.90	0.29	3.08	**0.002**	2.45 (1.39–4.33)
ASA grade					
<III					1.00 (Reference)
$\geq$III	0.91	0.32	2.85	**0.004**	2.49 (1.33–4.65)
Surgical method					
Replacement surgery					1.00 (Reference)
Internal fixation	0.49	0.28	1.73	0.084	1.62 (0.94–2.82)
Surgical duration					
<3 hours					1.00 (Reference)
$\geq$3 hours	0.20	0.34	0.58	0.559	1.22 (0.62–2.39)
Intraoperative hemorrhage					
<200 mL					1.00 (Reference)
$\geq$200 mL	0.21	0.38	0.54	0.590	1.23 (0.58–2.59)
Postoperative VAS score					
<4					1.00 (Reference)
$\geq$4	0.69	0.27	2.56	**0.010**	2.00 (1.18–3.39)
Postoperative hypoxemia					
No					1.00 (Reference)
Yes	0.86	0.28	3.09	**0.002**	2.36 (1.37–4.07)

Notes: $p < 0.05$ was shown in bold. OR, odds ratio.

Table 3. Analysis of independent risk factors for POD.

Variables	β	S.E.	Z	p	OR (95% CI)
Age					
≤80 years					1.00 (Reference)
>80 years	0.81	0.30	2.69	**0.007**	2.25 (1.25–4.05)
Diabetes					
No					1.00 (Reference)
Yes	0.65	0.32	2.04	**0.041**	1.91 (1.03–3.56)
Preoperative Hb					
≥90 g/L					1.00 (Reference)
<90 g/L	0.75	0.31	2.39	**0.017**	2.11 (1.14–3.90)
Preoperative ALB					
≥30 g/L					1.00 (Reference)
<30 g/L	1.33	0.33	3.96	**<0.001**	3.76 (1.95–7.25)
Preoperative waiting time					
<3 days					1.00 (Reference)
≥3 days	0.96	0.32	3.02	**0.003**	2.62 (1.40–4.90)
ASA grade					
<III					1.00 (Reference)
≥III	0.75	0.34	2.18	**0.029**	2.12 (1.08–4.17)
Postoperative hypoxemia					
No					1.00 (Reference)
Yes	0.80	0.31	2.60	**0.009**	2.22 (1.22–4.05)
Postoperative VAS score					
<4					1.00 (Reference)
≥4	0.94	0.31	3.03	**0.002**	2.55 (1.39–4.68)

Notes: $p < 0.05$ was shown in bold.

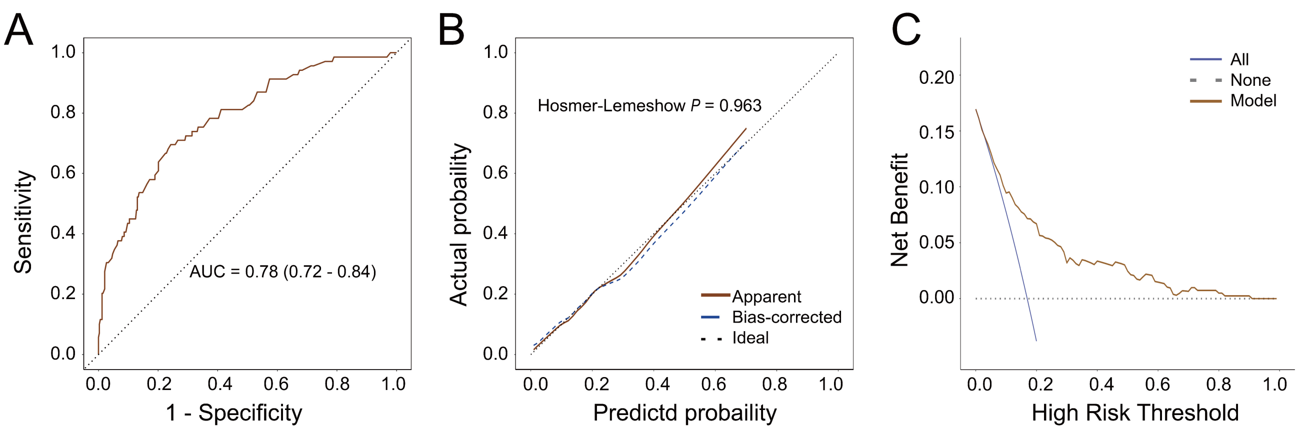

Fig. 3. Evaluation of the prediction model for the training cohort. (A) Receiver operating characteristic (ROC) curve. (B) Calibration curve. (C) Decision curve analysis (DCA). AUC, area under the curve.

