Application of a Risk Assessment-Based Stratified Early Warning Nursing Model to Prevent Postoperative Delirium in Geriatric Patients Undergoing Orthopedic Surgery

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AIM: To investigate the effectiveness of a risk assessment-based stratified early warning nursing model in preventing postoperative delirium (POD) in geriatric orthopedic patients.

METHODS: A retrospective study was conducted. Elderly patients who underwent elective orthopedic surgery at The First Hospital of Jilin University between January 2024 and December 2025 were enrolled. Based on the nursing model received, patients were divided into two groups: those receiving routine care were assigned to the control group (98 patients), while those receiving the risk assessment-based stratified early warning nursing model were assigned to the intervention group (113 patients). In the intervention group, a delirium risk assessment tool was used for preoperative risk stratification (low, moderate, and high risk), and graded early warning measures and targeted interventions were implemented according to the risk level. The incidence of postoperative delirium, delirium duration, length of hospital stay, and nursing satisfaction were compared between the two groups.

RESULTS: The incidence of postoperative delirium was significantly lower in the intervention group than in the control group (9.73% vs. 19.39%, $p = 0.045$). The intervention group also had a shorter median delirium duration (3.0 d vs. 5.0 d, $p = 0.005$), a shorter mean length of hospital stay (12.18 ± 2.60 d vs. 16.48 ± 3.13 d, $p < 0.001$), and a higher nursing satisfaction rate (96.46% vs. 85.71%, $p = 0.032$).

CONCLUSIONS: The risk assessment-based stratified early warning nursing model may reduce the incidence of postoperative delirium in geriatric orthopedic patients, shorten delirium duration and hospital stay, and improve nursing satisfaction, highlighting its potential clinical value.

Keywords: risk assessment; stratified early warning; geriatric patients; orthopedic surgery; postoperative delirium

Introduction

Postoperative delirium (POD) is an acute, fluctuating disorder of attention and cognition that usually occurs within hours to days after surgery and is characterized by an altered level of consciousness, disorganized thinking, and disorientation [1]. Due to decreased physiological reserve, multimorbidity, and altered drug metabolism, elderly patients are at high risk for POD. Orthopedic surgery, especially hip and knee arthroplasty and spinal surgery, often involves substantial surgical trauma, prolonged operative times, and severe postoperative pain. The incidence of POD in elderly orthopedic patients ranges from 15% to 30% [2] and can reach 35% to 65% after hip fracture surgery [3].

POD not only prolongs hospital stay and increases medical costs but is also closely associated with poor postoperative functional recovery, long-term cognitive decline, and increased risks of complications such as falls and pressure ulcers during hospitalization [4]. More importantly, POD is associated with increased long-term mortality and unfavorable cognitive trajectories [5]. Therefore, early identification of high-risk patients and implementation of targeted preventive measures are key components of perioperative nursing care for geriatric orthopedic patients.

To date, multiple studies have explored preventive strategies for POD, including optimized analgesia, early mobilization, improved sleep, nutritional support, cognitive training, and multidisciplinary collaborative interventions [6,7]. However, these interventions are often applied uniformly to all elderly patients without precise risk-based stratification. As a result, low-risk patients may receive excessive interventions (increasing nursing workload), while high-risk patients may receive insufficient interventions. In recent years, risk assessment tools (e.g., PIPRA [8] and the DRD score [9]) have been used to predict preoperative POD risk, but systematic studies combining these tools with a graded early warning nursing model remain limited.

Against this background, we retrospectively analyzed the stratified early warning nursing model implemented at our hospital, which involved preoperative risk stratification (low, moderate, and high risk) of elderly orthopedic patients

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using an assessment form containing 10 risk factors, with the intensity of interventions matched to the risk level (basic interventions, enhanced interventions, and multidisciplinary collaborative interventions). By comparing patients who received routine care in 2024 with those who received this model of care in 2025, we aimed to evaluate the association of the model with the incidence of POD, delirium duration, length of hospital stay, and nursing satisfaction, thereby providing evidence to inform risk-stratified nursing for the prevention of postoperative delirium in geriatric orthopedic patients.

Methods

Study Population

This retrospective cohort study enrolled elderly patients who underwent elective orthopedic surgery under general or neuraxial anesthesia at The First Hospital of Jilin University between January 2024 and December 2025. Patients enrolled in 2024 were assigned to the control group and received routine care, whereas patients enrolled in 2025 were assigned to the intervention group and received the risk assessment-based stratified early warning nursing model.

