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# Outcomes of Smart or Automated Sterilization Tracking in Central Sterile Services Departments (CSSDs): A Systematic Review

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## ABSTRACT

**Objective:** To evaluate the effectiveness and outcomes of smart or automated sterilization tracking systems in Central Sterile Services Departments (CSSDs) compared to conventional manual methods.

**Methods:** A systematic review was conducted following PRISMA guidelines. PubMed, Web of Science and Embase were searched from January 2010 to July 2025. Studies evaluating automated tracking systems in CSSDs were included. Data on clinical satisfaction, instrument cleaning and packaging qualification rates, and process outcomes were extracted. Study quality was assessed using JBI critical appraisal tools.

**Results:** Nine studies (390,130 instruments; 32 staff members) were included. Automated systems consistently outperformed manual methods across outcomes. Clinical satisfaction increased by 9-23% with automation. Cleaning qualification rates improved by 1-10%, while packaging qualification rates increased by 4-30%. Process efficiency also improved, with reductions in instrument turnaround times ranging from 1 to 5 minutes per item to 20 minutes per batch. All studies were of moderate to high methodological quality.

**Conclusion:** Implementation of smart, automated sterilization tracking systems in CSSDs leads to significant improvements in instrument processing quality, staff satisfaction, and operational efficiency compared to manual methods. CSSD managers and OR professionals should adopt smart sterilization tracking systems to ensure higher processing quality, improved efficiency, and safer patient outcomes. These technologies enhance patient safety and infection control practices in healthcare settings. Further research is needed to evaluate long-term clinical and economic impacts.

**Keywords:** Smart sterilization tracking, Central Sterile Services Department, automated systems, process efficiency, infection control, patient safety.

## INTRODUCTION

Central Sterile Services Departments (CSSDs) are considered as backbone of safe diagnostic and surgical practices in modern clinical or healthcare settings. The primary roles of CSSDs are to sterilize, disinfect, assemble and distribute surgical instruments or devices that maintain the sterility until the point of use (1). Additionally, the CSSD has a direct impact on patient safety, surgical site infection (SSI), and overall hospital efficiency despite being a behind-the-scenes operation (2). Any interruption in the sterilization chain or disrespect for established procedures may lead to contamination, postponed procedures, or expensive adverse outcomes. Thus, healthcare organizations all around the world are considering the optimization of CSSD procedure as a top priority (3, 4).

Historically, sterilization tracking in CSSDs has been practiced by manual processes that involved paper logs, staff documentation, and barcode systems to monitor instrument safety, load configurations and cycle parameters. Despite diverse functional outcomes in clinical settings, there are huge chances of human errors, difficult real-time monitoring, and incomplete documentation in manual processing of sterilization. Additionally, the immense rise in the number of instruments per tray, and frequency of processing cycles due to the increasing complexity of surgical procedures has also intensified workload on CSSDs (5, 6). Thus, there is an urgent need for more efficient and reliable tracking systems to reduce error rates and follow the guidelines outlined by the Association for the Advancement of Medical Instrumentation (AAMI), the Joint Commission, and ISO guidelines (7).

Smart or automated sterilization tracking systems have revolutionized the CSSDs in clinical settings by solving the challenges of manual processing. These systems relied on technologies such as Internet of Things (IoT) sensors, real-time data analytics, Radio Frequency Identification (RFID), and automated software platforms (8). RFID tags provide non-contact, mass, and continuous monitoring of surgical equipment throughout their lifecycle, in contrast to traditional barcode systems that need manual scanning. While smart dashboards give CSSD managers notifications, compliance reports, and predictive maintenance plans, IoT-enabled autoclaves and washers can automatically send cycle completion data to central databases. By enhancing accountability, traceability, and transparency in sterilization processes, these developments hope to reduce the risks brought on by human mistakes and inadequate documentation (9).

