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An AI-Assisted Traceability System for Risk Alerting and Efficiency Enhancement in the Central Sterile Supply Department: A Self-Controlled Study

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ABSTRACT: Objective This study evaluated the effectiveness of an AI-assisted information traceability system in risk early warning for nursing quality and operational efficiency assessment in the Central Sterile Supply Department (CSSD), providing evidence-based support for the intelligent and refined management of the CSSD. **Methods** A self-controlled study was conducted in the CSSD of a Grade A tertiary hospital. The control phase (January to June 2025) employed the conventional barcode-based traceability system, whereas the observation phase (July to December 2025) utilized the AI-assisted information traceability system. In the control group, the management model comprised process recording, manual spot-check quality control, and manual statistical efficiency management. For the observation group, AI modules were developed based on the existing traceability system, incorporating four core functional modules: full-process data collection, three-tier risk early warning, dynamic efficiency evaluation, and closed-loop rectification. The two groups were compared across nursing quality and risk control indicators, operational efficiency indicators, and nursing staff work experience indicators. All statistical analyses were performed using SPSS 26.0 software. **Results** In the observation group, the qualified rates for instrument cleaning, packaging, sterilization, and risk early warning accuracy were 99.94%, 99.97%, 99.99%, and 98.62%, respectively, outperforming the control group (99.71%, 99.78%, 99.83%, and 82.15%). The incidence rates of quality defects, adverse events, and healthcare-associated infection (HAI) related events in the observation group were 0.07%, 0.03%, and 0, respectively, which were lower than controls (0.32%, 0.18%, and 0.11%) (all $P<0.05$). The average instrument turnaround time, emergency item processing time, and daily manual verification time in the observation group were 16.58 ± 2.37 h, 1.21 ± 0.32 h, and 0.85 ± 0.21 h, respectively, all significantly shorter than the corresponding values in the control group (22.43 ± 3.26 h, 2.64 ± 0.57 h, and 4.12 ± 0.75 h). The instrument reuse rate, equipment utilization rate, and completeness rate of traceability information were also significantly higher in the observation group than in the control group (all $P<0.05$). Furthermore, nursing staff in the observation group reported significantly higher satisfaction with work efficiency and system use, along with a significantly lower risk management pressure score, compared with the control group (all $P<0.05$). **Conclusion** The AI-assisted information traceability system enables pre-event alerting, real-time interception, and post-event traceability for risks throughout the entire workflow in the CSSD. The AI-assisted system significantly enhanced nursing quality and safety, and reduced HAI risk. Furthermore, it facilitates dynamic and refined evaluation and optimization of departmental operational efficiency, alleviates the workload of nursing staff, and meets the requirements of smart hospital construction and high-quality nursing development. Collectively, these findings support the system's substantial potential for clinical translation and broad applicability.

KEY WORDS: Central Sterile Supply Department (CSSD); Artificial Intelligence (AI); Information Traceability System; Risk Early Warning; Efficiency Evaluation; Nursing Quality

The Central Sterile Supply Department (CSSD) is tasked with managing the full lifecycle of reusable medical instruments and acts as the primary defense against healthcare-associated infection (HAI) in hospitals. The Chinese industry standard series *Central Sterile Supply Department* (WS310) mandates that CSSDs implement full-process closed-loop traceability for instruments, and information system development has accordingly become a core indicator for hospital accreditation and smart hospital initiatives[1-2]. With the sustained increase in surgical volume, the limitations of conventional traceability systems have become increasingly evident[3]: risk control remains reactive, which offers only post-hoc documentation without early warning or real-time interception; efficiency management relies on manual statistics, which precludes refined assessment[4]; and data are underutilized, with large volumes of information failing to inform quality improvement[5]. In recent years, artificial intelligence (AI) has been increasingly adopted in nursing quality management and HAI prevention and control, offering unique strengths in mining large-scale datasets, identifying anomalous patterns, and supporting trend prediction and early warning[6]. While previous studies have indicated that information technology can enhance the quality and efficiency of instrument processing, empirical investigations that thoroughly integrate information technology with traceability systems, and that simultaneously address both full-chain risk early warning and operational efficiency evaluation, remain limited[7-9]. Accordingly, the present study, grounded in the specific characteristics of CSSD practice and relevant industry standards, developed an AI-assisted information traceability system and evaluated its effects on nursing quality risk early warning and operational efficiency, intending to provide empirical evidence to support the intelligent and refined management of CSSD.