Inclusion criteria: (1) age ≥65 years; (2) elective orthopedic surgery under general or neuraxial anesthesia; and (3) complete clinical data.

Exclusion criteria: (1) pre-existing cognitive impairment (Mini-Mental State Examination [MMSE] score ≤23) or a history of psychiatric disease; (2) severe vital organ dysfunction (American Society of Anesthesiologists [ASA] grade V); (3) pre-existing delirium; (4) transfer to the intensive care unit for >48 hours due to critical illness; and (5) death or discharge within 48 hours after surgery.

Patients were divided into two groups according to the nursing model received: those who received routine care formed the control group, while those who received the risk assessment-based stratified early warning nursing model formed the intervention group. This study was approved by the First Hospital of Jilin University ethics committee (approval number: 2026-412), and the requirement for informed consent was waived.

Nursing Methods

Control Group Nursing Methods

Routine postoperative nursing care included the following:

Vital Sign Monitoring. After returning to the ward, blood pressure, heart rate, respiratory rate, and oxygen saturation were measured every 15 minutes, then hourly after stabilization, for a total of 24 hours. Body temperature was measured four times daily.

Incision Care. Within 24 hours after surgery, the incision dressing was monitored for bleeding or exudation and kept clean and dry. Dressings were changed according to physicians' orders, with the first change on postoperative day 1, followed by changes every 2–3 days or immediately if soiled.

Pain Management. Pain was assessed daily using the Numerical Rating Scale (NRS). The postoperative pain NRS value used for between-group comparisons was determined according to the actual assessment time point and calculation method recorded in the original data. When the NRS score was ≥4, analgesics (e.g., flurbiprofen axetil 50 mg intravenously or tramadol 100 mg by injection) were administered as ordered. For patients using patient-controlled analgesia (PCA), PCA pump function was checked during each shift, and the number of demands and drug consumption were recorded.

Diet Guidance. Patients fasted for 6 hours after surgery, followed by a gradual transition from a liquid to a regular diet according to the anesthesia type and patient recovery. A high-protein, high-vitamin, easily digestible diet was encouraged, with a daily fluid intake of ≥1500 mL.

Early Mobilization Guidance. After emergence from anesthesia, patients were instructed to perform ankle pump exercises (every 2 hours, 5 minutes each) and quadriceps isometric contractions (3 times daily, 10–15 repetitions each). On postoperative day 1, patients were assisted into a semi-recumbent or sitting position. Patients who underwent hip or knee arthroplasty were assisted in standing or walking with a walker under the guidance of a rehabilitation therapist on postoperative day 1, for 5–10 minutes per session, 1–2 times daily.

Complication Prevention. Deep vein thrombosis prevention: patients were instructed to wear compression stockings, perform ankle pump exercises, and receive low-molecular-weight heparin as ordered.

Pressure ulcer prevention: patients were repositioned every 2 hours, and pressure-redistributing mattresses were used.

Pulmonary infection prevention: Patients were instructed in effective coughing and deep breathing, and nebulization was performed twice daily.

Urinary tract infection prevention: catheter patency was maintained, perineal care was performed twice daily, and early catheter removal was encouraged.

Sleep Management. The ward was kept quiet, the main lights were turned off after 21:00, and unnecessary nursing procedures were minimized. Hypnotics (e.g., Zopiclone 3 mg oral) were administered as ordered when necessary.

Psychological Support. The responsible nurse communicated with each patient for 5–10 minutes daily to assess psychological status, answer questions, and provide emotional support.

Intervention Group Nursing Methods

According to the nursing records, patients in the intervention group received a nurse-led, multidisciplinary stratified early warning comprehensive intervention model in addition to routine care. This model was a multicomponent intervention package integrating nursing and medical strategies. It consisted of four components: preoperative risk assessment, risk stratification, warning signs, and stratified interventions, implemented by a multidisciplinary team (MDT). The MDT comprised an attending orthopedic surgeon, an anesthesiologist, a geriatrician, a psychiatrist, a head nurse (or higher-ranking nurse) serving as the team leader, a specialist orthopedic nurse, a rehabilitation therapist, and a dietitian. All team members received standardized training on delirium identification (CAM criteria), use of the risk assessment tool (data collection and scoring for each factor in Table 1 [2,8,9,10]), and implementation standards for stratified interventions (specific procedures for each risk level). Only those who passed the training were permitted to care for patients in the intervention group. In contrast, the control group received routine postoperative care from ward nurses and rehabilitation therapists according to standard orthopedic postoperative protocols.