Several hospitals have reported diverse benefits after the adoption of smart tracking technologies in CSSDs. These benefits include significant improvements in turnaround time for surgical trays, reductions in lost or misplaced instruments, and better alignment with infection prevention goals and enhanced compliance with documentation requirements (10). Furthermore, it has been demonstrated that automated data capture increases staff productivity by lowering administrative workloads, freeing up CSSD employees to concentrate more on quality assurance than on human record-keeping. Automated tracking reduces instrument loss, lowers replacement costs, and supports preventive maintenance plans, all of which reduce costs in the larger framework of hospital administration. Despite these several benefits, the automated sterilization tracking has not yet been applied globally due to a few barriers. These barriers are interoperability issues, high implementation costs, and resistance to workflow change, old hospital information systems and the need for staff training that restricted its widespread use (11).

Smart and automated sterilization tracking represents a significant advancement in the modernization of CSSD operations. Few single-centre studies and case reports have reported the promising outcomes of automated systems in CSSDs (12). However, there is a lack of comprehensive evaluations across diverse healthcare settings. On the other hand, previous evidence suggested that these technologies enhance traceability, compliance, and efficiency, systematic evaluation of their outcomes across diverse contexts remains limited. Thus, this study aims to evaluate the effectiveness or outcomes of Smart or automated Sterilization Tracking in Central Sterile Services Departments (CSSDs) in healthcare settings by adopting a systematic review research approach.



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## METHODOLOGY

*Study Design*

This systematic review was undertaken to evaluate and compare the effectiveness or outcomes of Smart or automated Sterilization Tracking in Central Sterile Services Departments (CSSDs) of hospitals. This comprehensive review was conducted with transparency and integrity in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (13).

**PICO framework**

The PICO framework was used for screening and selection of research papers for this systematic review (14).

**Population (P)**: Central Sterile Services Departments (CSSDs), including healthcare workers and hospital settings where surgical instruments and medical devices are sterilized.

**Intervention (I):** Implementation of smart or automated sterilization tracking systems (e.g., RFID, barcoding, AI-driven tracking, IoT-enabled sterilization monitoring).

**Comparator (C):** Conventional/manual sterilization tracking and documentation methods (e.g., paper-based logs, non-automated tracking).

**Outcomes (O):** Process outcomes (such as error reduction, and turnaround time), and Clinical outcomes, such as clinical satisfaction or improved patient safety, were primary outcomes of this research

*Search Strategy*

A complete investigation of the literature was done to locate authentic studies or studies matching the eligibility criteria. Three electronic databases, such as PubMed, Web of Science and Embase, were thoroughly searched from January 2010 to July 2025. The search strategy for Pubmed was “(("Central Supply, Hospital"[Mesh] OR "Sterilization, Hospital"[Mesh] OR "Central Sterile Services Department*" OR "Central Sterile Supply Department*" OR "CSSD" OR "Sterile Processing Department*" OR "SPD")) AND (("Equipment and Supplies"[Mesh] OR "Surgical Instruments"[Mesh] OR "medical device*" OR "surgical instrument*")) AND (("Sterilization"[Mesh] OR sterilize* OR disinfection OR "reprocessing")) AND (("Management Information Systems"[Mesh] OR "Hospital Information Systems"[Mesh] OR "Data Collection"[Mesh] OR "Medical Records Systems, Computerized"[Mesh] OR "Quality Assurance, Health Care"[Mesh] OR "workflow" OR "traceability" OR "tracking system*" OR "quality control system*" OR "smart system*" OR "automated system*" OR "automation" OR RFID OR "Radio Frequency Identification" OR barcode* OR "QR code*" OR "Internet of Things" OR IoT OR "artificial intelligence" OR AI OR "machine learning")) AND (("outcome*" OR "process outcome*" OR "clinical outcome*" OR "workflow efficiency" OR "error reduction" OR "patient safety" OR "infection control" OR "surgical site infection*" OR "cost effectiveness" OR "staff productivity" OR compliance)) and similar was used for other databases. All previously published meta-analyses and systematic reviews on similar topics were searched to reach authentic data.