ble (Table 4). The ROC of the external validation cohort is shown in Fig. 5A, with an AUC of 0.85 and good discrimination. The calibration curve is shown in Fig. 5B, indicating that the model also has a good calibration degree in the validation cohort (Hosmer–Lemeshow p = 0.815). The DCA of the external validation cohort is shown in Fig. 5C, indicating clinical utility of the model.

Discussion

As a common and harmful complication following FNF surgery, the occurrence of POD can significantly affect quality of life in elderly patients [16]. Focusing on elderly patients undergoing FNF surgery, in this study, we investigated the factors influencing the occurrence of POD after intraspinal anesthesia and constructed a corresponding prediction model. It was found that the incidence of POD was 16.95%, with age >80 years, diabetes, preoperative Hb <90 g/L, preoperative ALB <30 g/L, preoperative waiting

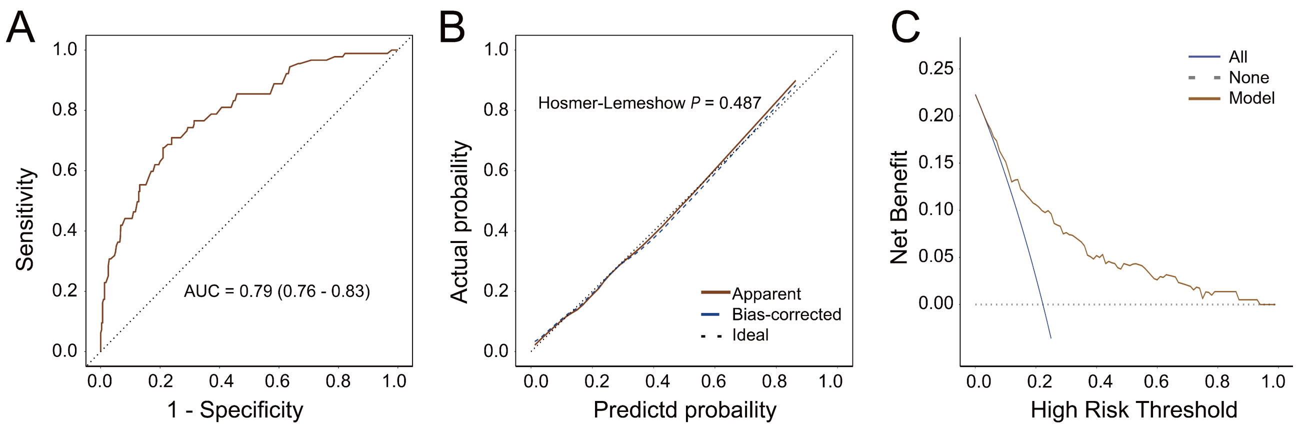

Fig. 4. Evaluation of the prediction model in internal validation. (A) ROC curve for internal validation. (B) Calibration curve for internal validation. (C) DCA for internal validation.