Table 1. Postoperative delirium risk factors and scoring criteria.

Risk factor	Points	Reference
Age ≥85 years	2	[2]
Age 75–84 years	1	[2]
ASA grade ≥ III	1	[2]
Diabetes mellitus	1	[2]
History of stroke	1	[8]
Hearing or visual impairment	1	[8]
Preoperative albumin <35 g/L	1	[10]
Surgery/Anesthesia duration ≥2 hours	1	[10]
Anticipated postoperative pain NRS score ≥4	1	[2]
Use of anticholinergics or benzodiazepines	1	[9]

Note: ASA, American Society of Anesthesiologists; NRS, Numerical Rating Scale.

Preoperative Risk Assessment

All patients in the intervention group underwent risk assessment by an orthopedic specialist nurse within 24 hours before surgery. The assessment tool was a self-developed *Risk Factor Assessment Form for Postoperative Delirium in Geriatric Orthopedic Patients*, containing 10 risk factors (Table 1). The variables were selected based on previously reported risk factors for POD in geriatric orthopedic surgery, including those identified in systematic reviews and meta-analyses. The weight assigned to each factor was determined based on the strength of evidence from previous studies and expert consensus. The cut-off values for risk stratification were determined based on previous literature, clinical feasibility, and the distribution of risk scores in our pilot assessment. Data on all risk factors were collected within 24 hours before surgery. For factors such as surgery/anesthesia duration, the estimated duration based on the surgical plan was used. For postoperative pain, the actual pain level was not yet known; thus, anticipated postoperative pain was used for scoring. Anticipated postoperative pain was assessed based on the following: (i) type of surgery (e.g., total knee arthroplasty, for which severe pain was anticipated); (ii) preoperative pain level (preoperative NRS ≥4); (iii) history of preoperative analgesic use; and (iv) assessment of anxiety/depression. The attending orthopedic surgeon and anesthesiologist jointly determined the anticipated postoperative pain score. If the anticipated postoperative pain NRS score within the first 24 hours postoperatively was ≥4, 1 point was assigned.

Risk Stratification and Warning Signs

Based on their total risk scores, patients in the intervention group were classified into three risk levels, with corresponding color-coded warning signs placed at their bedsides (Table 2).

Stratified Interventions

Patients received interventions of varying intensity according to their risk levels.

Basic Intervention (For Low-Risk Patients). The basic intervention consisted of a standardized care package implemented by the nurse responsible for the patient's care (Table 3).

Enhanced Intervention (For Moderate-Risk Patients). Moderate-risk patients received the following additional measures in addition to the basic intervention (Table 4):

Multidisciplinary Collaborative Intervention (For High-Risk Patients). High-risk patients received MDT interventions in addition to the measures provided to moderate-risk patients (Table 5):

Outcome Measures and Data Collection

Postoperative delirium was assessed using the Confusion Assessment Method (CAM) [11]. Assessments were performed by trained nurses responsible for patient care, twice daily (morning and evening), starting on postoperative day 1 and continuing for 7 days or until discharge, whichever occurred first. All nursing interventions and outcome assessments for both groups were continued until hospital discharge. The CAM assesses four key features: (1) acute onset and fluctuating course, (2) inattention, (3) disorganized thinking, and (4) altered level of consciousness. A diagnosis of delirium required the presence of both features 1 and 2 and at least one of features 3 or 4. Delirium duration was defined as the number of days from the first positive CAM

Table 2. Risk stratification and warning signs.

Risk level	Score range	Warning sign	Sign content	Sign management
Low	≤2	None		
Moderate	3–5	Yellow circular sign (diameter 10 cm)	Patient name, risk level "Moderate", assessment date, responsible nurse name, instruction "Increase observation, patrol every hour"	Sign placed by responsible nurse within 24 hours after assessment, above the bed head card, checked at each shift handover
High	≥6, or any of: age ≥85 years with ≥2 comorbidities, history of delirium, ASA grade IV	Red circular sign (diameter 10 cm)	Patient name, risk level "High", assessment date, responsible team leader name, instruction "MDT daily rounds, intensive nursing (responsibility taken by team leader nurse or specialist nurse; patrol every 1 hour)"	

Warning signs were magnetic or adhesive and highly visible. MDT, multidisciplinary team.

