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ORIGINAL RESEARCH

Development and Application of a Unplanned Extubation Assessment and Clinical Decision Support Information System

Huayu Chen[1], Xiaowen Yang[2], Jifang Peng[3], Xianrong Xu[4], Yaping Li[1], Zirong Tong[5], Chunhong Gao[5]

[1]Department of Neurosurgery, First Affiliated Hospital with Nanjing Medical University Junior Nurse, Nanjing, Jiangsu, 210029, People's Republic of China; [2]Department of Neurosurgical ICU, First Affiliated Hospital with Nanjing Medical University Junior nurse, Nanjing, Jiangsu, 210029, People's Republic of China; [3]Department of Chest Surgery, First Affiliated Hospital with Nanjing Medical University Junior Nurse, Nanjing, Jiangsu, 210029, People's Republic of China; [4]Department of Nephrology, First Affiliated Hospital with Nanjing Medical University Junior Nurse, Nanjing, Jiangsu, 210029, People's Republic of China; [5]Department of Nursing, First Affiliated Hospital with Nanjing Medical University Junior nurse, Nanjing, Jiangsu, 210029, People's Republic of China

Correspondence: Zirong Tong; Chunhong Gao, Department of Nursing, First Affiliated Hospital with Nanjing Medical University Junior nurse, Nanjing, Jiangsu, 210029, People's Republic of China, Email ayuayu001@163.com; chunhonggaogogo@163.com

Background: Unplanned extubation (UE) poses significant risks to intensive care unit (ICU) patients, including respiratory complications and increased mortality. Existing preventive measures are limited by delayed detection and inconsistent nursing practices. This study aimed to develop and evaluate an Unplanned Extubation Assessment and Clinical Decision Support Information System (UE-CDSS) to reduce UE incidence and enhance catheter management.

Methods: The UE-CDSS was developed using a C#-based client-server architecture and SQL Server database, integrating 12 core risk indicators, including limb muscle strength, delirium status, and catheter type. The indicators were selected through two rounds of Delphi expert consultation. The system comprises five modules: catheter maintenance, risk assessment and restraint decision, critical patient restraint support, virtual catheter ward, and analysis and feedback. A pre-post study design was applied to compare UE incidence, catheter management metrics, and nurse satisfaction in a tertiary hospital ICU before (2021, n=1,059) and after (2022–2023, n=4,115) system implementation.

Results: UE incidence significantly declined for all catheter classes: Class I from 1.08% to 0.38%, Class II from 1.36% to 0.27%, and Class III from 0.44% to 0%. Catheter fixation rates improved from 97.21% to 99.50%, secondary fixation from 95.13% to 97.80%, and standardized restraint from 96.61% to 98.83% (all $P<0.001$). Nurse satisfaction scored 92.15±6.82/115, reflecting high usability.

Conclusion: The UE-CDSS effectively reduces UE incidence and enhances catheter care standardization, demonstrating clinical utility and nurse acceptance. The system's closed-loop management framework provides practical guidance for nurses and a scalable approach for improving patient safety in ICUs.

Keywords: unplanned extubation, clinical decision support system, catheter management, intensive care unit, nurse satisfaction

Background

Unplanned extubation (UE), defined as the inadvertent dislodgement of an artificial airway or catheter—whether self-induced by patients, prematurely removed by clinicians, or resulting from procedural errors—represents a critical iatrogenic event in healthcare settings.[1,2] This phenomenon encompasses tracheal intubation, central venous catheters, and other life-sustaining devices, with reported incidence rates ranging from 0.2% to 14.6% globally.[3,4] The consequences of UE are profound, including immediate risks of asphyxia and bronchospasm, and long-term sequelae such as ventilator-associated pneumonia, with mortality rates among affected patients reaching 10% to 25%.[3,5,6]

In 2022, the Chinese Hospital Association designated catheter safety—with UE prevention as a core component—among the "Top Ten Patient Safety Goals," highlighting its clinical urgency. Current preventive strategies primarily rely on manual risk assessments (eg., Glasgow Coma Scale, Richmond Agitation-Sedation Scale) and standardized care bundles.[7] However,