*Study Selection Criteria*

*Inclusion Criteria*

The inclusion criteria applied to identify eligible studies were: 1). The studies discussing or analyzing Central Sterile Services Departments (CSSDs), Sterile Processing Departments (SPDs), or equivalent


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hospital sterilization units dealing with the distribution of surgical instruments or medical devices, 2). Implementation or evaluation of smart or automated sterilization tracking systems, e.g., Radio Frequency Identification (RFID) systems, Barcode or QR code–based tracking, Internet of Things (IoT) systems and Artificial Intelligence (AI), 3). Studies comparing automated/ smart tracking systems with conventional or manual tracking methods, 4). Study design must be Randomized controlled trials (RCTs), quasi-experimental studies, cohort studies, case–control studies, cross-sectional studies and publications in English.

**Exclusion Criteria**

Those articles were excluded 1). Those not conducted in CSSDs/SPDs or hospital sterilization units, 2). Interventions unrelated to smart or automated sterilization tracking (e.g., studies focusing solely on disinfection methods, sterilizer performance, or microbiological outcomes without tracking systems), 3). Case reports, editorials, letters to the editor, expert opinions, conference abstracts without full text, and narrative reviews, 4). Studies not reporting any relevant outcomes of interest (process, or clinical) and non-English studies.

***Study Selection & Data Extraction***

The identified studies' titles and abstracts were separately examined by two reviewers to determine whether they met the inclusion criteria. For ultimate inclusion, full-text publications of potentially qualifying research were gathered and evaluated. Any conflicts or differences between reviewers were settled by discussion or, if required, by consulting a third reviewer. The following information was extracted from each included study: study characteristics (authors, year of publication, study design), objectives, study population or settings, intervention, comparator details, outcome measures, and findings.

***Quality Assessment of Included Studies***

The Joanna Briggs Institute (JBI) critical appraisal checklist was used methodological quality assessment of included cohort studies for this meta-analysis. The methodological quality of the included cohort studies or empirical studies and the strategies they employed to address and minimize bias were evaluated using the JBI critical assessment instrument. Standardized critical appraisal questions or criteria are employed by JBI to evaluate the potential for various biases that may arise in quantitative research. Based on the methodology of studies, there are JBI-standardized appraisal instruments suitable for JBI reviews of efficacy (15).

## RESULTS

**Study Selection**

In this systematic review, the PRISMA guidelines were followed in the selection and screening of research articles pertaining to the study aim "Outcomes of Smart or automated Sterilization Tracking in Central Sterile Services Departments (CSSDs)." Database searches produced a total of 128 items, of which 88 remained after duplicates and insufficient text were eliminated. After an initial screening of 88 research publications, 54 papers were searched for retrieval. There were only 35 publications that assessed the eligibility requirements, and there were ultimately 9 research articles as shown in Figure 1.