Table 3. Basic intervention (for low-risk patients).

Intervention	Specific measures	Frequency
Optimized analgesia	Multimodal analgesia: preoperative oral acetaminophen (500 mg), intraoperative regional block (e.g., femoral nerve block or adductor canal block) by an anesthesiologist, postoperative non-steroidal anti-inflammatory drugs (parecoxib 40 mg IV q12h) as baseline analgesia, and routine opioid use was avoided. If NRS ≥4, tramadol 50–100 mg was administered as needed.	Pain assessed q4h, and analgesics administered as needed
Maintenance of homeostasis	Monitor serum electrolytes, blood glucose, and complete blood counts daily. Maintain serum potassium at 3.5–5.5 mmol/L, sodium at 135–145 mmol/L, blood glucose at 4.0–10.0 mmol/L, and SpO_2 ≥95% (supplemental oxygen at 2 L/min if needed).	Daily lab tests; continuous SpO_2 monitoring
Early mobilization	Ankle pump exercises (q2h, 5 min) and quadriceps isometric contractions (3 times/d, 10 reps) after emergence from anesthesia. Postoperative day 1: assist patients in sitting up and maintaining sitting balance at the bedside. Hip/knee arthroplasty: ambulate with a walker under therapist guidance on day 1 for 5–10 min, 2 times/d. Spinal surgery: ambulate with a brace on day 2.	As scheduled
Sleep environment improvement	Turn off main lights at 21:00, leaving bedside lamps on; turn off all lights except floor lighting after 22:00. Cluster nocturnal nursing procedures (non-essential procedures avoided 23:00–05:00). Provide earplugs and eye masks. Administer oral dexzopiclone 3 mg as needed.	Daily
Nutritional support	Nutrition risk screening (NRS 2002) by a dietitian on postoperative day 1. If albumin <35 g/L or NRS 2002 score ≥3, provide enteral nutrition (Abbott Ensure) 500 mL orally daily, or intravenous human albumin (10 g daily for 3 days). Maintain daily protein intake ≥1.2 g/kg.	Screening on day 1, then weekly
Orientation training	Three times daily (morning, noon, and evening), the nurse or family members remind patients of (i) the current date (year, month, day, weekday); (ii) their location (hospital name, department, bed number); and (iii) their name and primary caregiver name. Whiteboard with daily information placed at the bedside.	3 times/d
Family involvement	Provide a 20-minute preoperative educational session on delirium for family members (content: delirium manifestations, preventive measures, and communication skills). Visiting hours 10:00–12:00 and 15:00–17:00. Encourage family presence, conversation, and assistance with orientation training.	One preoperative session; implemented during visiting hours

Table 4. Enhanced intervention (for moderate-risk patients).

Intervention	Specific measures	Frequency
Cognitive function training	(i) memory game (show 3 pictures, ask recall after 5 min); (ii) backward digit span (count from 20 down to 1); (iii) categorization (classify fruits, animals, vehicles). 15–20 minutes per session, performed by the nurse or rehabilitation therapist.	Twice daily (09:00, 15:00)
Psychological counseling	Use open-ended questions to identify sources of anxiety (e.g., pain, recovery, family burden). Provide active listening, empathetic responses, and informational support. Each session lasts 10–15 minutes.	Once daily
Increased rounding frequency	Conduct hourly rounds (24 times/day) to assess mental status, sleep–wake cycle, and orientation; perform a brief CAM screening (approximately 1 minute) during each round.	Every hour

Table 5. Multidisciplinary collaborative intervention (for high-risk patients).