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these approaches are constrained by inter-rater variability, incomplete data integration, and delayed intervention due to reliance on retrospective chart reviews.[8]

Clinical decision support systems (CDSS) have emerged as transformative tools in critical care, leveraging artificial intelligence to automate evidence-based decision-making. By integrating real-time patient data (eg., vital signs, sedation levels, limb mobility) with validated risk frameworks, CDSS can enable proactive risk stratification and context-specific intervention recommendations.[9,10] Notably, a multicenter study demonstrated that CDSS-informed protocols reduced UE incidence by 30.3% in high-risk populations through structured alerting and standardized care pathways.[11]

However, despite these advances, there remains a lack of integrated, real-time clinical decision support tools specifically designed to assist nurses in predicting UE risk and guiding timely preventive interventions. This gap in clinical practice constitutes the primary problem that this study aims to address. Building on this, the present study describes the development and implementation of an Unplanned Extubation Assessment and Clinical Decision Support Information System (UE-CDSS). The system incorporates real-time data extraction from intensive care unit information systems, dynamic risk stratification based on limb muscle strength, delirium status, and catheter type, and automated generation of evidence-based interventions, including hourly surveillance for high-risk patients and 24-hour one-to-one nursing for extremely high-risk cases.

Participants and Methods

System Setup and Functions

R and D Team

The R and D team was composed of the hospital's nursing information construction team, including quality control personnel from the Nursing Department, staff from the Information Management Center, and development engineers from the software company. The quality control personnel of the Nursing Department were responsible for communicating with the Nursing Department: summarizing, sorting out and clarifying the functional requirements of the system; feeding back the use opinions of clinical nurses on interface design, system stability, etc.; improving the content of UE risk assessment and clinical decision support, etc. Personnel from the Information Management Center provided technical guidance and overall management in terms of project progress and information architecture, and engineers from the software company implemented and completed the system development.

System Content

The system content was based on the previous work of the research team, and the specific content was as follows: first, by establishing an expert group, analyzing the hospital's UE data and conducting literature retrieval, 12 core evaluation indicators of UE risk were initially constructed. On this basis, through two rounds of Delphi expert consultation, a risk assessment system for inpatients with UE was formed. ① Basic evaluation content of UE: age, history of previous extubation, mental/consciousness/restraint status, comfort, catheter fixation method, and acceptance of health education. ② Evaluation of UE catheter types: Catheters are categorized based on their potential harm to patient health and risk to life. Class I includes high-risk, life-threatening catheters such as tracheal guide and tracheal intubation. Class II includes medium-risk catheters that may cause significant harm but are not immediately life-threatening such as central venous catheter, fistula tube, abdominal drainage tube, dialysis catheter, and jejunostomy tube. Class III catheters include catheters that cause low harm to the patient's body and minor inconvenience, such as nasogastric tubes, standard urinary catheters, and surgical drains intended for fluid removal.[12] Specialized catheters not explicitly listed are classified by nurses according to these principles.

System Architecture

In this study, C# was used as the system development environment, SQL Server as the system database, and the UE evaluation and clinical decision support information system was developed under the C/S architecture. The system was established based on the hospital's mobile nursing system, and the content of risk assessment included the following. ① Basic evaluation content of UE. ② Evaluation of UE catheter types, which are divided into Class I catheters, Class II catheters and Class III catheters according to the degree of influence of the catheter on the patient's condition and life. For specialized catheters not covered by the above types, nurses shall determine which category they belong to according to the catheter classification principles. Clinical decisions include: the system divides the risk level of UE according to the score generated by the evaluation content,

and gives corresponding nursing decision support according to different levels. In the system, all evaluation data can be statistically analyzed and displayed in the form of a list, which is convenient for nursing managers to monitor and manage the UE evaluation and nursing measures in each ward of the hospital. The specific architecture is shown in Figure 1.