1 Materials and Methods

1.1 Study design

This study employed a self-controlled before-and-after design. In the control phase (January to June 2025), the conventional barcode-based traceability system was used, whereas in the observation phase (July to December 2025), the AI-assisted information traceability system was implemented. Baseline characteristics, including CSSD staffing, core equipment, instrument processing categories, and hospital-wide surgical volume, did not differ significantly between the two phases, ensuring comparability.

1.2 Study subjects

1.2.1 Instrument inclusion criteria

All reusable medical instruments processed by the hospital's CSSD during the study period were included, covering general surgical instruments, endoscopic instruments, external orthopedic instruments, implantable devices, and Da Vinci surgical instruments. Single-use sterile items were excluded. A total of 128,642 instrument packages were processed in the control phase, and 131,258 in the observation phase.

1.2.2 Personnel inclusion and exclusion criteria

Staff were included if they met the following inclusion criteria: current employment in the CSSD with valid certification as nursing professionals or sterilizer operators, at least one year of work experience in CSSD, and voluntary participation in the study. Exclusion criteria comprised trainees, interns, or rotational personnel during the study period, as well as staff with cumulative leave exceeding one month. Ultimately, 25 staff members were enrolled, including eighteen specialized nurses and seven certified sterilizer operators. The ages ranged from 28 to 52 years, with a mean of 38.62±6.15 years; work experience spanned 3 to 28 years, averaging 15.24±7.33 years. In terms of educational background, 22 staff held a bachelor's degree or higher, while three held an associate's degree. The professional hierarchy comprised one chief nurse, six associate chief nurses, eleven supervisor nurses, and seven primary nurses.

1.3 Interventions

1.3.1 Control group (traditional barcode traceability)

The hospital's existing fixed barcode traceability system was used, in which each instrument package was assigned a unique barcode. This system

enabled only barcode scanning for information recording and post-event traceability at six core nodes: retrieval, cleaning, packaging, sterilization, distribution, and clinical use.

For quality control, a combined approach of per-shift manual spot-checks, weekly comprehensive quality inspections, and monthly adverse event reviews was adopted. Specifically, each shift conducted a 5% spot-check of instrument cleaning and packaging quality; weekly full-process quality audits were performed; and monthly, adverse events were manually summarized, and corrective actions were formulated. All procedures strictly adhered to the standard series WS310—2016.

For efficiency management, designated staff manually compiled statistics at the end of each month on instrument turnaround time, qualification rates, equipment operating time, and other relevant metrics. The data were summarized and analyzed using Excel spreadsheets, and decisions regarding staffing schedules, equipment deployment, and instrument allocation were made based on experiential knowledge.

1.3.2 Observation group (AI-assisted traceability)

Built upon the existing hardware infrastructure of the traditional traceability system, AI-assisted core modules were developed and seamlessly integrated via the Internet of Things (IoT) with the hospital information system (HIS), the surgical anesthesia system, washer-disinfectors, and vacuum steam sterilizers. Specialized QR code labels, engineered to withstand extreme temperatures and corrosive chemicals, were employed to assign unique identifiers to individual instruments and instrument packages throughout their entire lifecycle. The system comprised the following four core functional modules:

1. Full-Process Closed-Loop Data Collection Module

This module enabled real-time acquisition of core operational data through IoT devices, encompassing the contamination level of retrieved instruments, washer-disinfector operating parameters (temperature, time, and enzyme concentration), sterilizer parameters (temperature, pressure, and sterilization duration), packaging material expiration dates, operator qualifications and operating times, clinical distribution details and using departments, and patient information. All data were rendered tamper-proof and fully traceable within a closed-loop system, establishing a complete chain of "patient → surgery → instrument → processing procedure → patient"[8].

2. AI-Based Three-Tier Risk Early Warning Module

A risk early warning indicator system was constructed based on the following three sources: historical quality defect data from the CSSD over the preceding three years, the standard series (WS310—2016), and expert consultation involving five senior nursing experts and two infection control specialists. The system covers five dimensions (human, machine, material, method, and environment) and incorporates 18 warning variables. Core variables for each dimension are as follows: human dimension includes operator qualification validity, prolonged continuous work duration, and historical error rate; machine dimension comprises washer-disinfector temperature and time fluctuations, sterilizer Bowie-Dick test results, sterilization parameters, and remaining equipment maintenance cycle; material dimension covers instrument package expiration date, residual enzyme solution and lubricant volumes, and packaging material barrier performance test values; method dimension encompasses time interval from instrument retrieval to cleaning, deviation index of emergency item processing from standard procedures, average daily manual verification time, packaging seal integrity rate, and sterilization qualification rate; and environment dimension includes pressure differentials across zones, temperature and humidity levels, and biological monitoring indicators.