Intervention	Specific measures	Frequency
MDT rounds	Daily morning rounds by the MDT (attending orthopedic surgeon, anesthesiologist, geriatrician, psychiatrist, team leader nurse) to assess mental status (CAM), pain, sleep, mobility, and laboratory values. Develop an individualized intervention plan after rounds and document it on the MDT rounding form.	Once daily
Dynamic adjustment	Adjust the analgesic regimen (e.g., addition of gabapentin), psychotropic medications (e.g., dexmedetomidine or quetiapine prescribed by a psychiatrist), and intensity of nutritional support according to MDT recommendations.	Daily adjustments
Intensive nursing	Assign responsibility to a nurse team leader (head nurse or above) or specialist nurse to conduct hourly rounds. Provide one-to-one bedside care, including assistance with eating, toileting, and cognitive stimulation.	Every 1 hour
Enhanced family training	Additional 30-minute training for family members: recognize early signs of delirium (e.g., nocturnal agitation, confused speech), non-pharmacological calming techniques (soft speech, touch reassurance, orientation reset). Family members sign an informed consent form.	One session within 24 hours postoperatively

assessment to two consecutive negative CAM assessments (≥24 hours apart). Length of hospital stay was defined as the total number of days from surgery to discharge. Nursing satisfaction was assessed at discharge using a self-designed *Nursing Satisfaction Questionnaire* completed by patients or their family members. The questionnaire contained 10 items covering nursing attitude, technical skills, health education, condition monitoring, pain management, assistance with daily living, discharge guidance, etc. Each item was rated on a 4-point scale (very satisfied, satisfied, neutral, dissatisfied). The satisfaction rate was calculated as (very satisfied + satisfied) / total cases × 100%.

Baseline data included age, sex, surgery type, anesthesia type, ASA grade, preoperative MMSE score, comorbidities (diabetes, history of stroke, etc.), sensory impairment, preoperative albumin, surgery duration, and use of anticholinergic drugs or benzodiazepines.

Statistical Analysis

Statistical analysis was performed using SPSS 26.0 (IBM Corp., Armonk, NY, USA). Normality was assessed using the Shapiro–Wilk test. Normally distributed continuous variables were expressed as mean ± standard deviation and compared using the independent samples *t*-test. Non-normally distributed continuous variables were expressed as median (Q1, Q3) and compared using the Mann–Whitney U test, with Z statistics reported. Categorical variables were expressed as number (percentage) and compared using the χ^2 test or Fisher's exact test, as appropriate. A *p*-value < 0.05 was considered statistically significant.

Results

Patient Inclusion and Baseline Characteristics

A total of 211 patients were included, with 98 in the control group and 113 in the intervention group. There were no statistically significant differences between the two groups in age, sex, surgery type, anesthesia type, ASA grade, preoperative MMSE score, comorbidities (diabetes, history of stroke), sensory impairment, preoperative albumin level, surgery duration, or use of anticholinergic drugs or benzodiazepines (all $p > 0.05$; Table 6).

Risk Score and Stratification Distribution

All 113 patients in the intervention group completed the preoperative risk assessment. Risk scores ranged from 0 to 9, with a mean of 4.02 ± 1.86. According to the risk stratification criteria: low-risk (≤2 points) 25 patients (22.12%), moderate-risk (3–5 points) 62 patients (54.87%), high-risk (≥6 points) 26 patients (23.01%) (Table 7).

Comparison of Postoperative Delirium Incidence and Duration

The incidence of postoperative delirium was 9.73% in the intervention group and 19.39% in the control group ($p = 0.045$). Delirium duration was also shorter in the intervention group ($p = 0.005$) (Table 8).

Postoperative Delirium Incidence by Risk Stratum in Both Groups

To further examine the distribution of POD incidence across risk strata, we retrospectively assessed the 98 patients in the control group using the same 10-factor tool. As shown in Table 9, POD incidence increased progressively with higher risk strata in both groups. In the control group, the incidence rates were 4.35% (1/23), 17.07% (7/41), and 32.35% (11/34) for the low-, moderate-, and high-risk groups, respectively ($p = 0.028$). In the intervention group, the corresponding rates were 0.00% (0/25), 8.06% (5/62), and 23.08% (6/26), respectively ($p = 0.015$). The stratified model reduced POD incidence across all risk strata, with the most pronounced absolute reduction in the high-risk group.

Comparison of Hospital Stay, Pain Score, and Nursing Satisfaction

Compared with the control group, the intervention group had a significantly shorter hospital stay, lower postoperative

Table 6. Baseline characteristics of the two groups.

