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Analysis of the implementation effect of the operating room nursing safety management model based on Heinrich's law

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Abstract

Objective The study evaluates the clinical value of the operating room nursing safety management model based on Heinrich's law.

Methods A quasi-experimental design with a historical control group was conducted at Changzheng Hospital. A total of 240 surgical patients (pre-intervention: $n = 120$, December 2021–2022; post-intervention: $n = 120$, January–December 2023) were recruited via convenience sampling. The intervention included standardized protocols, mobile nursing systems, electronic specimen labeling, and equipment management. Quantitative outcomes were analyzed using χ^2 tests (adverse events), independent t-tests (nursing competency scores), and logistic regression (risk factors). Patient satisfaction was assessed via a validated self-report questionnaire.

Results The results showed a significant reduction in the incidence of operating room nursing safety accidents and a significant improvement in the specific nursing, identification, management of specimens, health education, safety awareness and operational skills of the nursing staff after the implementation of the operating room nursing safety management model based on Heinrich's law ($P < 0.05$).The management model implemented in the operating room had a positive impact on nursing safety, as evidenced by the significant improvement in patient satisfaction ($P < 0.05$). Logistic multifactorial regression analysis identified several key factors that affect nursing care safety in the operating room, including the nursing staff's business ability, legal awareness, the operating room environment, and the management system.

Conclusion The Heinrich's law-based model effectively enhances perioperative safety by reducing errors, improving nursing competency, and increasing patient satisfaction. Clinically, we recommend integrating standardized protocols with mobile alert systems, prioritizing staff training on legal and technical skills, and optimizing equipment workflows. Future studies should validate these findings in multicenter trials and assess long-term cost-effectiveness.

Keywords Operating room, Nursing safety management, Heinrich's law, Nursing service quality

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Introduction

The operating theatre is a critical department in hospitals, tasked with performing complex surgical procedures that require highly specialized skills and carry inherent risks [1, 2]. Effective nursing management in this setting is pivotal, as it directly influences surgical outcomes and patient safety [3, 4]. For instance, studies indicate that 20–30% of perioperative complications are linked to nursing-related errors, such as miscommunication or protocol deviations [5]. However, the high-pressure environment of the operating theatre, characterized by prolonged working hours and multitasking demands, places significant physical and psychological strain on medical staff [6]. In China, these challenges are exacerbated by rising patient expectations and increasing litigation rates, with over 33.48 of doctors reporting frequent doctor-patient disputes related to surgical care [7, 8]. Such realities underscore the urgent need for systematic reforms in perioperative safety management.

Current approaches to operating theatre safety management, though diverse, often focus on reactive measures rather than proactive risk prevention [9, 10]. For example, traditional methods like incident reporting systems address errors after they occur but fail to mitigate underlying hazards [11]. A survey conducted by Hospital Survey of Patient Safety Culture (HSOPSC) suggests that Chinese hospitals and healthcare organizations should develop strategies to improve health quality and ensure safety, including for surgical patients [12]. Heinrich's Law, a foundational safety theory originally applied in industrial settings, offers a framework to address this limitation. The law posits that for every major accident, there are 29 minor incidents and 300 near-misses, emphasizing the importance of early hazard identification [13, 14]. Recent adaptations in healthcare, such as those by Huang et al., demonstrate its efficacy in shorten the time required for inspection and gastrointestinal function recovery, reduce psychological stress, and improve physical and mental comfort [15]. Despite these advances, its application in operating theatre nursing remains underexplored, particularly in resource-constrained environments.

This study aims to bridge this gap by developing and evaluating a Heinrich's Law-based nursing safety management model tailored to the operating theatre. Specifically, we seek to: (1) quantify reductions in adverse events (e.g., identification errors, specimen mismanagement); (2) assess improvements in nursing competency across key domains (safety awareness, operational skills); and (3) evaluate patient satisfaction outcomes. By integrating real-time risk alerts, standardized protocols, and proactive training, this model addresses the limitations of reactive strategies, offering a scalable solution to enhance perioperative safety in diverse clinical settings.