Tiered early warning thresholds were established using a combination of the percentile method and expert-defined thresholding, with risk levels classified into Yellow, Orange, and Red tiers. (1) Yellow level (attention warning) is triggered when a single variable exceeds its normal range by 10% to 20%, or when the predicted surgical volume increase over the next seven days is ≥15%; upon activation, the system automatically displays a pop-up prompt for the responsible nurse to increase vigilance. (2) Or-

ange level (intervention warning) is triggered when critical variables exceed predefined standards (e.g., sterilization temperature fluctuation >2 ℃, or instrument cleaning residue at ≥3 sites), or when the combined risk probability calculated by the logistic regression model reaches ≥30%; the system then locks the relevant instrument packages and pushes rectification tasks to the team leader. (3) Red level (release prohibition) is triggered when equipment parameters show severe deviations (e.g., sterilization temperature falls below the lower limit or exceeds the upper limit by ≥3 ℃), biological monitoring returns a positive result, or instrument functional integrity is compromised; upon activation, the entire batch of instruments is mandatorily intercepted, with simultaneous reporting to the head nurse and the HAI Prevention and Control Department, along with initiation of emergency response protocols.

The system implements active prevention and control across the entire workflow through three distinct mechanisms. (1) Pre-event early warning employs an LSTM-based time series algorithm to predict surgical volume peaks (providing staffing alerts seven days in advance), alongside automated monitoring and early warning for instrument expiration dates (three days in advance), consumable inventory safety thresholds, sterilization equipment maintenance cycles (seven days in advance), and operator qualification validity periods. (2) In-event interception utilizes an AI-powered visual quality inspection system[10] supplemented by periodic spot-check ATP monitoring; high-definition industrial cameras perform 100% full inspection of cleaned instruments, automatically detecting blood stains, residual soil, instrument defects, and joint jamming, with non-conforming instruments automatically locked and prevented from entering the packaging stage. Concurrently, real-time monitoring of cleaning and sterilization equipment operating parameters is conducted with automatic alarms and batch locking triggered when parameters deviate from specifications. (3) Post-event traceability and trend prediction apply the LSTM algorithm for in-depth analysis of historical quality defect data to identify high-risk workflow segments, instrument categories, and time periods, enabling advanced issuance of risk alerts and formulation of preemptive prevention strategies[7].

Model Dynamic Optimization: The model undergoes joint training using logistic regression (for risk probability estimation) and LSTM (for time series forecasting). Threshold parameters and algorithm weights are optimized quarterly based on newly accumulated quality data, ensuring continuous refinement of risk identification accuracy.

3. AI Multidimensional Efficiency Evaluation Module

An efficiency evaluation indicator system tailored to the specific characteristics of CSSD operations was established. The AI system automatically performs real-time statistical analysis of key metrics, including time consumed at each stage of the instrument turnover process, timeliness of emergency item processing, instrument re-washing rate, equipment utilization rate, staff workload, instrument reuse rate, and consumable costs. The system also generates dynamic visual management dashboards that intelligently flag process bottlenecks, thereby providing evidence-based support for managerial decision-making within the department.

4. PDCA-Based Rectification Module

For risk events and efficiency bottlenecks identified by AI alerts, the system automatically generates rectification task orders, assigns them to the responsible staff members, and specifies clear deadlines and requirements. Upon completion of the rectification, the responsible personnel upload supporting documentation for review and verification by quality control staff. Tasks that remain unaddressed past the deadline are automatically escalated to the head nurse. The entire rectification process is continuously tracked, thereby forming a complete closed loop comprising early warning, rectification, verification, review, and optimization.

Before the intervention, all participating researchers underwent a two-week systematic training program covering the operation of the AI-assisted traceability system, risk warning response procedures, the use and interpretation of efficiency dash-

boards, and closed-loop rectification protocols. Following the training, both theoretical and practical assessments were administered, with all participants achieving a 100% pass rate.