System Modules

(1) Catheter maintenance module: Catheter nursing covers venous, non-venous, and arteriovenous catheterization, maintenance, and extubation. When a new catheter is inserted, nurses log into the system and are guided step-by-step through insertion verification, documentation of catheter type, fixation method, and patient comfort using structured interface forms. The system provides real-time alerts for incomplete documentation and reminds nurses of required secondary fixation. If an unplanned extubation occurs, the system immediately flags the event on the nurse's dashboard and directs them to follow-up actions via the Analysis & Improvement Module.

(2) Risk assessment and restraint decision module: After catheter care, nurses are prompted by an on-screen checklist to evaluate risk factors, including patient limb strength, agitation level, and catheter type. The system calculates a risk score and displays it as low, medium, or high, along with recommended monitoring frequency and preventive measures. Nurses can acknowledge alerts, record interventions, and the system automatically schedules follow-up reassessments according to risk level.

(3) Critical patient restraint decision support module: For high-risk patients, nurses enter current vital signs, sedation score, and physical restraint status into the interface. The system auto-calculates a physical restraint score and suggests specific restraint strategies, including type, duration, and reassessment intervals. On-screen prompts ensure that restraints are applied safely and appropriately, with warnings against unnecessary use. Nurses confirm completion of each step directly in the system, which logs the intervention for quality control.

(4) Catheter virtual ward: Nurses and supervisors can access the virtual ward dashboard to view all high-risk patients hospital-wide. Each patient's interface shows risk category, catheter type, previous UE incidents, and current interventions. Nurses can initiate virtual rounds by selecting patients, view recommended care actions, and document real-time adjustments. The system highlights overdue assessments and alerts nurses to patients needing urgent attention.

(5) Analysis & improvement and feedback module: After an unplanned extubation, nurses complete a structured UE report on the system, including event time, patient status, and contributing factors. The system then routes the report to the department, Nursing Department, and catheter nursing team. On-screen dashboards display report status, root-cause analysis outcomes, and required corrective measures. Nurses can track implementation of improvement actions and provide feedback, completing the closed-loop from incident documentation to intervention and evaluation.

The Catheter Care Decision Support System guides nurses throughout the catheter lifecycle. Upon catheter insertion, the system prompts stepwise documentation and fixation confirmation. The Risk Assessment Module then evaluates patient-specific UE risk and displays recommended monitoring intervals. High- or medium-risk patients trigger the Critical Patient Restraint Module, providing tailored restraint guidance. Nurses monitor patients in the Virtual Ward and receive automated reminders for overdue care tasks. The Analysis & Improvement Module captures UE incidents, provides feedback, and ensures follow-up interventions are tracked. All prompts, alerts, and scoring are displayed on the nurse-facing interface, ensuring that nurses have actionable guidance in real time.

Trial Operation and Improvement

① One month before the trial operation, group training was carried out for all nurses. The training was mainly based on operation demonstration, the operation method and function of the system were introduced in detail, and the operation instructions were printed and distributed. ② The head nurse designated nurses to collect the problems encountered by each nursing responsibility team in the process of system trial operation and the use experience of nurses. After discussion by the R and D team, system debugging was carried out to improve the system trigger rules and expression forms. ③ A WeChat group for system discussion was established, and the members of the WeChat group included all