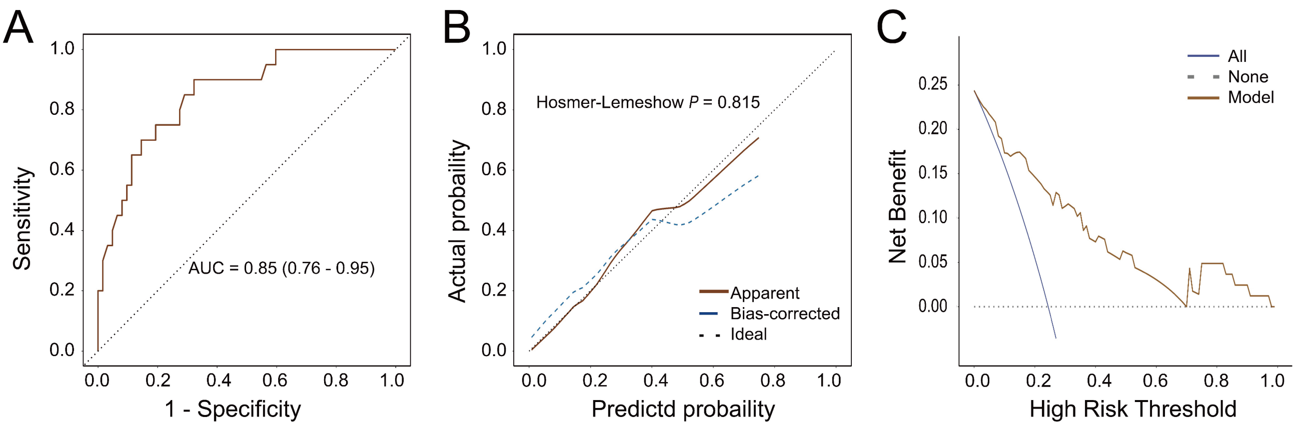

Fig. 5. Evaluation of the prediction model in external validation cohort. (A) ROC curve for external validation. (B) Calibration curve for external validation. (C) DCA for external validation.

time ≥3 days, ASA grade ≥III, postoperative hypoxemia, and postoperative VAS score ≥4 identified as independent risk factors for POD. The predictive nomogram model constructed based on these factors shows good discrimination and calibration ability, providing a practical tool for the early clinical identification of high-risk patients.

In this study, age >80 years was one of the independent risk factors for POD, which was consistent with the results of previous studies. An *et al.* [17] conducted a retrospective analysis of 648 elderly patients with fractures and reported a significant association between older age and an increased risk of POD. In addition, Fenta *et al.* [18] also reported that advanced age increases the risk of POD occurrence in surgical patients. From the perspective of neurodegeneration, elderly patients exhibit significant declines in brain structure and functional reserve, which lead to a markedly reduced capacity of the central nervous system to compensate for perioperative stress factors [19], elevating their vulnerability to acute cognitive dysfunction when facing delayed metabolism of anesthetic drugs and surgical trauma stress. In addition, elderly patients often present with multiple chronic diseases and decreased organ function reserves, such as cardiovascular diseases and respiratory diseases [20]. These underlying diseases can lead to hemodynamic instability and internal environment disorders during the perioperative period, thereby increasing the risk of ischemia and hypoxia in brain tissue. This study also found that coexisting diabetes was significantly associated with the risk of POD. Diabetes mellitus is a common chronic disease leading to unfavorable prognosis according to many studies. Haynes *et al.* [21] reported that preoperative diabetes was independently associated with the risk of POD in elderly patients with hip fractures. Diabetic individuals face chronic hyperglycemia, which can lead to microangiopathy throughout the body, especially in the brain [22]. Microvascular lesions can damage the microcirculation of the brain, resulting in insufficient blood supply and reduced oxygen supply to the brain tissue. After intraspinal anesthesia, the hemodynamics of the brain may change further due to the effects of anaesthetic drugs and surgical stress, thus exacerbating the hypoxic state of brain tissue. This hypoxic state interferes with the normal metabolism and function of nerve cells, increasing the risk of delirium [23]. Preoperative Hb <90 g/L and ALB

Table 4. Baseline characteristics of the external validation cohort and the training cohort.