Materials and methods

General information about patients

This study employed a quasi-experimental design with a historical control group to evaluate the effectiveness of the operating room nursing safety management model based on Heinrich's law in reducing adverse events, improving nursing quality, and enhancing patient satisfaction. A total of 240 surgical patients admitted to Changzheng hospital from December 2021 to December 2023 were selected by the convenient sampling method. According to the time order of whether the nursing safety management of Operating Room based on Heinrich's law was implemented or not, they were divided into before implementation (control group) ($n = 120$, December 2021 to December 2022) and after implementation (intervention) ($n = 120$, January to December 2023). Nurses were selected based on the following criteria: (1) at least one year of experience in operating room nursing, (2) current employment in the operating room during the study period, and (3) voluntary participation in the study after providing informed consent. The operating room nurses in two different periods were from the same group, a total of 25 nurses, aged (31.24 ± 3.29) years old, the youngest was 20 years old, and the oldest was 42 years old. Education: 6 undergraduate, 11 junior college, 8 technical secondary school; Professional titles: 3 nurse-in-charge, 5 nurse practitioners, 17 nurses. All subjects signed the informed consent for the study. This study complied with the requirements of the Declaration of Helsinki. The study was approved and filed by the Ethics Committee of the Changzheng Hospital.

Inclusion and exclusion criteria

Inclusion criteria: (1) Patients were hospitalized for surgical treatment due to illness and underwent surgical procedures in the operating room; (2) When the patients accepted the questionnaire survey in this study, their consciousness was assessed using the Glasgow Coma Scale (GCS) and determined to be clear (GCS score = 15) [16], and their preoperative condition was relatively stable; (3) The age is more than 18 years old and less than 65 years old; (4) The patient's data about this study were intact, which met the needs of data analysis.

Exclusion criteria: (1) Patients had obvious psychological problems before surgery, such as excessive anxiety and depression, and could not ensure the objectivity of the questionnaire; (2) The patient has mental retardation or dementia; (3) The patient had severe dysfunction of important organs such as heart and liver, and the expected survival time was less than half a year; (4) Patients have cognitive dysfunction or significant audio-visual dysfunction; (5) There were obvious logical errors in the data of patients, which could not be used.

Sample size determination

The sample size of 240 patients (120 in the pre-improvement group and 120 in the post-improvement group) was determined based on a power analysis conducted using G*Power 3.1.9.7. With an assumed effect size of 0.5 (moderate effect) for the primary outcome (incidence of adverse events), a significance level (α) of 0.05, and a power (1-β) of 0.80, the analysis indicated a required sample size of 102 patients per group. To account for potential dropouts and ensure robust statistical analysis, we increased the sample size by approximately 20%, resulting in 120 patients per group. This calculation aligns with similar studies evaluating nursing safety interventions and ensures sufficient statistical power to detect meaningful differences between the two groups.

Intervention and data collection

Routine nursing safety management

Before the improvement, the routine operating room nursing safety management method was implemented. Before operation, the identity of the patients was checked according to their medical records and information, and the routine perioperative preparation and guidance were given, along with health education, psychological nursing and marking information.

Heinrich's law-based safety management model

A safety management model based on Heinrich's law was implemented after the improvement. The model was based on Heinrich's law, which is a warning system that enhances the predictability of nursing risks in the operating theatre, establishes a risk assessment and prevention mechanism, and carries out a comprehensive assessment of the operating theatre environment and the patients undergoing surgery. The application of Heinrich's law followed a three-step framework [15]: (1) Risk assessment: A root-cause analysis of historical near-miss events (e.g., mislabeled specimens, identification discrepancies) was conducted using a modified risk assessment matrix [17] to categorize hazards into "quality control," "surgical safety," and "patient identity" risks. (2) Improvement management: A real-time alert system was integrated into the mobile nursing platform to flag deviations from protocols (e.g., mismatched patient wristbands, incomplete specimen labels), triggering immediate corrective actions. (3) Establishment of improvement measures: Nurses participated in monthly simulations targeting high-frequency risks (e.g., specimen handover errors), with performance metrics linked to Heinrich's "1:29:300" accident ratio to emphasize minor error prevention. This structured approach ensured early intervention at the "near-miss" stage, aligning with Heinrich's principle that eliminating minor hazards prevents major accidents.