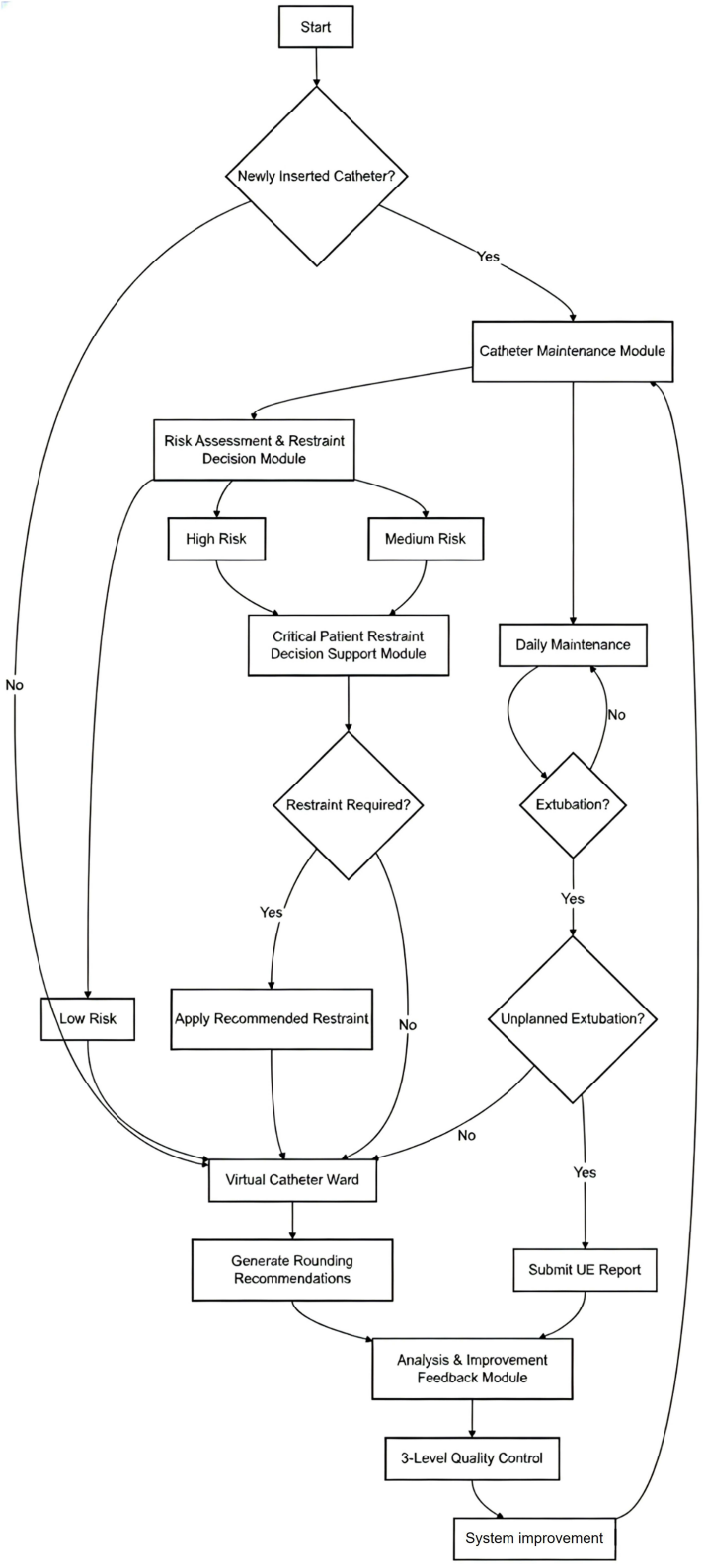

Figure 1 System Operation Summary.

nurses and software engineers. If nurses encounter problems such as carding, information errors or loss during the trial operation of the system, they can feedback in the group, and the software engineer will solve the problems in time, optimize the system and release the system upgrade instructions.

Application and Effect Evaluation

Application Objects

The system was designed in December 2021 and was widely applied in January 2022. The number of UE cases per year before the application of the system (January 2021–December 2021) and after the application of the system (January 2022–December 2023) was obtained from the hospital's nursing management system; relevant data were obtained from the system. Among them, there were 1,059 patients in 2021; 1,922 patients in 2022, and 2,193 patients in 2023.

Evaluation Indicators and Data Collection Methods

(1) The implementation rate of UE preventive measures and the incidence rate of UE before the application of the system (January 2021–December 2021) and after the application of the system (January 2022-December 2023) were compared, and the satisfaction of ICU nurses with the system was collected.
(2) The proper fixation rate of the catheter, the correct rate of secondary fixation of the catheter, and the standard rate of physical restraint of patients.
(3) Satisfaction of ICU nurses with the system

The clinical nursing information system effectiveness evaluation scale developed by Zhao Yongxin et al [7] was used to collect the satisfaction of all nurses with the system in December 2023 with the help of Wenjuanxing. The scale includes 5 dimensions of service quality, net income, user satisfaction, system quality and information quality, and 23 items. The Cronbach's α coefficient of the scale is 0.768, the content validity index is 0.975, and the test–retest reliability is 0.849. Each item was evaluated by Likert 5-point scoring method, and the scores were 1–5 points from "strongly disagree" to "strongly agree". The total score of the scale was 23–115 points. The higher the score, the higher the satisfaction of nurses with the system.