Variables	Total (n = 211)	Control (n = 98)	Intervention (n = 113)	Statistic	*p*
Age, Mean ± SD	81.25 ± 8.42	81.45 ± 8.29	81.07 ± 8.56	$t = 0.32$	0.746
Preop MMSE, Mean ± SD	27.08 ± 1.60	26.95 ± 1.56	27.19 ± 1.64	$t = –1.07$	0.286
Surgery duration, Mean ± SD	120.38 ± 30.44	122.64 ± 31.88	118.42 ± 29.14	$t = 1.00$	0.317
Albumin, M (Q_1, Q_3)	36.80 (34.95, 39.45)	36.70 (34.23, 39.18)	37.00 (35.30, 39.50)	Z = –1.26	0.208
Gender, n (%)				$\chi^2 = 1.59$	0.208
Female	111 (52.61)	47 (47.96)	64 (56.64)		
Male	100 (47.39)	51 (52.04)	49 (43.36)		
Surgery type, n (%)				$\chi^2 = 0.25$	0.883
Hip	79 (37.44)	35 (35.71)	44 (38.94)		
Knee	81 (38.39)	39 (39.80)	42 (37.17)		
Spine	51 (24.17)	24 (24.49)	27 (23.89)		
Anesthesia, n (%)				$\chi^2 = 0.58$	0.446
General anesthesia	143 (67.77)	69 (70.41)	74 (65.49)		
Neuraxial anesthesia	68 (32.23)	29 (29.59)	39 (34.51)		
ASA grade, n (%)				$\chi^2 = 3.61$	0.307
1	23 (10.90)	9 (9.18)	14 (12.39)		
2	95 (45.02)	49 (50.00)	46 (40.71)		
3	68 (32.23)	32 (32.65)	36 (31.86)		
4	25 (11.85)	8 (8.16)	17 (15.04)		
Diabetes, n (%)				$\chi^2 = 0.60$	0.440
No	156 (73.93)	70 (71.43)	86 (76.11)		
Yes	55 (26.07)	28 (28.57)	27 (23.89)		
Stroke, n (%)				$\chi^2 = 0.47$	0.491
No	186 (88.15)	88 (89.80)	98 (86.73)		
Yes	25 (11.85)	10 (10.20)	15 (13.27)		
Sensory impairment, n (%)				$\chi^2 = 0.22$	0.639
No	175 (82.94)	80 (81.63)	95 (84.07)		
Yes	36 (17.06)	18 (18.37)	18 (15.93)		
Anticholinergic or benzodiazepine use, n (%)				$\chi^2 = 0.30$	0.585
No	165 (78.20)	75 (76.53)	90 (79.65)		
Yes	46 (21.80)	23 (23.47)	23 (20.35)		

Note: MMSE, Mini-Mental State Examination; ASA, American Society of Anesthesiologists.

Table 7. Risk score and stratification distribution.

Variables	Intervention (n = 113)
Risk Score, Mean ± SD	4.02 ± 1.86
Risk Stratum, n (%)	
High	26 (23.01)
Low	25 (22.12)
Moderate	62 (54.87)

pain NRS scores, and a higher nursing satisfaction rate (all $p < 0.05$; Table 10).

Discussion

Our results show that the nurse-led, multidisciplinary stratified early warning comprehensive intervention model was associated with a reduced incidence of postoperative delirium ($p = 0.045$), shorter delirium duration ($p = 0.005$), shorter hospital stay ($p < 0.001$), and higher nursing satisfaction ($p = 0.032$) among elderly orthopedic patients. However, because the intervention was a comprehensive, multicomponent program incorporating regional nerve blocks, medication adjustments, nutritional support, and multidisciplinary collaboration, the observed effects may have resulted from the overall intervention rather than any single nursing component. Compared with previous studies, the incidence of POD in this study was lower than the previously reported rate of 15%–30% [2], however, differences in study populations and study designs should be considered when interpreting this comparison.

The core advantage of the stratified early warning model may lie in “precise matching”: based on a preoperative assessment of 10 risk factors, patients are stratified into low-, moderate-, and high-risk groups and receive progressively intensified interventions. Low-risk patients receive basic interventions, avoiding the waste of nursing resources associated with a one-size-fits-all approach; moderate-risk patients receive cognitive training and more frequent rounds in addition to basic interventions; for high-risk patients,

Table 8. Comparison of postoperative delirium incidence and duration between the two groups.