1.4 System implementation and transformation costs

The AI-assisted information traceability system implemented in this study was jointly developed by the hospital's IT Department and a third-party technology company. The primary costs associated with the system are summarized as follows. Software research and development and licensing, covering the AI algorithm modules, visual recognition system, and data dashboard, which included a three-year maintenance plan, amounted to CNY 138,000. Hardware renovation and IoT integration involved the installation of eight industrial high-definition cameras (totaling CNY 27,000) and interface development with the HIS, surgical anesthesia system, washer-disinfectors, and sterilizers, with the interface fee amounting to CNY 25,000. In addition, legacy system renovation required structural optimization of the existing barcode traceability system database and the addition of unstructured data storage fields, which entailed a two-week renovation period for CNY 12,000.

During the rollout of the AI-assisted system, two major implementation challenges were encountered and subsequently addressed through targeted measures.

First, some senior nursing staff initially exhibited resistance to the new system, particularly expressing apprehension regarding the "mandatory interception" function of the AI visual full-inspection feature. To mitigate this, staged scenario-based simulation training was conducted in three rounds, each lasting two hours. In addition, a rotating "System Experience Officer" position was established to facilitate peer support and hands-on familiarization. Furthermore, a manual verification buffer mechanism was implemented during the initial two-week period, allowing nurses to apply for manual exemption in cases of suspected system misjudgment. These measures collectively reduced operational anxiety and facilitated smoother adoption.

Second, we observed intermittent data transmission delays with the washer-disinfectors, which occasionally disrupted real-time connectivity. To resolve this, edge computing gateways were deployed, and local cache queues were added to the system architecture. In the event of network disconnection, data were temporarily stored on the device side and automatically re-transmitted once connectivity was restored, ensuring complete data integrity with zero loss.

1.5 Outcome measures

1.5.1 Nursing quality and risk control indicators

The indicators encompassed instrument cleaning qualification, packaging qualification, sterilization qualification, risk early warning accuracy, quality defect incidence, adverse event incidence, and instrument-related surgical site infection incidence. All indicators were evaluated against the *Central Sterile Supply Department (CSSD) - Part 2: Standard for operating procedure of cleaning, disinfection and sterilization* (WS 310.2—2016). The risk early warning accuracy rate was calculated as: Risk early warning accuracy rate = (number of AI warnings confirmed as risk events upon manual verification / total number of AI warnings)×100%.

1.5.2 Operational efficiency indicators

Operational efficiency metrics comprised average instrument turnaround time (defined as the total interval from clinical retrieval to sterile release), average emergency item processing time, average daily manual verification time, instrument reuse rate, average equipment utilization rate, and traceability information completeness rate.

1.5.3 Nursing staff work experience indicators

Work experience was evaluated using a self-developed questionnaire specifically designed for CSSD nursing staff. The instrument was reviewed and revised by three CSSD experts (one chief nurse and two associate chief nurses) and demonstrated a content validity index of 0.92 and a Cronbach's α coefficient of 0.87, indicating satisfactory reliability and validity. The questionnaire comprised two dimensions: work efficiency satisfaction and system use satisfaction, each scored on a 10-point scale, with higher scores reflecting greater satisfaction; and a

risk management pressure score, also on a 10-point scale, with higher scores indicating higher perceived work pressure. Questionnaires were distributed at the end of both study phases, yielding a 100% effective response rate.

1.6 Statistical analysis

Statistical analyses were conducted using SPSS version 26.0. Continuous data following a normal distribution were presented as mean ± standard deviation ($\overline{X}$±s), and inter-group comparisons were performed using the independent-samples *t*-test. Categorical data were expressed as rates (%) or per mille (‰), with inter-group differences examined by the chi-square (x^2) test. A significance level of α=0.05 was set, and P<0.05 was considered statistically significant.

2 Results

2.1 Baseline data comparison

No statistically significant differences were found between the control and observation phases in baseline characteristics, including total CSSD instrument processing volume, hospital-wide surgical volume, staffing, and core equipment (all P>0.05), indicating comparability between the two periods. Detailed baseline data are provided in Table 1.

2.2 Comparison of nursing quality and risk control indicators

In the observation group, the qualified rates for instrument cleaning, packaging, sterilization, and risk early warning accuracy were significantly higher, whereas the incidence rates of quality defects, adverse events, and instrument-related surgical site infections were significantly lower, compared with the control group (all P<0.05). Detailed data are presented in Table 2.

