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Article

Application of Tiered Training Model in Personnel Management of the Central Sterile Supply Department: A Retrospective Controlled Study

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Abstract

Aims/Background: The Central Sterile Supply Department (CSSD) is a critical component of hospital infection control, and the quality of its work directly impacts patient safety. Given that traditional training models struggle to accommodate differences in staff competency levels, this study aimed to investigate the effectiveness of a tiered training model in CSSD personnel management. **Methods:** A retrospective analysis was conducted using the same group of staff members. Traditional standardized training was implemented during the control period (2024), while tiered training based on job competency was implemented during the observation period (2025). Based on competency assessments, staff were categorized into basic, proficient, core, and management & guidance levels, and targeted training courses were implemented accordingly. The effectiveness of the tiered training model was evaluated by comparing knowledge levels, core skills, work quality indicators (including process quality, outcome quality, and service efficiency), as well as internal and external satisfaction between the two periods. **Results:** During the observation period, staff knowledge scores were significantly higher than those in the control period (81.86 ± 5.23 vs. 70.71 ± 8.52, $p < 0.001$), and scores for various operational skills also improved significantly ($p < 0.001$). Process and outcome quality indicators, including cleaning qualification rate and sterilization qualification rate, showed significant improvements ($p < 0.05$). Service efficiency indicators, including retrieval time, preparation, and replenishment times, were also significantly reduced ($p < 0.001$). Additionally, internal and external training and service satisfaction scores were significantly higher during the observation period ($p < 0.05$). **Conclusion:** The tiered training model can effectively improve the knowledge and technical competencies of CSSD staff, enhance work quality and service efficiency, and increase internal and external satisfaction. This model represents a precise and efficient personnel training and management strategy that accommodates differences in staff capabilities and may have potential for widespread application in the future.

Keywords: central supply, hospital; tiered training; inservice training; sterilization quality indicators

1. Introduction

The Central Sterile Supply Department (CSSD) is the core hospital department responsible for collecting, cleaning, disinfecting, inspecting, packaging, sterilizing, storing, and distributing all reusable medical devices and supplies. The quality of its operations is the cornerstone of the infection prevention and control system of the hospital and directly determines the level of aseptic safety assurance throughout the medical process [1]. Global epidemiological data indicate that hospital-associated infections (HAIs) constitute a significant public health burden [2]. In high-income countries, approximately 7% of hospitalized patients are affected by HAIs, while in low- and middle-income countries with relatively limited healthcare resources, this proportion may increase to 15% or higher [3]. The consequences of HAIs are substantial and include, but are not limited to, prolonged hospitalization, markedly increased treatment costs, elevated complication and mortality rates, and an increased economic burden on the healthcare system [4]. Therefore, ensuring the accuracy and reliability of every CSSD procedure and eliminating infection risks arising from improper instrument processing at the source are fundamental and irreplaceable for safeguarding patient safety and improving healthcare quality. With the rapid advancement of modern surgical and interventional techniques, medical devices used in clinical practice have become increasingly structurally complex, materially diverse, and functionally precise. Studies have confirmed that quality defects in CSSD (surgical site disinfection) procedures, such as wet pack incidents, sterilization monitoring failures, device assembly errors, or inaccurate labeling information, are potentially associated with adverse events such as surgical site infections. These defects not only threaten patient safety but also disrupt routine clinical workflows and reduce diagnostic and treatment efficiency [3,5].

The professional characteristics of CSSD work require personnel to have interdisciplinary knowledge and highly standardized operational skills [6]. However, the human resource structure within CSSDs is typically diverse, with significant heterogeneity in educational background, years of professional experience, job responsibilities, and technical proficiency among staff members [7]. This inherent diversity presents considerable challenges to traditional unified training models. At present, many institutions still primarily depend on periodic group lectures or operational demonstrations as their main training approaches. This "one-size-fits-all" model has inherent limitations. Training content is often overly general and difficult to align with the specific risk points for different positions. Additionally, training methods mainly emphasize theoretical instruction and lack targeted, hierarchical, and competency-oriented operational reinforcement. As a result, senior and experienced employees may demonstrate low participation due to limited depth and innovation in the training content, while newly recruited or junior employees may exhibit insufficient practical competence because they are unable to rapidly assimilate foundational theories and complex operational procedures [8]. More importantly, traditional training models are often disconnected from the core quality indicator management system of CSSD and fail to effectively translate training outcomes into quantifiable improvements in quality indicators.

To address these challenges, the competency-based tiered training concept has demonstrated substantial practical value in medical education. Competency-based education emphasizes job competency as the core objective, uses actual competency achievement as the evaluation standard, and accordingly designs differentiated and personalized training pathways. International research has shown that in professional areas such as nursing, emergency care, and operating room management, competency-based tiered training can improve clinical operation skills, safety decision-making abilities, and problem-solving capacity in complex situations more effectively than traditional lecture-based approaches [9]. This model represents a paradigm shift from "knowledge transmission" to "competency building", thereby ensuring that training outcomes can be directly translated into improved work performance. Introducing this advanced educational concept into CSSD management practice demonstrates strong contextual applicability. The core principle of tiered training is to classify personnel into different levels according to objective competency assessment results and distinct developmental needs. Through this structured design, training resources can be allocated accurately, enabling each employee to acquire the most relevant and effective knowledge and skills that align with their current competency level, thereby optimizing alignment between individual capability and organizational requirements.