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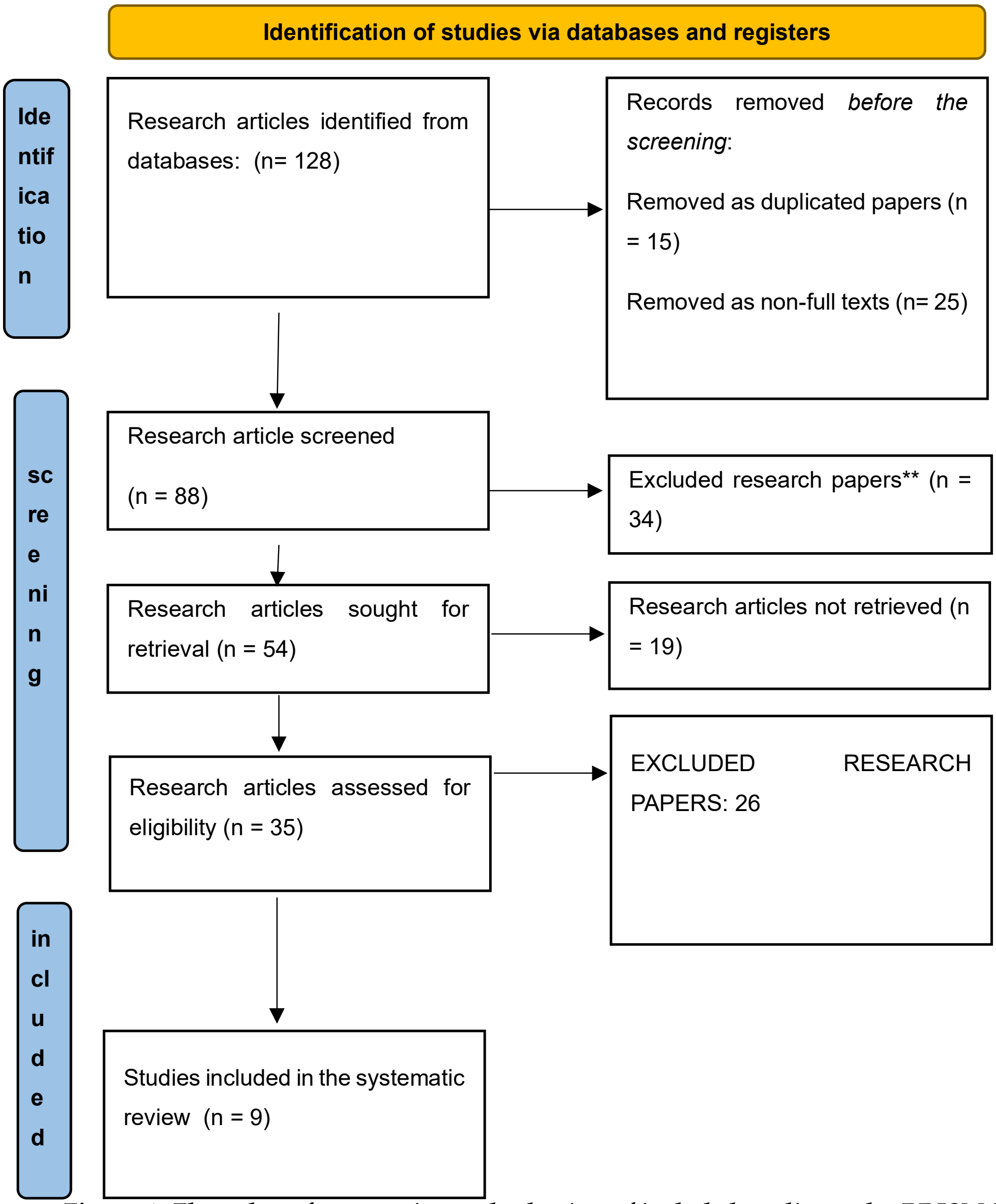


**Figure 1:** *Flow chart for screening and selection of included studies under PRISMA guidelines*

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Table no. 1: Characteristics of Included Studies

| Author, Year | Country | Objective | Population | Intervention | Comparator | Clinical satisfaction | Instrument cleaning and packaging qualification rate | Process Outcomes | Findings |
|---|---|---|---|---|---|---|---|---|---|
| Yuan et al., 2024 (16) | China | To investigate the effectiveness of visual management flow diagrams in improving work quality, efficiency, error reduction, and clinical satisfaction in the CSSD | 800 instruments: n = 400 instruments within a CSSD setting & n = 400 instruments in controls | Visual flow diagrams (used for instrument/equipment handling, infection control, and instrument package or management) | Conventional/ manual tracking methods (e.g., paper logs) | Observation group: 99% vs Control: 90% | **Cleaning** Observation: 99% vs Control: 95% And **Qualification** Observation: 96% vs Control: 92% | | Triggered positive impact on the work quality and enhances clinical work satisfaction in the central sterile supply department |
| Zhu et al., 2024 (17) | China | To investigate the application and effectiveness of automated guided vehicles (AGV) and sterilization monitoring reports | CSSD staff and processes at Nantong First | Automated guided vehicle (AGV) (used for auto loading/unloading & transport or monitoring | Manual transportation and recording of sterilization | Before automated tools: 75% After automated tools: 98.4% | | Before automated tools: 5 mins After automated tools: 1 min | Reduction in occupational exposure, physical exertion, and error probability; improved working environment and |