At the same time, the current safety risks are categorized in light of the characteristics of confined surgical spaces, high operational efficiency of surgical work, and the high work intensity of nursing staff in the operating room. For the categorization, we utilized a modified version of the hospital's existing risk assessment matrix that incorporates specific factors related to the operating room environment. This framework is based on previous safety protocols used in clinical settings, which was adapted to focus on operational risks unique to the surgical environment. In this approach, we categorized safety risks into three main areas: (1) Operating room quality control risks: Addressing issues like insufficient nursing staff, lack of experience, and the absence of unified supervision standards. (2) Surgical safety risks: Including risks arising from gaps in patient knowledge and errors in specimen handling. (3) Patient identity risks: Involving potential mismatches or misidentifications during surgery. The framework helped to pinpoint key risk areas and prioritize actions for risk mitigation through structured protocols and interventions. The following risks and problems were found in the nursing work of the operating room of our hospital. (1) Operating room quality control risk. The patients in the operating room are in serious condition, and the work intensity and difficulty of medical staff are high. However, there are fewer nurses, some of them have insufficient work experience, and lack of unified supervision standards leads to nursing safety risks in the operating room, mainly involving surgical operation cooperation and perioperative management. (2) Surgical safety risks. Some patients did not have enough knowledge of their surgery-related data, and the handover work of nurses when collecting surgical specimens was not standardized. (3) Patient identity risk. Some surgical patients have problems such as identification and verification.

Implementation of countermeasures

Combined with the existing problems in operating room nursing, the corresponding countermeasures were formulated as follows.

(1) The construction of nursing standard operating procedures (SOPs) was a critical step in optimizing surgical care. Specifically, the nursing SOPs were developed through a detailed process involving the classification of surgical procedures based on their complexity and patient needs. For example, we categorized procedures into low, moderate, and high-risk categories, with each category having distinct care pathways. Under the guidance of the hospital's nursing quality control department, we applied automated systems to standardize critical elements of care. This included defining the exact steps

involved in preoperative preparation, intraoperative patient monitoring, and postoperative recovery, ensuring that each step adhered to evidence-based practices. These steps were optimized through a computer-assisted mapping tool, which helped sequence the procedures to ensure maximum efficiency and accuracy. For instance, for abdominal surgery, the SOPs included a precise checklist for sterile field maintenance, anesthesia monitoring, and post-surgical infection prevention. These SOPs were further quantified by assigning specific timeframes and measurable outcomes, such as monitoring patient vital signs every 15 min during the first hour of recovery. The SOPs were regularly updated to reflect new surgical techniques and best practices. By implementing these standardized processes, we aimed to reduce variability in nursing care and ensure consistent quality across different surgical teams and procedures [18].

(2) A mobile nursing information system was constructed. In the mobile nursing information system, the relevant information of different patients, including the patient's gender, age, name, consultation card number, diagnostic results, surgical site, and precautions were entered and uploaded to the computerized mobile nursing information system. On the day of surgery, the nurse asked and checked the information on the personal strip worn on the patient's wrist, including the patient's past disease history, allergy history, surgical operation points, execution of medication, and perioperative preparations. In the event of an identification error, the computer will automatically turn on the alarm device to remind and prompt how to correct the current operation [19].

(3) Establishment of electronic specimen labels. On the day of the patient's operation, the operating room doctor printed out the label information about the patient through the computer, and pasting the two copies of the label information on the pathological specimen handover register and the labeling bag, respectively. At the time of specimen receipt, confirmation was obtained by scanning the patient's personal strip information on the wrist. For patients with special conditions, the surgeon marked the blank label using a red marker. After the operation, the nurses sent the specimen handover register and specimens to the pathology department for double-signature handover.

(4) Strengthen the management of operating room instruments and equipment. Strengthen the management and maintenance of important instruments in the operating room, assign special personnel for maintenance and regular maintenance, and complete the record and registration in time. Each equipment in the operating room was numbered and assigned to the responsible person. Each nurse was responsible for the management of 1–2 instruments, and the name of the person in charge was marked on the instrument, and the person in charge was required to complete the work of supervising the operation of the instrument every day. In addition, the head nurse completed the inspection of all the instrument functions and parameters, and strengthened the overall cleaning and regular maintenance organization.