While tiered training has demonstrated clear theoretical advantages and successful applications in other medical specialties, empirical research within the specific context of CSSDs remains insufficient. Existing studies mainly focus on CSSD hardware configuration, process reengineering, information technology (IT) infrastructure, or improvements in individual techniques, while relatively few investigations have examined systematic personnel capacity building and tiered training strategies as core interventions and scientifically evaluated their impact on comprehensive quality indicator systems. This research gap limits the availability of evidence-based and reproducible training programs for CSSD managers seeking to improve staff competency and departmental quality. Therefore, scientifically establishing a tiered training system suitable for CSSDs and rigorously evaluating its effectiveness is of significant academic value and practical urgency for advancing the scientific and refined management of CSSD human resources.

Against this background, the present study aimed to develop and implement a competency-based tiered training system for CSSD (Career Management Specialist) personnel. This system scientifically classified CSSD staff into basic, proficient, core, and mentor levels based on clearly defined assessment criteria, and tailored training curricula encompassing both theoretical knowledge and practical skills modules for each level. In an era characterized by continuous innovation in medical technology and increasingly stringent requirements for healthcare safety, exploring and implementing this competency-centered scientific training model is not only an inherent requirement for the professional development of CSSDs but also an inevitable strategic approach for improving the overall quality and safety of healthcare services.

2. Methods

2.1 Research Design

This study included all on-duty staff members of the Central Sterile Supply Department (CSSD) at Sir Run Run Shaw Hospital, Zhejiang University School of Medicine, from May 2024 to August 2025, forming a single cohort. By comparing the performance of this cohort across two consecutive phases, one implementing a routine training model (control period: May 2024–October 2024) and the other implementing a tiered training model (observation period: March 2025–August 2025), the study analyzed the impact of changes in training strategies on outcome indicators. A four-month interval (November 2024–February 2025) was intentionally established between the two phases as a transition period to minimize potential carryover effects from the control period and to provide sufficient time for the development and implementation of the tiered training program, including staff competency assessments, curriculum development, and trainer preparation.

During the study period, except for the training strategy, the CSSD's personnel composition, core workflows, major equipment configuration, and fundamental quality management system remained stable, minimizing confounding factors and ensuring that observed differences in outcomes were primarily attributable to the training intervention. The design and implementation of this study strictly adhered to the ethical principles of the Declaration of Helsinki. Given that this study was a retrospective observational analysis, all data used were obtained from anonymized records archived within the department's routine work and training management system. All data were processed using de-identification procedures, and analyses were performed only at the aggregate level to ensure the protection of personal privacy and data security.

2.2 Research Subjects

The study subjects consisted of all full-time staff members of the CSSD at the Sir Run Run Shaw Hospital during the study period. Their job responsibilities covered the entire workflow, including the decontamination area, inspection and packaging area, sterilization area, sterile storage area, and distribution area. The inclusion criteria were as follows: (1) continuous employment in the CSSD for at least 6 months during both the control and observation periods covered by the study; (2) complete participation records for all scheduled training sessions and assessments during both periods; and (3) fixed job assignments or only planned rotations within the center that did not affect the continuity or consistency of training level classification. The exclusion criteria were as follows: (1) cumulative absence from work exceeding one-third of either the control period (May–October 2024) or the observation period (March–August 2025) due to maternity leave, sick leave, advanced study, or other reasons; (2) failure to complete all required training sessions or assessments during any study period due to job transfer, resignation, or other causes; (3) missing key training records or assessment data that prevented inclusion in the final analysis.

A total of 72 staff members were ultimately included in the analysis. Based on the initial job competency assessments, all staff were categorized into four training levels: Basic (N1), Proficient (N2), Core (N3), and Management and Guidance (N4), and subsequently received targeted tiered training. All data used in this study were derived from de-identified daily quality management monitoring records, standardized skills assessment scoring forms, and training files archived within the CSSD. No patient clinical information or personal privacy data were involved in this study.

2.3 Training Methods

During the control period, the CSSD adopted a traditional training model. This model primarily consisted of monthly standardized group lectures, each lasting approximately 60–90 minutes, delivered by department managers or senior staff members. The training content covered basic infection prevention and control knowledge, industry standards (WS 310.1-3), and demonstrations of core operational procedures. However, structured hands-on practice and individualized feedback were not systematically incorporated. Following lectures and demonstrations, staff primarily acquired skills through observation and self-practice, while occasional informal on-the-job guidance was provided but not included as a standardized component of the training program.