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|---|---|---|---|---|---|---|---|---|---|
| | | in the disinfection and sterilization process | People's Hospital | sterilization process) | | | | | professional experience. |
| Ding et al., 2024 (18) | China | To design and evaluate an IoT- and RFID-based automated visual quality tracking information system for CSSD to improve efficiency, traceability, and medical safety. | Instruments in CSSD at Shenzhen People's Hospital<br>Observation:<br>>280,000<br>Control: >100,000 | IoT-based automated sterilization quality tracking system (RFID tags + data visualization + microservice architecture) | Conventional/manual system (paper records, C/S software) | | **Cleaning**<br>Before: 99.59%<br>After: 99.89%<br>Packaging:<br>Before: 99.93%<br>After: 99.98%, | Before: 30 mins/ batch<br>After: 10 mins/ batch | Improved medical safety: rapid tracing of instruments during infection events; stronger infection prevention through real-time monitoring |
| Hung et al., 2020 (19) | Taiwan | To optimize surgical instrument sterilization by monitoring temperature and time via IoT sensors | Hospital sterile supply center | High-temperature pressure sensors by internet of things (IoT) (used to monitor sterilization tempreture) | Conventional/manual methods | Implied improvement in medical service quality by ensuring instruments are fully sterilized | | Enabled detection of sterilization failures or errors immediately | Ensured the safety of the patient's use of surgical instruments, and reduced additional cost of emergency sterilization. |
| Palacio et al., 2018 (20) | Colombia | To develop an IoT-based method to improve steam | Hospital sterilization settings | IoT-enabled instrumentation (e.g., IoT | Conventional autoclave | Inferred enhancement of | | reduced inefficiencies and errors | Reduced risk of microbial contamination and |

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|---|---|---|---|---|---|---|---|---|---|
| | | quality monitoring in hospital autoclaves by applying thermodynamic principles | | platform, sensors and single board computer) | monitoring without IoT | sterilization effectiveness | | in sterilization cycles | improved accuracy by use of IoT enabled instrumentation |
| Yang et al., 2022 (21) | China | To evaluate whether applying the "defect management improvement mode" (automated systems) improves cleaning/disinfectio n effectiveness and management quality in CSSD | 32 medical staff from CSSD<br><br>Observation : 16<br><br>Controls: 16 | Defect management improvement mode under JCI standards | Standardized management mode | | Packaging<br><br>Observation: 98.67%<br><br>Control: 81.34%<br><br>Cleaning<br><br>Observation: 98.01 %<br><br>Control: 88.54 % | | Improved the cleaning effect of instruments, enhanced the work situation |
| Ma et al., 2012 (22) | USA | To design and develop a real-time RFID-enabled workflow management framework for Sterile Processing | SPD at John D. Dingell VA Medical Center | RFID-enabled real-time SPD operation management system integrated with a Service-Oriented Architecture | Conventional manual SOP-driven SPD workflows | | | | Improved traceability and monitoring of workflow steps and RMEs<br><br>SOP rule engine introduced for automatic |

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|---|---|---|---|---|---|---|---|---|---|
| | | Departments (SPDs). | | (SOA) workflow system | | | | | performance verification. Real-time data capture of locations, expiry, inventory status, and sterilizer/environment indicators (e.g., temperature). Enhanced failure handling with alerts for environmental deviations (e.g., sterilizer temperature mismatch) |
| Hu et al., 2025 (23) | China | To evaluate the effects of quality traceability system in shared medical community disinfection centers. | Instrument packages; Observation group: 3,302 packages Control group: 3,028 packages | Implementation of a **quality traceability system** | Manual handling | Observation: 65% Control: 55% | Packaging: Observation: 96% Control: 66% | | Improved the quality of medical community instrument management, increased efficiency, and improved staff satisfaction with the process. |

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|---|---|---|---|---|---|---|---|---|---|
| Xiong et al., 2025 (24) | China | To evaluate the effectiveness of a cleaning quality control module integrated into the Disinfection Supply Center (DSC) for improving precision instrument cleaning quality | 3,000 instrument sets | Augmented traceability | Routine/ manual procedures before module implementation | Observation: 99%<br>Control: 91% | Cleaning<br>Observation: 99.2%<br>Control: 96.9% | | Improved instrument cleaning quality, improved technicians training efficiency, and enhanced departmental operational efficiency |

**Characteristics of Included Studies**

Our systematic review analyzed nine studies published between 2012 and 2025 that evaluated the role of smart and automated sterilization tracking systems in Central Sterile Services Departments (CSSDs) and Sterile Processing Departments (SPDs). The main characteristics of the included studies are summarized in Table 1. The studies were conducted across four different countries, including China (16-18, 21, 23, 24), Taiwan (19), Colombia (20) and the USA (22).