Variables	Total	Control	Intervention	Statistic	*p*
Delirium Duration, M (Q_1, Q_3) (Total n = 30; Control n = 19; Intervention n = 11)	5.00 (3.00, 5.75)	5.00 (4.00, 7.00)	3.00 (2.00, 4.50)	Z = –2.80	0.005
Delirium, n (%) (Total n = 211; Control n = 98; Intervention n = 113)				χ^2 = 4.01	0.045
No	181 (85.78)	79 (80.61)	102 (90.27)		
Yes	30 (14.22)	19 (19.39)	11 (9.73)		

Note: Delirium duration was calculated only for patients who developed postoperative delirium (n = 30).

Table 9. Postoperative delirium incidence by risk stratum in both groups.

Variables	Level	High	Low	Moderate	Statistic	*p*
Delirium, n (%)	Intervention				—	0.015
No		20 (76.92)	25 (100.00)	57 (91.94)		
Yes		6 (23.08)	0 (0.00)	5 (8.06)		
Delirium, n (%)	Control				χ^2 = 7.13	0.028
No		23 (67.65)	22 (95.65)	34 (82.93)		
Yes		11 (32.35)	1 (4.35)	7 (17.07)		

Note: Risk-stratum sizes were 26, 25, and 62 in the intervention group and 34, 23, and 41 in the control group for the high-, low-, and moderate-risk strata, respectively. —, no test statistic reported for Fisher's exact test.

Table 10. Comparison of hospital stay, pain score, and nursing satisfaction between the two groups.

Variables	Total (n = 211)	Control (n = 98)	Intervention (n = 113)	Statistic	*p*
Hospital stay, Mean ± SD	14.18 ± 3.57	16.48 ± 3.13	12.18 ± 2.60	*t* = 10.90	<0.001
Postoperative pain, M (Q_1, Q_3)	4.00 (2.00, 5.00)	4.00 (3.00, 6.00)	3.00 (2.00, 5.00)	Z = –4.16	<0.001
Satisfaction, n (%)				—	0.032
Dissatisfied	2 (0.95)	2 (2.04)	0 (0.00)		
Neutral	16 (7.58)	12 (12.24)	4 (3.54)		
Satisfied	78 (36.97)	35 (35.71)	43 (38.05)		
Very satisfied	115 (54.50)	49 (50.00)	66 (58.41)		

Note: —, no test statistic reported for Fisher's exact test.

multidisciplinary team (MDT) rounds are initiated to allow individualized, dynamic adjustments. This stratification strategy is consistent with the concept of "risk-stratified management" recommended by domestic and international guidelines [12]. Zahed et al. [7] conducted a systematic review of 11 studies involving 15,761 patients and found that multi-component non-pharmacological interventions significantly reduced POD incidence among elderly orthopedic surgery patients; comprehensive nursing protocols reduced delirium incidence and duration. Moreover, studies have shown that multi-component non-pharmacological interventions are the most effective strategy for reducing POD incidence among hospitalized elderly patients [13,14].

The possible mechanisms by which the stratified early warning model may reduce POD include the following: (i) Optimized analgesia: multimodal analgesia can reduce opioid use, which is an independent risk factor for POD. Studies have shown that a nurse-led, multidisciplinary perioperative comprehensive intervention program effectively reduces POD incidence in elderly patients with hip fractures, with optimization of pain management as a core component [15]. (ii) Early mobilization and orientation training: These interventions help maintain cognitive function and circadian rhythms while reducing sensory deprivation. Zahed et al.'s systematic review [7] specifically identified maintaining adequate intraoperative blood pressure, implementing enhanced recovery pathways, avoiding unnecessary fresh frozen plasma transfusions, and using comprehensive care bundles as effective evidence-based strategies. (iii) Sleep management: clustering nursing procedures and using earplugs and eye masks can improve sleep quality, while sleep disturbances are an important trigger for POD. (iv) MDT collaboration: daily rounds involving geriatricians and psychiatrists for high-risk patients allow timely identification and management of prodromal delirium symptoms. Zhao and Yuan [15] showed that a nurse-led, multidisciplinary comprehensive intervention program is feasible and effective in elderly patients with hip fractures, encompassing pain monitoring and management, orientation training, and other aspects. Compared with sim-