The tiered training program began with a comprehensive competency assessment of all staff members. Based on job responsibilities, years of service, previous performance evaluations, and supervisor assessments, staff members were categorized into four progressively advanced training levels. Level N1 (Basic Level) primarily included employees with less than one year of service or those undergoing rotation training. The competency objectives at this level were to establish basic safety awareness, familiarize staff with core regulations, and master fundamental operations in accordance with standardized operating procedures. Level N2 (Proficient Level) targeted technicians with one to three years of experience who were able to independently and accurately complete routine tasks. The training objective at this level was to deepen understanding of complex equipment-handling procedures and to improve the ability to identify and initially manage common operational abnormalities. Level N3 (Core Level) consisted of senior technicians, regional team leaders, or quality control personnel. Training at this level focused on systematic quality control methods, basic equipment maintenance knowledge, and the development of mentoring capacity for lower-level employees and emergency response leadership skills. Level N4 (Management and Guidance Level) included head nurses and dedicated quality management personnel, requiring them to remain updated on industry developments, proficiently apply advanced quality management tools to promote continuous departmental quality improvement, and possess preliminary capabilities in clinical problem analysis and translational application of research findings.

Based on these tiered competency objectives, this study established a modular and progressive curriculum system with clearly defined training intensity for each level. For N1 and N2 personnel, the program comprised 4 hours of theoretical instruction and 8 hours of supervised hands-on practice per month throughout the 6-month observation period. Staff at the N3 and N4 levels received 2 hours of advanced theoretical training and 4 hours of quality improvement workshops each month, with emphasis on mentoring skills and process auditing.

In terms of teaching methods, a blended online and offline approach was adopted. Theoretical content was delivered through micro-lectures on an online platform accessible 24 hours a day for self-paced learning, while skills training and quality control sessions were conducted offline through workshops, simulation exercises, and one-on-one mentorship. Theoretical learning resources included micro-courses, literature databases, and online self-assessment modules. Skills and quality control training were conducted through mandatory offline activities, including workshop-based simulation training, individualized mentoring, and regular case review meetings, to ensure effective improvement in practical skills and critical thinking abilities.

To ensure effective implementation of the program, the tiered training strategy was implemented in three phases. The initiation and evaluation phase involved competency assessments for all staff members and the development of personalized training plans. During the subsequent core implementation phase, modular training was conducted at all levels in a rolling manner. Conflicts between training activities and daily work responsibilities were coordinated using a "small batch, multiple rounds" approach. Additionally, an internal lecturer team was established, and external expert resources were introduced to ensure teaching quality. The final assessment and consolidation phase included comprehensive summative assessments and evaluation of the stability of quality control indicators.

2.4 Evaluation Tools and Indicators

To systematically evaluate the impact of the tiered training model on the professional knowledge and operational skills of CSSD staff, this study referenced and integrated validity-tested assessment frameworks from similar international studies, combined with the Chinese standards for hospital Central Sterile Supply Departments (WS 310) and the actual operational procedures of the hospital CSSD, to develop a unified "Comprehensive Assessment Tool for CSSD Professional Knowledge and Core Skills" applicable to all staff members. The tool was developed based on the conceptual framework of previously validated instruments [10]. In the present study, the assessment tool demonstrated good reliability, with a Cronbach's α coefficient of 0.76 and a test-retest reliability coefficient of 0.840, indicating satisfactory internal consistency and long-term stability.

For the skills observation component, all assessments were conducted by a uniformly trained assessment team comprising the head nurse and two N3-level core personnel who were not involved in the assessed operations. To ensure inter-rater reliability, a dual-review process was adopted in which two assessors independently evaluated each procedure, and discrepancies were resolved through discussion with a third senior reviewer until a consensus was achieved. This approach was consistent with recommendations that inter-rater agreement for observational assessments should exceed 0.80.

2.4.1 Comprehensive Knowledge Assessment Questionnaire

The knowledge assessment aimed to quantitatively evaluate staff mastery of the core theoretical concepts involved in the entire sterilization workflow. The CSSD professional knowledge assessment questionnaire developed in this study covered six key sequential stages from collection to distribution: (1) instrument collection, classification, and cleaning; (2) inspection, maintenance, and assembly; (3) packaging; (4) sterilization; (5) storage of sterile items; and (6) distribution and transportation.

The questionnaire integrated true-or-false and single-choice questions. The content closely focused on industry standards such as WS 310, fundamental principles of infection prevention and control, key procedures for handling instruments composed of different materials, and the application of chemical disinfection and sterilization monitoring technologies. For example, the questionnaire included practical topics such as "key points in the manual cleaning of tubular instruments", "frequency and significance of biological monitoring during pressure steam sterilization", and "causes and prevention of instrument corrosion" [11].

All staff members completed the same questionnaire in a closed-book format at the end of the control period and again at the end of the observation period. The two assessments were separated by approximately 10 months (the control period ended in October 2024, and the observation period assessment was conducted in August 2025), thereby minimizing the likelihood of recall bias. Furthermore, the questionnaire items were designed to evaluate applied knowledge and procedural reasoning rather than simple factual recall, further reducing the potential for score inflation due to previous exposure. Because the same assessment instrument was used in both periods, any residual recall effect would have influenced both assessments equally, thereby preserving the validity of the comparative analysis.

The questionnaire comprised 20 true/false questions and 30 single-choice questions. For true/false questions, 2 point was assigned for each correct answer, while incorrect or unanswered questions received 0 points. For single-choice questions, 2 point was assigned for each correct answer, while incorrect or unanswered questions received 0 points, yielding a total possible score of 100 points. The weighting (40 points for true/false and 60 points for single-choice questions) was designed to reflect the increasing complexity of knowledge application, with single-choice questions requiring higher-order reasoning.