The primary objectives across these studies were to assess the effectiveness of digital innovations in sterilization tracking and quality control, including improving cleaning and packaging qualification rates, enhancing traceability, reducing errors, improving staff satisfaction, and strengthening infection control. A variety of automated technologies were adopted. These included visual management flow diagrams (16), automated guided vehicles (AGVs) with sterilization monitoring reports (17), and IoT- and RFID-based quality tracking systems (18, 22). Additional approaches involved high-temperature IoT pressure sensors to monitor sterilization (19), IoT-enabled autoclave steam quality monitoring (20), and a defect management improvement mode under JCI standards (21). More recently, quality traceability systems in community-based centers (23) and augmented cleaning quality control modules (24) demonstrated significant gains in efficiency and error reduction, as mentioned in Table 1.

**Quality Assessment of Included Studies**

The methodological quality of the included studies was assessed using a 9-point checklist covering aspects such as cause–effect clarity, comparability of groups, treatment consistency, control group presence, follow-up, outcome measurement, and statistical appropriateness. As shown in Table 2, most studies achieved **moderate-to-high or high quality**, with total scores ranging from 6/9 to 9/9. Three studies (16, 18, 20, 21) scored 8 or above, reflecting strong methodological

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rigor, particularly in outcome measurement reliability and statistical reporting. However, some studies lacked complete follow-up or adequate control groups, slightly lowering their overall ratings.

Table no. 2: Quality Assessment of included studies by JBI

| Study (Author, Year) | Q1 Cause/Effect | Q2 Similarity of Groups | Q3 Similar Treatment | Q4 Control Group | Q5 Multiple Measurements | Q6 Complete Follow-up | Q7 Same Outcome Measured | Q8 Reliable Outcome Measurement | Q9 Appropriate Statistics | Total Score (out of 9) | Overall Quality |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Yuan et al., 2024 (16) | ✓ | ✓ | ✓ | ✓ | ✓ | ? | ✓ | ✓ | ✓ | 8/9 | High |
| Zhu et al., 2024 (17) | ✓ | ✓ | ✓ | ✗ | ✓ | ? | ✓ | ✓ | ✓ | 7/9 | Moderate–High |
| Ding et al., 2024 (18) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 9/9 | High |
| Hung et al., 2020 (19) | ✓ | ✓ | ✓ | ✓ | ✗ | ? | ✓ | ✓ | ✓ | 7/9 | Moderate–High |
| Palacio et al., 2018 (20) | ✓ | ✓ | ✓ | ✓ | ✓ | ? | ✓ | ✓ | ✓ | 8/9 | High |

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| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Yang et al., 2022 (21) | ✓ | ✓ | ✓ | ✓ | ✓ | ? | ✓ | ✓ | ✓ | 8/9 | High |
| Ma et al., 2012 (22) | ✓ | ? | ✓ | ✗ | ✓ | ? | ✓ | ✓ | ✓ | 6/9 | Moderate |
| Hu et al., 2025 (23) | ✓ | ? | ✓ | ✗ | ✓ | ? | ✓ | ✓ | ✓ | 6/9 | Moderate |
| Xiong et al., 2025 (24) | ✓ | ✓ | ✓ | ✓ | ✗ | ? | ✓ | ✓ | ✓ | 7/9 | Moderate–High |
| Yuan et al., 2024 (16) | ✓ | ? | ✓ | ✗ | ✓ | ? | ✓ | ✓ | ✓ | 6/9 | Moderate |