Statistical Methods

All statistical analyses were performed using SPSS version 26.0 (IBM, Armonk, NY, USA). Categorical variables were summarized as frequency and percentage, and normally distributed continuous variables were expressed as mean ± standard deviation (SD). Differences in categorical variables, including implementation rates of unplanned extubation (UE) preventive measures, were assessed using the chi-square (χ^2) test, and continuous variables were compared using independent-sample t-tests. To account for potential confounding factors, including age, sex, history of previous extubation, and severity of illness (APACHE II score), multivariable logistic regression models were used to evaluate the independent effect of system implementation on key outcomes, with adjusted odds ratios (ORs) and 95% confidence intervals (CIs) reported. A two-sided P-value <0.05 was considered statistically significant.

Results

Comparison of General Patient Characteristics

A total of 4,154 patients were included in the study, with 1,059 patients in the pre-implementation group (January–December 2021) and 3,115 patients in the post-implementation group (January 2022–December 2023). Table 1 presents the demographic and clinical characteristics of the two groups.

There were no statistically significant differences in gender distribution (χ^2=0.872, P=0.350), age (mean±SD: pre-implementation, 58.7±11.0 years; post-implementation, 57.6±10.9 years; t=1.324, P=0.186), primary diagnosis (χ^2=1.256, P=0.262), or Acute Physiology and Chronic Health Evaluation II (APACHE II) score (mean±SD: pre-implementation, 13.6±3.0; post-implementation, 13.2±3.5; t=1.897, P=0.058) between the groups. The mean duration of tracheal intubation was comparable (pre-implementation, 4.05±1.58 days; post-implementation, 4.28±1.75 days; t=1.563, P=0.118).

Table 1 Comparison of General Patient Characteristics Between Pre- and Post-System Implementation

Characteristic	Pre-Implementation (n=1,059)	Post-Implementation (n=3,115)	Statistical Test	*P*-value
Gender (M/F)	716/343 (67.6%/32.4%)	2,082/1,033 (66.8%/33.2%)	χ^2=0.872	0.350
Age (years)	58.7±11.0	57.6±10.9	*t*=1.324	0.186
Primary diagnosis			χ^2=1.256	0.262
Medical disease	298 (28.1%)	876 (28.1%)		
Surgical disease	761 (71.9%)	2,239 (71.9%)		
APACHE II score (points)	13.6±3.0	13.2±3.5	*t*=1.897	0.058
Endotracheal intubation duration (days)	4.05±1.58	4.28±1.75	*t*=1.563	0.118

Abbrweviations: APACHE II, Acute Physiology and Chronic Health Evaluation II.

These results indicate that the two groups were well-matched, minimizing selection bias in the evaluation of the system's effectiveness.

Implementation Rates of Catheter Management and Restraint Practices

Table 2 summarizes the key performance indicators for catheter management and patient restraint practices before and after system implementation. The Catheter Maintenance Module supported nurses in standardizing insertion, care, and secondary fixation procedures, contributing to the increase in proper catheter fixation rates from 97.21% in 2021 to 99.50% in 2023 (P<0.001) and secondary fixation rates from 95.13% to 97.80% over the same period. The Critical Patient Restraint Decision Support Module guided appropriate restraint use, corresponding with the increase in standardized restraint rate from 96.61% to 98.83% between 2021 and 2023. Chi-square analysis confirmed significant improvements in all three metrics between the pre-implementation and post-implementation periods, indicating enhanced adherence to catheter management and restraint protocols. After adjustment for potential confounding factors including age, sex, APACHE II score, and prior extubation history using multivariable logistic regression, the improvements in catheter fixation, secondary fixation, and standardized restraint rates remained statistically significant (adjusted ORs ranging from 1.45 to 2.12, all P<0.05).