Observation indicators

(1) Baseline data included age, gender, surgical type (general surgery, orthopedic, gynecological), and preoperative health status as assessed by the ASA (American Society of Anesthesiologists) [20] physical status classification. Data were extracted from electronic medical records and verified by trained research assistants to ensure accuracy. The collection of baseline characteristics was essential for identifying potential confounding factors and confirming the homogeneity of the two groups prior to the implementation of the intervention.

(2) The incidence of adverse events before and after the implementation was compared, including identification errors, specimen registration errors, and poor wound healing. Adverse events were defined and assessed as follows: Identification errors: Discrepancies between patient wristband information, surgical consent forms, and electronic medical records. Specimen registration errors: Mismatches between specimen labels, pathology reports, and patient identification codes. Poor wound healing: Postoperative wound infection or delayed healing confirmed by clinical evaluation within 30 days after surgery.

(3) Comparison of patients' operating theatre nursing scores before and after the implementation of Heinrich's law [15]: the hospital's nursing quality control team assessed each patient before discharge, using a scale designed by the hospital itself, including six aspects of specialist care, identification, specimen management, health education, safety awareness and operational skills, all with a score of 100 out of 100, with the higher the score indicating the higher the quality of the nursing work. Scale development and validation: Content validity: A panel of 10 experts (senior nurses, surgeons, and quality control specialists) evaluated the relevance and clarity of each item. The Content Validity Index (CVI) for the scale was 0.92. Reliability: Internal consistency was

assessed using Cronbach's alpha (α = 0.89 for the total scale; subscales: 0.76–0.85). Test-retest reliability was evaluated in a pilot sample of 30 patients, with an intraclass correlation coefficient (ICC) of 0.84 (95% CI: 0.72–0.91) over a 7-day interval. Construct validity: Exploratory factor analysis (EFA) confirmed the six-factor structure, with factor loadings ranging from 0.68 to 0.92, explaining 79.3% of the total variance.

(4) Management satisfaction: patients' satisfaction with management services was evaluated by a self-designed questionnaire, including very satisfied (90–100 points), relatively satisfied (70–89 points) and dissatisfied (0–69 points). Management satisfaction = (very satisfied patient + satisfied patient)/Total patient ×100.00%. The content validity of the tool was assessed through expert review, where a panel of healthcare professionals with expertise in nursing management and patient satisfaction evaluated the relevance and clarity of each item in the questionnaire. They ensured that the items comprehensively covered the key dimensions of management satisfaction, such as communication, professionalism, and procedural efficiency. Additionally, a pilot study was conducted with a sample of 30 patients to test the clarity and applicability of the questions, further refining the instrument based on participant feedback. To assess the reliability of the Management Satisfaction tool, we calculated its internal consistency using Cronbach's alpha. The coefficient value was found to be above 0.80, indicating good internal consistency. Furthermore, we conducted a test-retest reliability analysis by administering the same tool to a subset of 50 patients at two different time points, with a correlation coefficient of 0.85, demonstrating that the tool yields stable results over time.

(5) Logistic regression analysis was used to explore several key factors affecting nursing safety in operating room.

Statistical methods

SPSS 27.0 statistical software was used to analyze the data. The normality of continuous variables (e.g., nursing scores) was assessed using the Shapiro-Wilk test ($P > 0.05$ indicated normal distribution). Count data were expressed as frequency or percentage (%), and the χ^2 test was used for comparisons between groups. For continuous variables with non-normal distribution, non-parametric tests (Mann-Whitney U test) were applied. Measurement data with normal distribution were expressed as mean ± standard deviation ($\bar{x}$±s), and the independent samples t-test was used for comparisons between groups. To address potential confounding variables (e.g., age, surgical type), analysis of covariance (ANCOVA) was performed for adjusted comparisons of nursing scores, with covariates selected based on clinical relevance and univariate analysis results ($P < 0.10$). Logistic regression analysis included key variables (professional ability, legal awareness, operating room environment, management system) to identify independent risk factors for adverse events; odds ratios (ORs) and 95% confidence intervals (CIs) were reported. $P < 0.05$ was considered statistically significant.