2.3 Comparison of operational efficiency indicators

The observation group had significantly shorter mean instrument turnaround time, emergency item processing time, and daily manual verification time, as well as significantly higher instrument reuse rate, equipment utilization rate, and traceability information completeness rate, compared with the control group (all P<0.05). Detailed data are presented in Table 3.

2.4 Comparison of nursing staff work experience indicators

Compared with the control group, the observation group reported significantly higher satisfaction with work efficiency and system usability, and significantly lower perceived risk-management pressure (all P<0.05). Detailed data are presented in Table 4.

3 Discussion

3.1 AI-assisted system upgrades risk prevention and control

HAI prevention is the cornerstone of CSSD safety. The standard series (WS310—2016) explicitly

Table 1 Baseline Data Comparison between the Two Groups

Indicator	Control Group (January–June 2025)	Observation Group (July–December 2025)	χ^2 Value	*P* Value
Total instrument packages	128 642	131 258	0. 274	0. 601
Total hospital-wide surgical procedures	18 624	19 037	0. 452	0. 501
Number of nursing staff	25	25	—	—
Core equipment	5 washer-disinfectors, 8 sterilizers	5 washer-disinfectors, 8 sterilizers	—	—

Table 2 Comparison of Nursing Quality and Risk Control Indicators between the Two Groups

Indicator	Control Group (*n*=128,642)	Observation Group (*n*=131,258)	χ^2 Value	*P* Value
Cleaning qualification (%)	99. 71	99. 94	128. 362	<0. 001
Packaging qualification (%)	99. 78	99. 97	87. 645	<0. 001
Sterilization qualification (%)	99. 83	99. 99	62. 317	<0. 001
Risk early warning accuracy (%)	82. 15	98. 62	156. 284	<0. 001
Quality defect incidence (%)	0. 32	0. 07	112. 473	<0. 001
Adverse event incidence (‰)	0. 18	0. 03	7. 862	0. 005
Instrument-related SSI incidence (‰)	0. 11	0	5. 874	0. 015

Table 3 Comparison of Operational Efficiency Indicators between the Two Groups

Indicator	Control Group (n=128,642)	Observation Group (n=131,258)	t/χ^2 Value	P Value
Average instrument turnaround time (h)	22. 43±3. 26	16. 58±2. 37	48. 623	<0. 001
Average emergency item processing time (h)	2. 64±0. 57	1. 21±0. 32	52. 174	<0. 001
Average daily manual verification time (h)	4. 12±0. 75	0. 85±0. 21	41. 386	<0. 001
Instrument reuse (%)	89. 26	96. 74	78. 625	<0. 001
Average equipment utilization (%)	72. 38	88. 62	65. 374	<0. 001
Traceability information completeness (%)	98. 23	100	42. 156	<0. 001

Table 4 Comparison of Nursing Staff Work Experience Indicators between the Two Groups (scores, $\bar{x}\pm s$)

Indicator	Control Group (n=18)	Observation Group (n=18)	t Value	P Value
Work efficiency satisfaction	6. 23±1. 12	8. 76±0. 85	7. 623	<0. 001
System use satisfaction	6. 58±1. 03	8. 92±0. 76	7. 845	<0. 001
Risk management pressure score	7. 85±1. 03	4. 12±0. 96	10. 627	<0. 001

mandates a risk prevention and control mechanism that covers the entire reprocessing workflow. Traditional barcode-based traceability systems, however, are limited to process recording and post-event traceability; risk prevention and control rely largely on manual spot-checking, which results in limited coverage and a substantial risk of missed detection[3]. In the present study, we found that following the implementation of the information-assisted traceability system in the observation group, the qualified rates for instrument cleaning, packaging, and sterilization all rose to above 99.9%, the risk early warning accuracy rate increased from 82.15% to 98.62%, and the incidences of quality defects, adverse events, and instrument-related surgical site infections all decreased significantly. These findings are consistent with previous reports[8-10].