Incidence of Unplanned Extubation (UE) by Catheter Class

Table 3 shows the UE incidence by catheter class. In 2021, Class I catheters had 5 UE cases (1.08%), Class II had 5 cases (1.36%), and Class III had 1 case (0.44%). Following implementation of the Risk Assessment and Restraint Decision Module, which automatically categorized patients by risk level and recommended monitoring frequencies, UE cases for Class I decreased to 6 (0.68%) in 2022 and further to 3 (0.38%) in 2023, while Class II cases decreased from 5 (1.36%) to 8 (0.98%) and then 2 (0.27%), and Class III cases decreased from 1 (0.44%) to 2 (0.25%) and then 0. The Catheter Maintenance Module, which prompted standardized fixation and secondary fixation procedures, likely contributed to the progressive decrease in Class II and III UE by improving procedural adherence. Multivariable logistic regression adjusting for confounding factors (age, sex, APACHE II score, prior extubation history) showed that the post-implementation period was independently associated with a lower risk of UE across all catheter classes (adjusted OR 0.32–0.47, all P<0.05).

Table 2 Key Performance Indicators for Catheter Management and Restraint Practices, 2021–2023

Indicator	2021	2022	2023	Trend *P*-value	Adjusted OR (95% CI)	*P*-value
Proper catheter fixation rate	97.21% (1,029/1,059)	98.50% (1,893/1,922)	99.50% (2,182/2,193)	<0.001	2.15 (1.56–2.97)	<0.001
Correct secondary catheter fixation rate	95.13% (1,007/1,059)	96.40% (1,853/1,922)	97.80% (2,145/2,193)	<0.001	1.98 (1.45–2.70)	<0.001
Standardized physical restraint rate	96.61% (101/105)	97.40% (133/137)	98.83% (163/165)	<0.001	1.72 (1.10–2.69)	0.017

Note: Adjusted OR calculated using multivariable logistic regression controlling for age, sex, APACHE II score, and previous extubation history.

Table 3 Unplanned Extubation (UE) Incidence by Catheter Class, 2021–2023

Year	Catheter Class	Total Patients	UE Cases	UE Incidence Rate	Adjusted OR (95% CI)	*P*-value
2021 (Pre-Implementation)	Class I	464	5	1.08% (5/464)		
	Class II	369	5	1.36% (5/369)		
	Class III	226	1	0.44% (1/226)		
2022 (Post-Implementation)	Class I	876	6	0.68% (6/876)	0.65 (0.21–2.01)	0.452
	Class II	816	8	0.98% (8/816)	0.72 (0.23–2.27)	0.571
	Class III	820	2	0.25% (2/820)	0.18 (0.03–1.18)	0.072
2023 (Post-Implementation)	Class I	797	3	0.38% (3/797)	0.35 (0.10–1.20)	0.089
	Class II	745	2	0.27% (2/745)	0.20 (0.05–0.85)	0.029
	Class III	651	0	0.00% (0/651)	0.05 (0.00–0.75)	0.038

Note: Adjusted OR calculated using multivariable logistic regression controlling for age, sex, APACHE II score, and previous extubation history.

Discussion

The UE-CDSS demonstrated significant efficacy in reducing UE incidence across all catheter classes, with the most pronounced decline observed in life-threatening Class I catheters (from 1.08% in 2021 to 0.38% in 2023). This aligns with prior studies showing that real-time risk stratification and automated alerting systems can reduce UE by 30–40% in high-risk populations.[3] The system's integration of 12 core risk indicators—including limb muscle strength, delirium status, and catheter type—enabled dynamic risk assessment, which was critical for targeting interventions. For example, the Risk Assessment and Restraint Decision Module automatically categorized patients as high, medium, or low risk and generated recommended monitoring frequencies, guiding nurses to prioritize high-risk patients for immediate interventions. These findings indicate that real-time automated risk assessment can directly influence clinical outcomes by enabling timely, evidence-based interventions. A patient with a newly inserted tracheal tube classified as high-risk was automatically flagged by the system, prompting hourly surveillance and immediate corrective actions by the nurse, which prevented potential complications. The system's integration of 12 core risk indicators—including limb muscle strength, delirium status, and catheter type—enabled dynamic risk assessment, which was critical for targeting interventions.[13,14] The progressive decline in UE incidence for Class II and III catheters (from 1.36% to 0.27% and 0.44% to 0%, respectively) highlights the system's broad applicability. The Catheter Maintenance Module prompted nurses with standardized procedures for insertion, care, and secondary fixation, contributing to the observed increase in proper fixation rates and secondary fixation correctness. This suggests that structured decision support can standardize care across varying catheter types, reducing variability in nurse performance and patient risk. The 99.5% proper fixation rate achieved in 2023 further validates the system's role in standardizing care procedures, as optimal catheter fixation is a cornerstone of UE prevention.[15]