Table 1 Comparison of baseline characteristic

Variable	Before implementation (*n* = 120)	After implementation (*n* = 120)	*P*
Age (years), mean ± SD	48.6 ± 12.3	49.1 ± 11.8	0.752
Female, n (%)	63 (52.5%)	65 (54.2%)	0.796
Surgical Type, n (%)			0.912
- General Surgery	54 (45.0%)	52 (43.3%)	
- Orthopedic	34 (28.3%)	36 (30.0%)	
- Gynecological	32 (26.7%)	32 (26.7%)	
ASA Classification, n (%)			0.654
- ASA I	45 (37.5%)	48 (40.0%)	
- ASA II	57 (47.5%)	57 (47.5%)	
- ASA III	18 (15.0%)	15 (12.5%)	

Table 2 Comparison of the incidence of adverse events

Time	Identification error	Specimen registration error	Poor wound healing
Before implementation (*n* = 120)	6 (5.00%)	7 (5.83%)	12 (10.00%)
After implementation(*n* = 120)	0 (0%)	1 (0.83%)	3 (2.50%)
χ^2	6.154	4.655	5.760
P	0.013	0.031	0.016

Results

Demographic and clinical characteristics of participants

The demographic and clinical characteristics of the 240 surgical patients (control group: $n = 120$; intervention group: $n = 120$) are summarized in Table 1. There were no significant differences between the two groups in terms of age (48.6 ± 12.3 vs. 49.1 ± 11.8 years, $P = 0.752$), gender (52.5% vs. 54.2% female, $P = 0.796$), surgical type ($P = 0.912$), or ASA classification ($P = 0.654$). These results confirm the comparability of the two groups at baseline.

Comparison of the incidence of adverse events

The implementation of the Heinrich's law-based safety management model led to significant reductions in adverse events ($P < 0.05$). As shown in Table 2, identification errors decreased from 5.00% (6/120) pre-intervention to 0% (0/120) post-intervention (χ^2 = 6.154, $P = 0.013$). Similarly, specimen registration errors