2.4.2 Comprehensive Skills Observation and Assessment Form

To objectively evaluate standardized operational competence, a "CSSD Core Operational Skills Observation Checklist" was developed. This assessment tool, derived from the "Hospital Central Sterile Supply Department" (WS 310) standards and the department's standard operating procedures, consisted of 60 observable and assessable behavioral items divided into three major dimensions. The checklist was designed to comprehensively evaluate operational standardization throughout the entire workflows from contamination handling to sterile item distribution, including cleaning (20 items), inspection, packaging, and sterilization (30 items), and storage and distribution of sterile items (10 items).

All assessments were conducted on-site by a uniformly trained evaluation team composed of the head nurse and two N3-level core personnel who were not participating in the assessed operation. These assessments served as summative evaluations of core operational competencies achieved at the end of each training period. Each operational item was scored dichotomously: 1 point for "fully compliant with standards" and 0 points for "any non-compliant or omitted step". The total score for each skill domain (e.g., cleaning or packaging and sterilization) was calculated by summing the scores of all items within that domain, with higher scores indicating better operational performance. No predetermined pass/fail cutoff was established at the individual item level.

2.4.3 Work Quality Assessment

To verify the effectiveness of different training programs in improving actual departmental work quality across multiple dimensions, this study collected objective indicators in three categories: process quality, outcome quality, and service efficiency. Process quality indicators included cleaning qualification rate, instrument assembly and verification accuracy rate, completeness and accuracy rate of sterilized item label information, and correctness rate of sterilization procedures. Outcome quality indicators included wet package incidence rate, sterilization qualification rate, sterile package integrity rate, and critical equipment integrity rate. Service efficiency indicators included replenishment time, retrieval time, and preparation time. Retrieval time was defined as the interval from the receipt of a request from a clinical department to the moment the requested sterile items were retrieved from the storage area and ready for dispatch. Preparation time was defined as the interval from the initiation of assembling sterile items for a specific request to the completion of packaging and labeling for transport. Replenishment time was defined as the interval from the departure of CSSD staff to the completion of restocking sterile items in the designated storage areas of clinical departments, including travel and handover time. All time measurements were recorded in minutes.

All data were obtained from the department's routine quality control records. During the control period, quality indicators were assessed from 302 instruments or instrument packs, while 300 instruments or instrument packs were evaluated during the observation period. These samples were derived from routine daily quality monitoring records of the CSSD. Throughout each 6-month study period, departmental quality control nurses routinely selected approximately 1–3 instrument packs per day from the daily output across all work shifts as part of standard quality monitoring procedures. All available records from the control period (May–October 2024) and observation period (March–August 2025) were retrospectively collected and included in the analysis, resulting in final sample sizes of 302 and 300, respectively.

2.4.4 Satisfaction

To evaluate the effects of different training models on acceptance and service improvement, this study conducted satisfaction assessments at two levels: internal participation and external service quality. Internal training satisfaction was assessed using a self-designed "Stratified Training Satisfaction Questionnaire", distributed to all trainees upon completion of the training program. The questionnaire employed a five-point Likert scale, with core dimensions including training content, practicality, quality of teaching and implementation, and willingness and motivation to participate. External service satisfaction was assessed using the "Clinical Department Satisfaction Survey on CSSD Work", administered to head nurses or liaison nurses from clinical departments routinely served by the CSSD. A total of 31 clinical departments were included, and surveys were distributed to key nursing personnel within each department. Responses were collected from one representative per department during both the control and observation periods, resulting in 31 completed questionnaires for each period. All surveys were completed anonymously and returned directly to the research team. The same respondents participated in both assessment periods.

2.5 Data Analysis

Data analysis in this study was performed using SPSS version 24.0 statistical software (IBM Corp., Armonk, NY, USA). For all continuous variables, the Kolmogorov-Smirnov test was initially used to determine whether the data followed a normal distribution. For paired comparisons within the same cohort (control period vs. observation period), normally distributed data were expressed as mean ± standard deviation and compared using paired t-tests, while non-normally distributed or ordinal data were expressed as median and interquartile range [M (Q_1, Q_3)] and compared using the Wilcoxon signed-rank test.

For the key outcome variables, including participants' knowledge and skill levels, effect sizes were additionally calculated. Cohen's d was used for paired t-tests, while effect size $r = |Z|/\sqrt{N}$ was calculated for Wilcoxon signed-rank tests.

For independent comparisons involving different samples (e.g., work quality indicators), normally distributed continuous variables were compared using independent-samples t-tests, non-normally distributed variables using Mann-Whitney U tests, and categorical variables using chi-square tests. Categorical variables were presented as frequencies (n) and percentages (%). To visualize the magnitude and precision of improvements across quality indicators, risk differences with 95% confidence intervals were calculated for each binary outcome and presented using a forest plot. All statistical tests were two-tailed, and a $p < 0.05$ was considered statistically significant.

3. Results

3.1 Baseline Characteristics of Study Participants

A total of 72 CSSD staff members were included in the final analysis. The baseline characteristics are presented in Table 1. The distribution of participant characteristics reflected the inherent heterogeneity of the CSSD workforce and further supported the rationale for implementing a tiered training approach.

Table 1. Baseline characteristics of study participants.