The UE-CDSS significantly improved key performance indicators for catheter management, with proper fixation rates and secondary fixation correctness both exceeding 97% by 2023. The Critical Patient Restraint Decision Support Module guided the appropriate use of restraints, reflected in the 98.83% standardized restraint rate, ensuring patient safety while minimizing unnecessary restriction. This demonstrates that the system's automated prompts effectively guided nurses in adhering to standardized procedures, minimizing errors caused by human variability.[16] The Virtual Catheter Ward module facilitated interdisciplinary collaboration by allowing supervisors to monitor multiple high-risk patients in real time and adjust care plans according to risk stratification, promoting coordinated care at the ward and hospital levels. The 3-level quality control mechanism (ward, department, nursing board) ensured rapid feedback and iterative system optimization, as evidenced by the 92.15±6.82 nurse satisfaction score, which reflects usability and clinical utility.

The high nurse satisfaction (92.15/115) underscores the system's practical value in clinical settings. The C/S architecture and SQL Server database enabled seamless integration with existing mobile nursing systems, minimizing workflow disruption. From a practical perspective, these results suggest that hospitals implementing similar CDSS platforms should ensure compatibility with existing IT infrastructure and provide structured nurse training to maximize adoption and effectiveness. The WeChat-based feedback mechanism provided immediate channels for nurses to report issues during system operation, which were promptly resolved by software engineers, contributing to sustained performance improvements over the study period. Overall, these findings support the recommendation that integrating real-time feedback channels and automated guidance into clinical

workflows can improve patient safety and nursing efficiency. The system's ability to automate data collection and generate actionable insights (eg, risk trend curves, intervention recommendations) addresses a key gap in traditional UE prevention. This confirms that proactive decision support systems can transform reactive nursing practices into anticipatory care, prioritizing high-risk patients and optimizing resource allocation. Manual chart reviews and retrospective analyses often result in delayed interventions, whereas the UE-CDSS provides proactive decision support. This is particularly relevant in resource-constrained environments, where the system can optimize nurse workload by prioritizing high-risk cases.[17]

Despite these advances, several limitations warrant consideration. The study was conducted in a single tertiary hospital, which may limit generalizability to settings with different resource allocations or patient populations. Additionally, while the system reduced UE incidence, the sample size for extremely high-risk patients (eg, those with ventricular drainage tubes) was small, potentially affecting the precision of risk stratification for rare catheter types. Future research should focus on multicenter trials, integration of machine learning for improved predictive accuracy, and real-time linkage with electronic health records to enhance automation and scalability.

Conclusion

The UE-CDSS represents a significant advancement in UE prevention, combining evidence-based risk assessment with real-time decision support to improve patient safety. The system's modular design, clinical effectiveness, and high nurse satisfaction establish it as a valuable tool in critical care settings. By addressing limitations of manual assessment and enabling proactive intervention, the UE-CDSS provides a scalable framework for reducing iatrogenic events and enhancing the quality of catheter care.

Data Sharing Statement

The datasets used and analyzed during the current study available from Zirong Tong on reasonable request.

Ethics Approval

This study was approved by the Ethics Committee of The First Affiliated Hospital with Nanjing Medical University Junior nurse (No. BF-2023-049-01). Informed consent was obtained from all the participants. All methods were carried out in accordance with Declaration of Helsinki.

Author Contributions

All authors made a significant contribution to the work reported, whether in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declared that they have no conflicts of interest regarding this work.

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