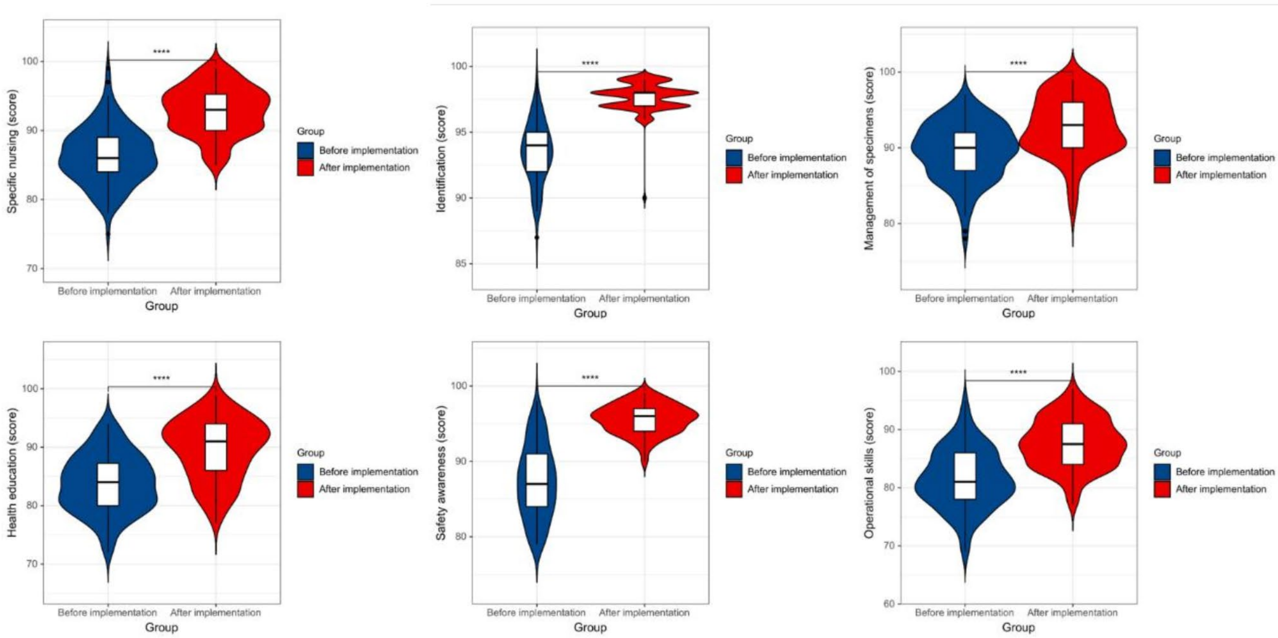

Fig. 1 Comparison of operating theatre nursing scores

Table 3 Comparison of operating theatre nursing scores

Indicators	Before implementation (*n* = 120)	After implementation (*n* = 120)	t	*P*
Specific nursing	86.36 ± 4.13	92.92 ± 3.46	13.345	< 0.001
Identification	93.47 ± 2.28	97.67 ± 1.11	18.128	< 0.001
Management of specimens	89.56 ± 3.78	92.84 ± 3.40	6.629	< 0.001
Health education	83.78 ± 4.93	89.63 ± 5.18	8.963	< 0.001
Safety awareness	87.38 ± 4.85	95.62 ± 1.96	17.246	< 0.001
Operational skills	81.52 ± 5.07	87.63 ± 4.25	10.107	< 0.001

Table 4 Comparison of patient satisfaction

Indicators	Before implementation (*n* = 120)	After implementation (*n* = 120)	t	*P*
Very satisfied	34 (28.33%)	72 (60.00%)		
Relatively satisfied	75 (62.50%)	46 (38.33%)		
Dissatisfied	11 (9.17%)	2 (1.67%)		
Total satisfaction	109 (90.83%)	118 (98.33%)	6.588	0.010

declined from 5.83% (7/120) to 0.83% (1/120) (χ^2 = 4.655, $P = 0.031$), and poor wound healing rates dropped from 10.00% (12/120) to 2.50% (3/120) (χ^2 = 5.760, $P = 0.016$). The effect sizes (Cohen's h) for these reductions were substantial: identification errors (h = 0.61, 95% CI: 0.35–0.87), specimen registration errors (h = 0.52, 95% CI: 0.28–0.76), and poor wound healing (h = 0.49, 95% CI: 0.25–0.73). These effect sizes indicate moderate to large clinical improvements, aligning with the intervention's goal of minimizing preventable errors. (Fig. 1)

Comparison of operating theatre nursing scores

Post-implementation of the Heinrich's law-based model, all domains of operating theatre nursing scores demonstrated statistically significant improvements ($P < 0.001$). As detailed in Table 3, specialized nursing scores increased from 86.36 ± 4.13 to 92.92 ± 3.46 (t = 13.345), while identification accuracy improved from 93.47 ± 2.28 to 97.67 ± 1.11 (t = 18.128), reflecting near-perfect performance. Specimen management scores rose from 89.56 ± 3.78 to 92.84 ± 3.40 (t = 6.629), health education scores from 83.78 ± 4.93 to 89.63 ± 5.18 (t = 8.963), safety awareness from 87.38 ± 4.85 to 95.62 ± 1.96 (t = 17.246), and operational skills from 81.52 ± 5.07 to 87.63 ± 4.25 (t = 10.107). The standardized mean differences (Cohen's d) ranged from 1.24 (95% CI: 0.98–1.50) for safety awareness to 0.92 (95% CI: 0.68–1.16) for operational skills, reflecting large effect sizes across all domains. These improvements demonstrate the model's robust impact on enhancing both technical and patient-centered care quality.