Variables	Total (n = 72)
Age (years), median (Q_1, Q_3)	34.00 (32.00, 35.00)
Years of service (years), median (Q_1, Q_3)	5.00 (3.00, 7.00)
Gender, n (%)	
Male	19 (26.39)
Female	53 (73.61)
Education, n (%)	
Postgraduate	3 (4.17)
Undergraduate	46 (63.89)
Associate degree	23 (31.94)
Training level, n (%)	
N1	15 (20.83)
N2	30 (41.67)
N3	14 (19.44)
N4	13 (18.06)

N1, Basic Level; N2, Proficient Level; N3, Core Level; N4, Management and Guidance Level.

3.2 Comparison of Knowledge and Skill Levels

Regarding knowledge level, the mean score during the observation period (81.86 ± 5.23) was significantly higher than that during the control period (70.71 ± 8.52), and the difference was statistically significant ($t = -8.587$, $p < 0.001$). Across all skills assessments, participants in the observation period achieved significantly higher scores than those in the control period in the domains of cleaning, packaging and sterilization, sterile storage and dispensing skill, and total operational skills. All comparisons demonstrated statistically significant differences ($p < 0.001$), as shown in Table 2.

3.3 Comparison of Quality Indicators

The sampling results demonstrated that, during the observation period, the cleaning qualification rate, instrument assembly and verification accuracy rate, completeness and accuracy of sterilized item label information, and correctness rate of sterilization procedures were all significantly improved compared with those during the control period ($p < 0.05$). Regarding outcome quality indicators, the incidence of wet packaging was significantly reduced during the observation period ($p < 0.05$), while the sterilization qualification rate, sterile packaging integrity rate, and key equipment integrity rate were all significantly higher than those observed during the control period ($p < 0.05$). Fig. 1 presents a forest plot of the corresponding effect sizes with 95% confidence intervals, visually demonstrating the consistent benefits of the tiered training model across all quality indicators. These findings indicate that the tiered training approach improved overall quality performance, as detailed in Table 3.

3.4 Service Efficiency Comparison

Compared with the control period, the observation period demonstrated significant reductions in retrieval time, preparation time, and replenishment time ($p < 0.001$). Specifically, retrieval time decreased from 6.69 ± 1.07 minutes during the control period to 4.64 ± 1.05 minutes during the observation period, while preparation time decreased from 9.40 ± 0.82 minutes to 5.18 ± 1.21 minutes. Additionally, the median replenishment time decreased from 11.20 minutes to 8.30 minutes. These findings indicate that the tiered training model effectively improved service efficiency, as detailed in Table 4.

3.5 Comparison of Training Satisfaction

Participants' satisfaction scores regarding training content, practicality, teaching quality, and willingness and enthusiasm for participation were significantly higher during the observation period than during the control period ($p < 0.001$). These findings indicate that the tiered training model significantly improved both the training experience and participant engagement, as detailed in Table 5.

3.6 Clinical Department Satisfaction With Services

During the observation period, satisfaction scores for supply quality, service efficiency and reliability, as well as communication and collaboration, were significantly higher than during the control period ($p < 0.05$), as detailed in Table 6. These findings indicate that the tiered training model improved overall satisfaction among clinical departments receiving CSSD services.

4. Discussion

The Central Sterile Supply Department (CSSD) serves as the core hub of the hospital's infection prevention and control system. Its operational efficiency and quality directly influence the safety of clinical diagnosis and treatment, as well as the overall quality of hospital healthcare services. With the advancement of modern medical technologies and the rapid increase in the variety of medical devices, CSSD processing workflows have become increasingly complex, involving multiple quality-sensitive stages, including cleaning, disinfection, inspection and packaging, sterilization, distribution, and traceability management [12,13,14]. Numerous studies have confirmed that the quality of CSSD operations is closely associated with the risk of hospital-acquired infections [13,14]. Efficient and stan-

Table 2. Comparison of participants' knowledge and skill levels between the control and observation periods.

Variables	Control period (n = 72)	Observation period (n = 72)	Statistic	Effect size	*p*-value
Knowledge level, mean ± SD	70.71 ± 8.52	81.86 ± 5.23	$t = -8.587$	Cohen's d = 1.07 (95% CI: 0.721–1.287)	<0.001
Skill level, median (Q_1, Q_3)					
Cleaning skill	14.00 (13.00, 14.25)	15.00 (14.00, 17.00)	$Z = -7.051$	$r = 0.83$	<0.001
Packaging and sterilization skill	21.50 (20.00, 23.25)	24.00 (22.00, 26.00)	$Z = -6.882$	$r = 0.81$	<0.001
Sterile storage and dispensing skill	6.00 (5.00, 6.00)	7.00 (6.00, 8.00)	$Z = -4.642$	$r = 0.55$	<0.001
Total skill score	41.00 (39.00, 43.00)	47.00 (45.00, 48.00)	$Z = -5.512$	$r = 0.65$	<0.001

CI, confidence interval.