ilar studies, this model is highly practical and may offer advantages in resource allocation and potential economic benefits. Although we did not directly measure hospitalization costs in this study, recent health economic evaluations of delirium risk prediction models provide indirect, hypothesis-generating evidence supporting the potential economic value of our stratified early warning model. Graves et al. [16] modeled the cost-effectiveness of the PIPRA plus risk screening tool and showed that using the tool, followed by non-pharmacological interventions in high-risk patients, reduced costs by 3075 Swiss francs per patient (SD 997), with a 100% probability of cost savings and a 91% probability of cost-effectiveness. Additionally, Chan et al. [17] noted that routine cognitive screening is useful and cost-effective for reducing postoperative delirium, with a cost-effectiveness ratio of 2.89 (adjusted 2.34), offering added value over targeted screening or routine intervention. These findings suggest that preoperative risk assessment combined with stratified intervention, as used in our study, is not only clinically effective but also potentially cost-effective. However, further health economic evaluations are needed to confirm this possibility.

This study has several limitations. First, this was a retrospective, non-randomized study, and the two groups were drawn from different time periods (control group, 2024; intervention group, 2025), which may have introduced temporal bias (e.g., improvements in nursing proficiency and overall perioperative management). Although baseline characteristics were balanced, unmeasured confounding factors cannot be completely excluded. Because the control and intervention groups were recruited in different years, temporal changes in nursing proficiency and perioperative management may have influenced the observed outcomes, and residual confounding due to these changes cannot be excluded. Consequently, the observed association between the nursing model and reduced POD incidence should be interpreted as a correlation, and a causal relationship cannot be definitively established. We have emphasized this limitation throughout the discussion and conclusion sections. Second, some factors included in the risk assessment scale (e.g., postoperative pain NRS scores) are postoperative variables; therefore, preoperative assessment relied on predicted values, which may have affected the accuracy of risk stratification. Third, delirium was assessed using the CAM. Although assessment training was standardized, blinding of outcome assessors was not feasible because the nurses performing the CAM assessments were also the primary care providers. This lack of blinding may have introduced measurement bias and affected the assessment of postoperative delirium incidence. As these nurses were aware of patients' risk stratification and intervention status, the lack of blinding could have introduced measurement bias, representing a significant limitation. Fourth, the single-center design limits the generalizability of the findings. Fifth, we did not conduct a formal cost-effectiveness analysis or quantitatively measure nursing workload. In addition, nursing satisfaction was assessed using a self-designed questionnaire without formal psychometric validation. Therefore, the nursing satisfaction results should be interpreted with caution, as the reliability and validity of the questionnaire have not been established. The lack of evidence supporting its reliability and validity may introduce measurement bias, and the nursing satisfaction results should therefore be interpreted with caution. Future studies should include health economic and resource utilization indicators and use validated instruments to assess nursing satisfaction. Because detailed information on the local anesthetics used for intraoperative nerve blocks and the routes of administration, dosages, and indications for gabapentin, dexmedetomidine, and quetiapine was not consistently documented in the retrospective records, the reproducibility of these interventions may be limited, and potential heterogeneity in medication use may have influenced the observed outcomes. Moreover, although the self-designed risk assessment tool used in this study was based on literature-derived risk factors with corresponding weights, it lacked formal internal or external validation of its predictive performance and the selected cutoff values for risk stratification. As the tool has not undergone formal development and validation procedures, its reproducibility, predictive accuracy, and generalizability should be interpreted with caution. Future multicenter, prospective randomized controlled trials are needed, and further exploration of combining biomarkers (e.g., inflammatory factors IL-6, S100β) with risk stratification models is warranted.

Conclusions

The risk assessment-based stratified early warning nursing model was associated with a reduced incidence of postoperative delirium in elderly orthopedic patients, shorter delirium duration and hospital stay, and a higher nursing satisfaction rate. By matching different intervention intensities to preoperative risk stratification levels (low, moderate, high), this model may contribute to more precise resource allocation for delirium prevention and has potential for clinical implementation. Further health economic evaluations are needed to confirm its potential. Further prospective and multicenter studies are needed to validate the clinical utility and generalizability of risk assessment tools and stratified early warning approaches in geriatric orthopedic perioperative nursing.

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

WL and DXL designed the research study. WL performed the research. DXL analyzed the data. WL drafted the arti-

cle. Both authors contributed to the critical revision of the manuscript for important intellectual content. Both authors read and approved the final manuscript. Both 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 study protocol was approved by The First Hospital of Jilin University ethics committee (ethics number: 2026-412) and the requirement for informed consent was waived. This study complies with the relevant requirements of the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

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