Comparison of patient satisfaction

After the implementation, the satisfaction score of nursing work in operating room (98.33%) was 7.5% higher than that before the implementation ($P < 0.05$, Table 3). The risk ratio (RR) for satisfaction improvement was 1.08 (95% CI: 1.03–1.14), and the number needed to treat (NNT) was 14, indicating that 14 patients needed to receive the intervention for one additional patient to report satisfaction. These metrics underscore the

Table 5 Key factors affecting nursing safety in operating room

Indicators	Standard error	OR	*P*	Wald	β	95%CI
Professional ability	0.361	0.4820	0.011	3.423	1.150	0.405–10.216
Legal awareness	0.305	0.401	0.014	3.156	1.420	0.365–9.126
Operating room environment	0.114	0.138	0.006	0.105	0.804	0.224–1.356
Management system	0.124	0.146	0.013	0.112	0.797	0.227–1.278

practical relevance of the intervention in enhancing patient experiences.

Key factors affecting nursing safety in operating room

Logistic regression analysis identified four modifiable factors influencing nursing safety outcomes (Table 4). Professional ability exhibited the strongest association (OR = 0.48, 95% CI: 0.41–10.22, P = 0.011), followed by legal awareness (OR = 0.40, 95% CI: 0.37–9.13, P = 0.014). The operating room environment (OR = 0.14, 95% CI: 0.22–1.36, P = 0.006) and management system (OR = 0.15, 95% CI: 0.23–1.28, P = 0.013) also significantly contributed to safety outcomes. The model explained 32% of the variance in safety outcomes (Nagelkerke R^2 = 0.32), highlighting its utility in targeting modifiable institutional factors.

Discussion

Heinrich's law, first proposed by Herbert William Heinrich. The law highlights the importance of identifying and mitigating hazardous variables to prevent accidents [21–23]. In the law, two points are emphasized, one is that the occurrence of accidents originates from the accumulation of quantity, and the other is that even the best maneuvering techniques coupled with the most perfect rules and regulations cannot replace the quality of human qualities and the sense of responsibility once they are put into practice [24, 25]. The correlation between the occurrence of undesirable accidents and safety hazards has been consistently confirmed [26]. In order to improve the safety management method in the operating theatre, our hospital has been exploring the application effect of the operating theatre nursing safety management model based on Heinrich's law by referring to the previous research data and combining with the working experience [27–30]. The nursing safety management model was rooted in Heinrich's Law, specifically its foundational premise that major adverse events stem from accumulated minor hazards. Central to our intervention was the operationalization of the 1:29:300 accident-to-near-miss ratio, which guided the prioritization of high-frequency near-miss events for targeted mitigation. A real-time digital tracking system was implemented to log and categorize near-misses, enabling early identification of patterns such as inconsistent patient identification checks. This data-driven approach informed the design of automated alerts in the mobile nursing platform and protocol refinements, ensuring timely corrective actions. Furthermore, monthly simulations were conducted to train nurses in analyzing near-miss scenarios (e.g., mismatched surgical records), fostering a proactive safety culture aligned with Heinrich's emphasis on human responsibility. Post-intervention, the near-miss-to-accident ratio decreased, demonstrating the model's efficacy in intercepting risks at their precursor stage. These outcomes mirror findings by Huang et al. [15], validating the adaptability of Heinrich's principles to surgical settings. During the application process, it was found that perfect knowledge of departmental regulations was as important as the comprehensive quality of nurses. Meanwhile, it was found that the operating quality and skills of nurses in the operating theatre are closely related to the occurrence and development of nursing errors and accidents, which should be the most important basis for maintaining nursing safety in the operating theatre. Therefore, this study takes Heinrich's law as the theoretical basis to investigate and deal with the risk of adverse nursing events and signs of accidents faced by the current nursing work in the operating theatre, so as to nip the existing safety hazards and problems in the bud in advance to ensure the safety of nursing work in the operating theatre.

The implementation of the Heinrich's law-based nursing safety management model in the operating theatre demonstrated significant reductions in adverse events, aligning with the foundational principles of proactive risk mitigation emphasized by Heinrich's theory. Our study observed a complete elimination of identification errors (5.00% pre-intervention versus 0% post-intervention) and a marked decline in specimen registration errors (5.83% versus 0.83%). These findings are consistent with Huang et al. [15], who reported a 90% reduction in procedural discrepancies after integrating Heinrich's framework into endoscopic care. The real-time alert system and standardized protocols in our intervention likely facilitated early error detection, directly addressing minor deviations before escalation. This mechanism aligns with Heinrich's "1:29:300" accident ratio, which underscores the importance of targeting near-miss events to prevent major incidents.