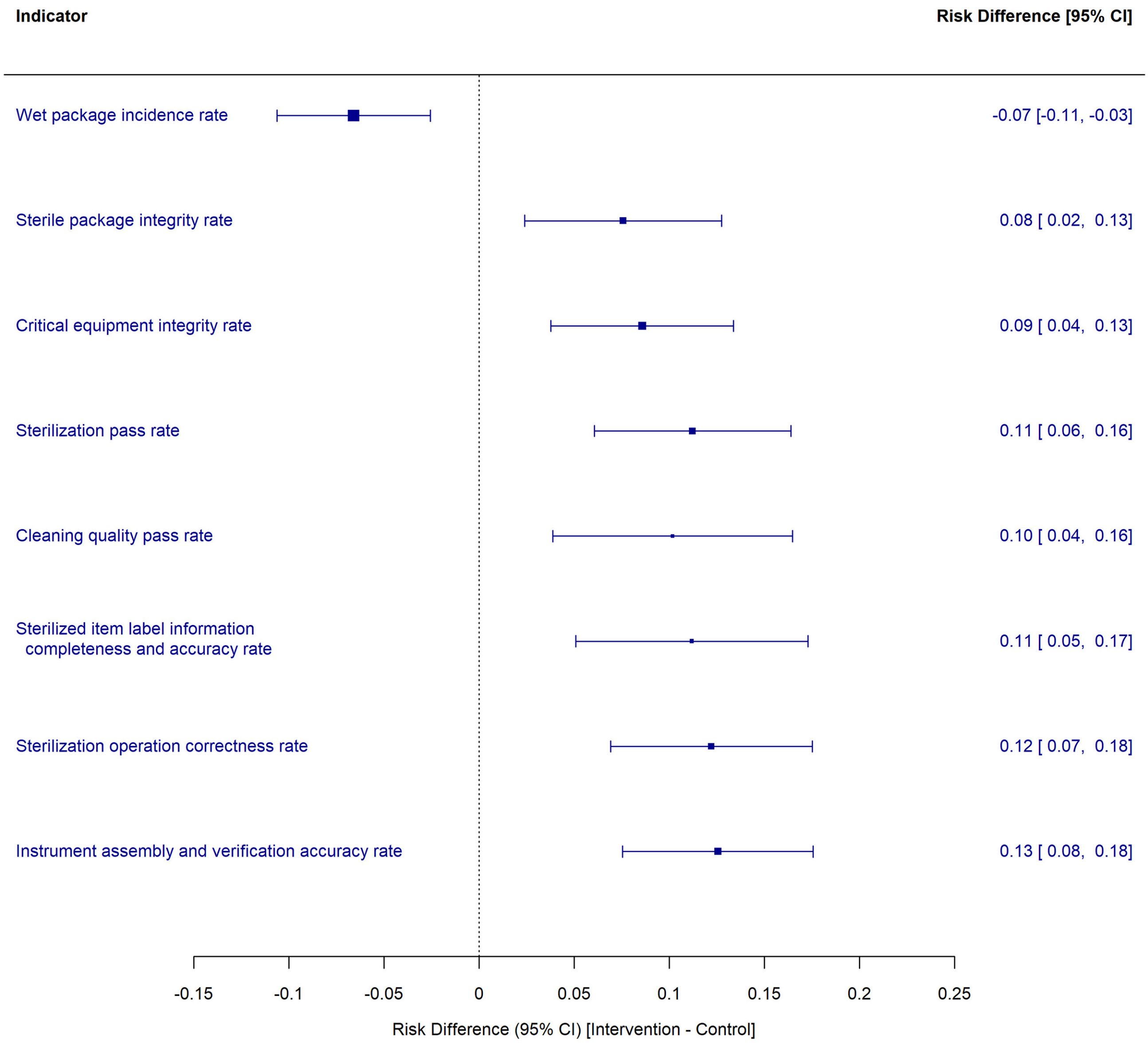

Fig. 1. Forest plot of risk differences for key quality indicators between the control and observation periods.

dardized instrument reprocessing procedures can significantly reduce the incidence of surgical site infections and improve patient safety [15]. Therefore, improving CSSD work quality through personnel training and process optimization has become a critical component of continuous improvement in healthcare institutions.

Table 3. Comparison of quality indicators between the control and observation periods.

Variables	Control period (n = 302)	Observation period (n = 300)	Statistic	*p*-value
Process quality indicators				
Cleaning qualification rate, n (%)	227 (75.17)	256 (85.33)	χ^2 = 9.810	0.002
Instrument assembly and verification accuracy rate, n (%)	248 (82.12)	284 (94.67)	χ^2 = 23.058	<0.001
Completeness and accuracy rate of sterilized item label information, n (%)	230 (76.16)	262 (87.33)	χ^2 = 12.584	<0.001
Sterilization procedure correctness rate, n (%)	244 (80.80)	279 (93.00)	χ^2 = 19.665	<0.001
Outcome quality indicators				
Wet packing incidence rate, n (%)	31 (10.27)	11 (3.67)	χ^2 = 10.096	0.001
Sterilization qualification rate, n (%)	248 (82.12)	280 (93.33)	χ^2 = 17.555	<0.001
Sterile package integrity rate, n (%)	254 (84.11)	275 (91.67)	χ^2 = 8.074	0.004
Critical equipment integrity rate, n (%)	258 (85.43)	282 (94.00)	χ^2 = 11.963	<0.001

Table 4. Comparison of service efficiency between the control and observation periods.