Variables	Total (n = 489)	External validation cohort (n = 82)	Training cohort (n = 407)	Statistic	p
Age				χ^2 = 1.90	0.168
≤80 years	284 (58.08)	42 (51.22)	242 (59.46)		
>80 years	205 (41.92)	40 (48.78)	165 (40.54)		
Gender				χ^2 = 0.00	0.998
Female	173 (35.38)	29 (35.37)	144 (35.38)		
Male	316 (64.62)	53 (64.63)	263 (64.62)		
BMI				χ^2 = 0.66	0.418
≤28 kg/m^2	369 (75.46)	59 (71.95)	310 (76.17)		
>28 kg/m^2	120 (24.54)	23 (28.05)	97 (23.83)		
Marital status				χ^2 = 0.24	0.626
Married	397 (81.19)	65 (79.27)	332 (81.57)		
Divorced/widowed	92 (18.81)	17 (20.73)	75 (18.43)		
Smoking				χ^2 = 0.46	0.497
No	318 (65.03)	56 (68.29)	262 (64.37)		
Yes	171 (34.97)	26 (31.71)	145 (35.63)		
Drinking				χ^2 = 0.00	0.966
No	327 (66.87)	55 (67.07)	272 (66.83)		
Yes	162 (33.13)	27 (32.93)	135 (33.17)		
Hypertension				χ^2 = 0.12	0.734
No	260 (53.17)	45 (54.88)	215 (52.83)		
Yes	229 (46.83)	37 (45.12)	192 (47.17)		
Diabetes				χ^2 = 0.57	0.449
No	345 (70.55)	55 (67.07)	290 (71.25)		
Yes	144 (29.45)	27 (32.93)	117 (28.75)		
Coronary heart disease				χ^2 = 1.00	0.317
No	384 (78.53)	61 (74.39)	323 (79.36)		
Yes	105 (21.47)	21 (25.61)	84 (20.64)		
Preoperative Hb				χ^2 = 0.20	0.657
≥90 g/L	354 (72.39)	61 (74.39)	293 (71.99)		
<90 g/L	135 (27.61)	21 (25.61)	114 (28.01)		
Preoperative ALB				χ^2 = 0.38	0.539
≥30 g/L	405 (82.82)	66 (80.49)	339 (83.29)		
<30 g/L	84 (17.18)	16 (19.51)	68 (16.71)		
Preoperative waiting time				χ^2 = 0.11	0.735
<3 days	217 (44.38)	35 (42.68)	182 (44.72)		
≥3 days	272 (55.62)	47 (57.32)	225 (55.28)		
ASA grade				χ^2 = 0.34	0.559
<III	177 (36.20)	32 (39.02)	145 (35.63)		
≥III	312 (63.80)	50 (60.98)	262 (64.37)		
Surgical method				χ^2 = 0.34	0.559
Replacement surgery	199 (40.70)	31 (37.80)	168 (41.28)		
Internal fixation	290 (59.30)	51 (62.20)	239 (58.72)		
Surgical duration				χ^2 = 0.87	0.350
<3 hours	405 (82.82)	65 (79.27)	340 (83.54)		
≥3 hours	84 (17.18)	17 (20.73)	67 (16.46)		
Intraoperative hemorrhage				χ^2 = 0.05	0.826
<200 mL	427 (87.32)	71 (86.59)	356 (87.47)		
≥200 mL	62 (12.68)	11 (13.41)	51 (12.53)		
Postoperative VAS score				χ^2 = 0.82	0.364
<4	243 (49.69)	37 (45.12)	206 (50.61)		
≥4	246 (50.31)	45 (54.88)	201 (49.39)		
Postoperative hypoxemia				χ^2 = 0.76	0.384
No	338 (69.12)	60 (73.17)	278 (68.30)		
Yes	151 (30.88)	22 (26.83)	129 (31.70)		

Notes: Categorical variables are expressed as count (percentage).

<30 g/L increased the risk of POD by 2.11 and 3.76 times, respectively, suggesting that anemia and hypoproteinemia may increase susceptibility to delirium by affecting cerebral oxygen supply and the neuronal microenvironment. Anemia directly reduces the oxygen-carrying capacity of the blood, while hypoproteinemia may be accompanied by activation of the systemic inflammatory response or electrolyte disturbances, both of which together weaken the CNS's resistance to injury [24].