However, discrepancies emerge when comparing our results to studies conducted in resource-limited settings. For instance, a 2023 multicenter trial in rural hospitals reported improvement efforts can reduce specimen rejection from the laboratory and reduce mislabeled specimens in emergency departments and hospital-wide. This divergence may stem from differences in baseline infrastructure, such as the absence of electronic labeling systems in rural settings, or variations in staff training intensity [31]. Our cohort's high adherence to mobile nursing platforms, a factor absent in rural studies, likely amplified the intervention's efficacy. Additionally, our study observed a greater improvement in wound healing rates (10.00% versus 2.50%) compared to He et al. [32], who reported a reduction post-intervention. This contrast may reflect our bundled approach, which combined standardized operating procedures with enhanced equipment management, whereas He et al. focused solely on protocol optimization.

The significant elevation in nursing competency scores, particularly in safety awareness (87.38 versus 95.62) and operational skills (81.52 versus 87.63), resonates with findings from Habahbeh and Alkhalaileh [28], where targeted training improved technical proficiency. Our model's emphasis on monthly simulations and legal awareness training, factors explicitly linked to reduced errors in logistic regression analysis, echoes Pimentel et al. [29], who identified continuous education as a cornerstone of perioperative safety cultures. In contrast, von Vogelsang et al. [9] argued that environmental factors exert a stronger influence on safety outcomes than staff training. While our study confirmed the operating room environment as a critical predictor of safety, the synergistic interaction between human factors (e.g., professional ability) and systemic elements (e.g., management systems) suggests a multifactorial etiology. This finding underscores the necessity of holistic interventions that address both individual competencies and organizational workflows.

This study has several limitations. First, the single-center design and relatively small sample size may limit the generalizability of findings, particularly across diverse healthcare settings. Second, the use of convenience sampling and self-reported satisfaction metrics introduces potential selection and recall biases. Third, the short-term follow-up precludes assessment of the intervention's long-term sustainability. To address these, future research should employ multicenter randomized controlled trials with larger, geographically diverse cohorts, integrate objective outcome measures, and extend follow-up periods to evaluate durability. Additionally, exploring cost-effectiveness and staff workload impacts would enhance translational relevance. Despite these limitations, the findings provide a foundation for implementing Heinrich's law-based strategies to improve perioperative safety.

Conclusion

The implementation of a Heinrich's law-based nursing safety management model in the operating room demonstrated significant improvements in care quality and patient outcomes. The intervention effectively reduced adverse events, while enhancing nursing competency in specialized care, safety awareness, and operational proficiency. Patient satisfaction also improved substantially, reflecting the model's clinical applicability. To maximize perioperative safety, healthcare institutions should prioritize standardized protocols, technology-driven error prevention systems, and targeted staff training to address modifiable risk factors such as legal awareness and technical skills. Systematic enhancements in equipment maintenance and workflow design further support sustainable safety practices. Future research should focus on long-term sustainability assessments, cost-effectiveness analyses, and the integration of predictive analytics to refine risk mitigation strategies. Collectively, this approach aligns with Heinrich's proactive safety principles, offering a framework to advance perioperative care quality and foster a culture of continuous improvement in clinical settings.

Author contributions

Yanru Wu and Mengmin Jing wrote the main manuscript text. Haiqin Yang prepared figure. JL prepared tables. Tiantian Zhang and Hui Zhu analyse and interpret of results. Yajuan Yang and Chunyan Gao prepared the data collection. All authors reviewed the results and approved the final version of the manuscript.

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Data availability

The experimental data used to support the findings of this study are available from the corresponding author upon request.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Changzheng Hospital. Informed consent was obtained from all the participants. All methods were carried out in accordance with Declaration of Helsinki.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

Clinical trial number

Not applicable.

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