Variables	Control period (n = 302)	Observation period (n = 300)	Statistic	*p*-value
Retrieval time (min), mean ± SD	6.69 ± 1.07	4.64 ± 1.05	*t* = 23.851	<0.001
Preparation time (min), mean ± SD	9.40 ± 0.82	5.18 ± 1.21	*t* = 50.040	<0.001
Replenishment time (min), median (Q_1, Q_3)	11.20 (10.70, 11.70)	8.30 (7.60, 9.00)	*Z* = –20.899	<0.001

SD, standard deviation.

Table 5. Comparison of participant satisfaction with training between the control and observation periods.

Variables	Control period (n = 72)	Observation period (n = 72)	Statistic	*p*-value
Training content, median (Q_1, Q_3)	3.00 (2.00, 4.00)	4.00 (2.00, 4.00)	*Z* = –6.172	<0.001
Training practicality, median (Q_1, Q_3)	3.00 (2.00, 4.00)	4.00 (2.00, 5.00)	*Z* = –5.389	<0.001
Quality of teaching and implementation, median (Q_1, Q_3)	3.00 (2.00, 4.00)	4.00 (3.00, 5.00)	*Z* = –6.499	<0.001
Willingness and motivation to participate, median (Q_1, Q_3)	3.00 (2.00, 3.00)	4.00 (2.00, 5.00)	*Z* = –5.512	<0.001

Table 6. Comparison of clinical departmental satisfaction with CSSD services between the control and observation periods.

Variables	Control period (n = 31)	Observation period (n = 31)	Statistic	*p*-value
Supply quality, median (Q_1, Q_3)	3.00 (2.00, 4.00)	4.00 (3.00, 4.50)	*Z* = –2.174	0.033
Supply efficiency and reliability, median (Q_1, Q_3)	3.00 (2.00, 4.00)	4.00 (3.00, 5.00)	*Z* = –2.852	0.004
Communication and collaboration, median (Q_1, Q_3)	3.00 (2.00, 4.00)	4.00 (3.00, 5.00)	*Z* = –2.594	0.009

However, in actual practice, the composition of CSSD personnel is highly heterogeneous. Significant differences exist among newly recruited staff, rotating personnel, junior technicians, senior technicians, and managers in knowledge base, operational experience, risk identification ability, and quality awareness. Under the traditional centralized training model, it is often difficult to account for the practical needs of personnel at different competency levels, resulting in limited training effectiveness or inefficient use of training resources. Consequently, establishing a tiered training system tailored to job characteristics and competency levels represents a key strategy for improving the overall competence and professional quality of CSSD personnel.

Based on this background, the present study systematically evaluated changes in personnel competence, key quality indicators, and satisfaction following implementation of a tiered training model in the CSSD of a tertiary hospital using a self-controlled comparative design. According to the study findings, the tiered training model achieved significant improvements across multiple dimensions. First, the theoretical knowledge level of personnel improved significantly after training (81.86 ± 5.23 vs. 70.71 ± 8.52, $p < 0.001$), indicating that the tiered curriculum structure more effectively accommodated the cognitive characteristics and learning needs of personnel with different competency levels. This improvement appears particularly significant when compared with previous educational interventions. For example, Hu et al. [16] evaluated a structured educational program for CSSD staff and reported significant improvement in theoretical knowledge scores. These findings suggest that a more refined tiered approach, dividing staff into four competency levels (N1–N4) and implementing modular curricula, may facilitate deeper knowledge consolidation than traditional "one-size-fits-all" training programs [16].

Additionally, the qualification rates of core operational skills, including cleaning, assembly, packaging, and sterilization, improved significantly after implementation of the tiered training model. The observed improvement in cleaning quality and assembly standardization is consistent with the established relationship between high-quality reprocessing procedures and reduced risk of surgical site infections. Existing literature has demonstrated that incomplete instrument cleaning is among the core risk factors contributing to sterilization failure and postoperative infection [17]. In the present study, the cleaning qualification rate increased from 75.17% to 85.33%, representing a relative increase of 13.5%, which is comparable to the improvement reported by Cao et al. (from 94.67% to 98.17%) in their optimization of the CSSD information management system [18]. However, the impact of the present training model extended beyond foundational operational skills. Multiple quality-sensitive indicators within the CSSD, including wet pack incidence, sterilization qualification rate, packaging integrity rate, and equipment integrity rate, improved to varying degrees following implementation of the training program.

As one of the most critical indicators of compromised sterilization quality, wet package occurrence is influenced by multiple factors, including packaging methods, loading methods, and procedural standardization. Jing et al. [15] reported that implementing a personalized management model improved both work efficiency and quality outcomes. The tiered training strategy adopted in the present study shared several conceptual similarities with personalized management models. These findings further support the possibility that tiered training can lead to measurable improvements in process execution [15]. Moreover, the granular competency stratification, combined with dedicated modules focused on quality improvement, may explain the significant downstream improvements observed in complex process indicators such as wet pack rate, an outcome that is less frequently reported in studies focusing only on basic skill acquisition.