In addition, prolonged preoperative waiting time was also found to be significantly associated with POD. This may be related to the fact that patients are bedridden for long periods of time while waiting for surgery, resulting in decreased physical functioning and increased psychological stress [25]. Delayed surgery may also cause the internal environment disorder of the patient to fail to be corrected in time, further increasing the risk of brain function impairment [26]. The OR value of ASA grade ≥III was 2.12, indicating that assessment of the overall condition is a key link in the risk stratification of POD. Wang *et al*. [27], through an observational study of 272 elderly patients with hip fractures, also reported that ASA grade ≥III would significantly increase the probability of POD. A higher ASA grade suggests that the patient has more comorbid underlying conditions, has poorer physical functioning, and is less tolerant of surgery and anaesthesia [28]. This may result in patients being more susceptible to postoperative adverse events, including POD. Postoperative hypoxemia and pain (VAS score ≥4 points) are also independent risk factors for POD. After intraspinal anesthesia, the patient's respiratory function may be affected to a certain extent due to the inhibitory effect of anaesthetic drugs on the respiratory center and the physiological stress response caused by surgical trauma. In the event of postoperative hypoxemia, the oxygen supply to brain tissue will be significantly reduced. The metabolic activities of nerve cells will be disturbed when brain tissue is hypoxic, leading to abnormal synthesis, release and reuptake processes of neurotransmitters, which in turn affects the transmission of nerve signals and cognitive functions of the brain [29]. This metabolic disturbance represents a key pathophysiological mechanism underlying the development of delirium. Higher levels of postoperative pain (VAS score ≥4) may put patients in a state of stress, affecting the quality of sleep and psychological state, which in turn increases the risk of postoperative delirium [30]. Therefore, active measures should be taken to improve patients' oxygenation status and effectively control postoperative pain in order to reduce the incidence of postoperative delirium.

The nomogram model constructed in this study holds significant potential for clinical utility—particularly in preoperative and postoperative assessments. By referring to the weight proportions of each risk factor (such as age, preoperative ALB level, postoperative pain score, etc.) in the nomogram, high-risk individuals can be intuitively identified. For instance, for patients with preoperative ALB <30 g/L, nutritional support can be initiated in advance; for those with postoperative VAS score ≥4 points, analgesic intervention can be promptly strengthened. Thus, the risk of POD can be reduced through implementation of targeted measures. However, this study also has certain limitations. Firstly, as a single-center retrospective study, the limitations in sample sources and data collection can lead to selection and information biases in the research. For instance, our study lacked data on important covariates that could limit the extrapolation of results, including baseline cognitive status, drug exposure, and intraoperative blood pressure fluctuations. Second, the sample size of the external validation cohort was small (n = 82), necessitating larger multicenter studies for further validatation in order to enhance the model's generalizability to other populations or demographics. In addition, this study did not include certain potential influencing factors, such as preoperative sleep quality, dosage of medications used, and genetic factors, which are variables that may play an important role in the occurrence of POD. Future studies can be expanded in the following directions: first, to conduct a multicenter prospective study to incorporate more influencing factors to further optimize the prediction model; second, to explore the associations of serum inflammatory factors, markers of neurological injury, and other bioindicators with POD, in order to improve the predictive efficacy of the model; and third, to formulate a personalized POD prevention strategy based on the model, such as preoperative nutritional support, anemia correction, optimization of surgical waiting time, postoperative intensive oxygen therapy management, and multimodal analgesia, and assess the effectiveness of the interventions through randomized controlled trials, thereby translating risk prediction into tangible clinical benefits and offering a more precise strategy to reduce the incidence of postoperative delirium in elderly patients.

Conclusions

In conclusion, this study identified independent risk factors for POD in elderly patients undergoing FNF surgery under intraspinal anesthesia, including age >80 years, comorbid diabetes, preoperative Hb <90 g/L, preoperative ALB <30 g/L, preoperative waiting time ≥3 days, ASA grade ≥III, postoperative hypoxemia, and postoperative VAS score ≥4. With robust discrimination and calibration performance, the nomogram model developed from these factors highlights substantial clinical utility, offering a robust tool for identifying high-risk patients at an early stage and facilitating implementation of personalized prevention strategies. Nevertheless, multicenter prospective studies are warranted for further model validation and optimization.

Availability of Data and Materials

All experimental data included in this study can be obtained by contacting the first author if needed.

Author Contributions

JL: conceptualized and designed the study, conducted the research, analyzed the data, and drafted the manuscript. XFL: contributed to experimental design, methodology development, and manuscript revision. CZ: supervised the study design, performed statistical analysis, interpreted clinical data, and provided expert clinical guidance throughout the research process. All authors have been involved in revising the manuscript critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was approved by the Medical Ethics Committee of Beijing Chaoyang Hospital, Capital Medical University (CY2024142) and all participants signed an informed consent form. This study adhered strictly to all principles outlined in the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

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