This system fundamentally replaces the traditional reactive prevention and control approach through its three-tier risk early warning model. Pre-event alerts are generated based on expiration dates, equipment status, and staffing levels, enabling proactive risk avoidance at the source. Intra-process interception, supported by full visual inspection and real-time monitoring of equipment parameters, ensures the capture of non-conforming items at every step, thereby reducing missed detection[10]. Post-process trend prediction, achieved through data mining, identifies potential risk points and shifts the prevention threshold further upstream. Similarly, Zhang et al. [7] confirmed that intelligent tracking modules can reduce both false alarm rates and delays for emergency items. This proactive, full-process risk prevention and control model aligns with the principles of precision infection prevention and contributes to a strengthened patient safety framework. The successful deployment of the system hinged on the precise specification of 18 risk variables, the evidence-based calibration of three-tier warning thresholds, and the effective resolution of practical challenges, including label durability and staff adaptation during the initial rollout. Although the upfront investment was approximately CNY 202,000, cost savings were realized within six months—primarily through reduced adverse event-related losses and improved instrument turnover efficiency—affirming both the clinical utility and economic feasibility of the system.

3.2 AI-assisted system promotes refined efficiency management

As public hospitals pursue quality-driven transformation, the CSSD has emerged as a critical node in both hospital operations and cost containment[4]. Traditional efficiency management, which relies heavily on manual data compilation and experience-based decision-making, is hampered by data latency, impeding timely identification of process bottlenecks and frequently results in prolonged instrument turnaround, suboptimal equipment utilization, and substandard staffing allocation[5]. In the observation group, after implementation of the information-assisted traceability system, the average instrument

turnaround time reduced by nearly 6 hours, emergency item processing time was shortened by more than 50%, the average daily manual verification time dropped from 4.12 hours to 0.85 hours, and both the instrument reuse rate and equipment utilization rate improved substantially.

Through its multidimensional efficiency evaluation module, the system enables real-time data collection, automated statistical processing, and intelligent analytical capabilities for departmental operational metrics, thereby relieving management staff from cumbersome manual record-keeping and computation. The visual management dashboard can pinpoint process bottlenecks with precision, offering evidence-based guidance for staff scheduling, equipment deployment, and instrument allocation, effectively shifting decision-making away from traditional experience-based management[4]. In addition, the reduction in instrument turnaround time contributes to improved satisfaction among clinical departments, enhanced reuse rates of high-value instruments, lower procurement expenditures, and stronger support for refined hospital operations[8].

3.3 AI-assisted system empowers nursing staff

CSSD nursing staff have been tasked with repetitive, labor-intensive duties while confronting considerable pressure related to HAI prevention and control, contributing to a high burnout rate[11]. Under traditional management models, they spend a large portion of their time on manual verification, data entry, and other clerical tasks, which leaves limited time for specialty-focused quality control and improvement activities and ultimately undermines their sense of professional value[12]. Following the implementation of the information-assisted traceability system, the present study observed marked improvements in nursing staff satisfaction with both work efficiency and system usability, alongside a notable decrease in perceived risk management pressure. The system supplants a considerable volume of repetitive and mechanized tasks, thereby alleviating both the physical workload and psychological strain on staff. Furthermore, the closed-loop quality control model reduces the likelihood of human error, freeing nursing personnel to dedicate greater attention to higher-value professional activities, including precision instrument processing, external instrument review, specialized training, and continuous quality improvement, thus fully capitalizing on the expertise of specialized nurses and bolstering their professional identity and sense of accomplishment[11]. Fan et al.[12] have emphasized that efforts to enhance professional value perception should prioritize key population groups and incorporate humanized management practices; the implementation of this system offers a technological foundation for achieving that objective.

The AI-assisted information traceability system enables pre-event alerting, real-time interception, and post-event traceability for risks throughout the entire CSSD workflow. It substantially enhances nursing quality control, improves early risk-warning accuracy, and reduces the occurrence of adverse events and instrument-related surgical site infections. Additionally, the system effectively shortens instrument turnaround time, boosts departmental operational efficiency, alleviates nursing staff workload, and improves both job satisfaction and professional identity. However, several limitations should be acknowledged. This was a single-center study, and the generalizability of our findings may be limited by variations in hospital resources and practices across regions, given the single-center design. Future research could further extend the system's functionalities to achieve deeper integration with hospital-wide smart infection prevention platforms and enable linkage and joint analysis of instrument processing data with surgical site infection data to construct more robust predictive models. Moreover, the system's applications could be broadened to encompass cost control, consumable management, and staff training, thereby building a comprehensive, multidimensional smart management system for the CSSD and offering stronger support for high-quality hospital development.

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