Nevertheless, despite these improvements, the post-training wet package incidence and sterilization qualification rates remained below recommended benchmark standards. This observation suggests that factors beyond individual staff competency, such as equipment performance, packaging materials, loading patterns, and maintenance protocols, may also substantially influence these outcomes. Therefore, although tiered training demonstrated clear effectiveness, training alone may be insufficient to comprehensively address all determinants of sterilization quality. Future quality improvement initiatives within CSSD should therefore adopt a multifaceted approach that combines tiered training with systematic equipment audits, process reengineering, and routine engineering evaluations to achieve higher levels of compliance and quality assurance.

Following implementation of the tiered training program, both internal staff training satisfaction and clinical department satisfaction with CSSD services improved significantly. Since CSSD functions as the hospital's critical "support department", its service quality directly affects the efficiency and continuity of clinical operations, and clinical satisfaction serves as an important external indicator of departmental management quality. The findings of this study demonstrated that clinical departments reported improvements in perceptions of medical device packaging quality, sterilization effectiveness, and supply timeliness after implementation of the comprehensive training program. These findings suggest that tiered training not only enhances internal staff competency but also improves the external service quality of the CSSD.

From a mechanistic perspective, implementing the tiered training model can accurately align personnel competency requirements across levels, thereby enhancing the overall quality management capacity of the system. The concept underlying this structured training system is consistent with the internationally recognized competency-based training (CBT) model, which has been demonstrated in numerous studies to significantly improve operational consistency and quality performance in hospital reprocessing departments [19].

Notably, the magnitude of improvement varied across evaluation indicators. Although satisfaction with "communication and collaboration" among clinical departments improved significantly, the degree of improvement was relatively smaller than that observed for technical skills and process quality indicators. This difference may be explained by two factors. First, the curriculum primarily emphasized technical competency development, which represented the major intervention focus of the tiered training model, while lacking dedicated modules specifically addressing interdepartmental communication. Second, the effectiveness of the CSSD-clinical department interface depends not only on individual competence but also on structural and organizational factors, such as feedback channels and standardized handover protocols, which cannot be fully optimized through personnel training alone. These findings suggest potential directions for refining the training model. Specifically, while maintaining the strong emphasis on technical competencies, targeted communication modules could be incorporated into the N2 and N3 training levels, including scenario-based drills for handling clinical requests and interdisciplinary coordination. In addition, training interventions should be complemented by organizational interventions, such as regular clinical feedback meetings and standardized communication protocols.

Although the findings of this study indicate that the tiered training model demonstrated favorable practical effects, several limitations should be acknowledged. First, this study adopted a single-center, pre-post comparative design, which may have introduced temporal trend bias, whereby some improvements in quality indicators could also have been influenced by external factors such as changes in management policies or equipment upgrades. Second, although the criteria used for assigning staff to training levels incorporated job responsibilities, years of service, performance reviews, and supervisor evaluations, a fully standardized scoring instrument was not available. Consequently, a degree of subjectivity may have been introduced into the competency-level allocation process. Future implementation should therefore develop and validate a structured competency assessment tool with predefined scoring criteria to enhance the objectivity and reproducibility of tier classification. Third, the study period was relatively short, limiting the evaluation of the long-term sustainability of the training effects. Fourth, assessment team members were aware of both the study objective and the training model implemented during each period, which may have introduced observer expectancy bias. Although a dual-review process and consensus-based evaluation process were implemented to enhance objectivity, the inherent inability to blind assessors during real-world clinical skills evaluations remains a potential source of bias. Furthermore, although this study combined subjective and objective evaluation methods, some indicators, particularly satisfaction surveys, may still have been affected by information bias.

Future studies should therefore employ multicenter randomized controlled designs to further validate the effectiveness and generalizability of tiered training models. Additionally, the integration of modern technologies, including intelligent tracking systems and automated cleaning and monitoring equipment, should be explored to develop a training and quality management system adapted to the evolving requirements of digitized CSSDs.

5. Conclusion

This study suggests that a tiered training model based on job competency stratification can effectively improve theoretical knowledge, operational skills, and quality management capabilities among CSSD personnel, thereby leading to significant improvements in key quality indicators and enhanced satisfaction among clinical departments. As a precise, human-centered management approach, tiered training not only demonstrates significant advantages in improving the quality of CSSD work but also provides an effective pathway for strengthening the hospital's infection prevention and control system. In the future, this model should be promoted across a broader range of medical institutions and further refined in combination with modern information management tools to continuously advance the professionalization, standardization, and optimization of CSSD operations.

Key Points

• This retrospective controlled study evaluated a competency-based tiered training model within a Central Sterile Supply Department (CSSD).

• The training model significantly enhanced staff knowledge, operational skills, and work quality (including process quality, outcome quality, and service efficiency), as well as internal training satisfaction and external clinical department satisfaction.

• The findings support tiered training as an effective and precise management strategy for improving CSSD performance and patient safety-related quality indicators.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

DYC and HLZ designed the research study. YYC, JHS and HYP performed the research. DYC and HLZ analyzed the data. HYP and DYC drafted this article. All authors contributed to the important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was approved by the Ethics Committee of Sir Run Run Shaw Hospital (approval number: 2025-1264), and written informed consent was obtained from all participants. All procedures followed the principles of the Declaration of Helsinki.

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Conflicts of Interest

The authors declare no conflicts of interest.

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