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**Primary Outcomes**

**1). Clinical Satisfaction**

The graph illustrates clinical satisfaction (%) in observation vs. control groups across four studies (16, 17, 20, 23). Overall, observation groups that adopted automated or smart sterilization tracking systems consistently outperformed controls relying on conventional/manual methods. For instance, Yuan et al. (16) reported nearly universal satisfaction (99%) in the observation group compared to 90% in controls, highlighting the benefits of visual management flow diagrams. Zhu et al. (17) showed a significant improvement from 75% (pre-automation) to 98.4% (post-automation) when automated guided vehicles and sterilization monitoring reports were introduced. Similarly, Hu et al. (23) demonstrated a rise in satisfaction from 55% in manual handling to 65% with quality traceability systems. Xiong et al. (24) also revealed significant gains, with observation groups reaching 99% satisfaction vs 91% in controls. Overall, these findings confirm that digital automation enhances staff satisfaction by reducing workload, minimizing errors, and improving workflow efficiency in CSSDs.

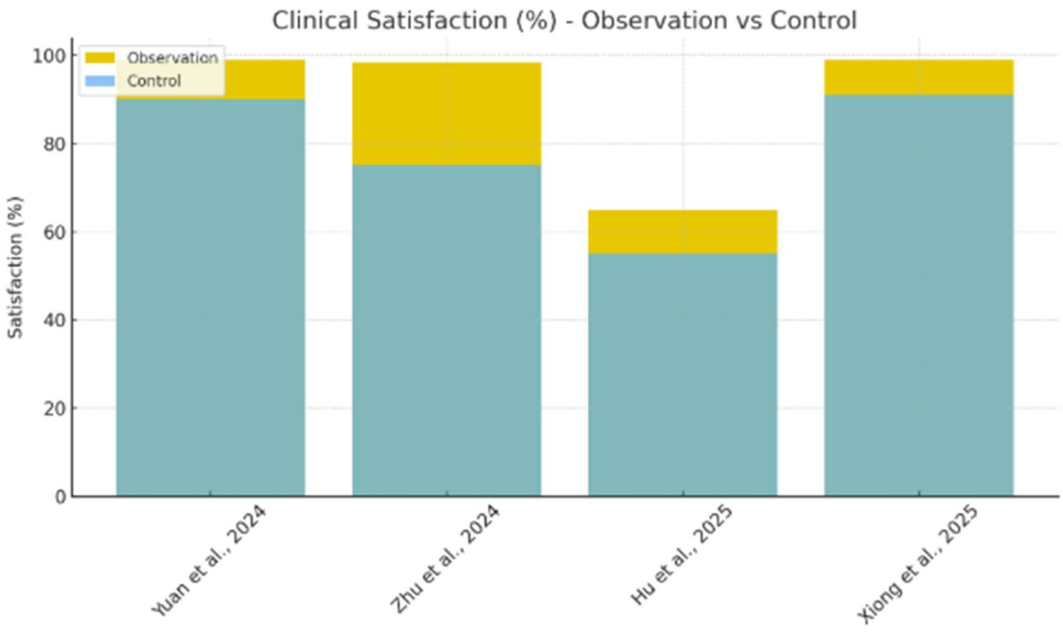


Figure 2: Graphical illustration of % percentage of clinical satisfaction as an outcome of automated systems

**2). Instrument Cleaning qualification rate**

The graph on cleaning qualification rates (%) clearly demonstrates the advantage of automated and smart sterilization systems over conventional manual methods across studies. Yuan et al. (16) reported a rise in cleaning qualification from 95% in controls to 99% in the observation group, reflecting the benefits of visual management flow diagrams. Ding et al. (18) showed a near-perfect improvement with IoT- and RFID-based tracking, where cleaning rates increased from 99.59% to 99.89% and packaging rates from 99.93% to 99.98%, alongside significant time savings per batch. Similarly, Yang et al. (21) demonstrated substantial gains with the defect management improvement mode, showing 98.01% vs 88.54% cleaning effectiveness between observation and control groups. Xiong et al. (24) also reported the effective outcomes, with cleaning qualification improving from 96.9% in controls to 99.2% in the automated system group. Overall, these results demonstrated how automation improves instrument reprocessing's accuracy, dependability, and safety while guaranteeing adherence to sterilization guidelines and reducing the mistakes and unpredictability that come with human procedures.



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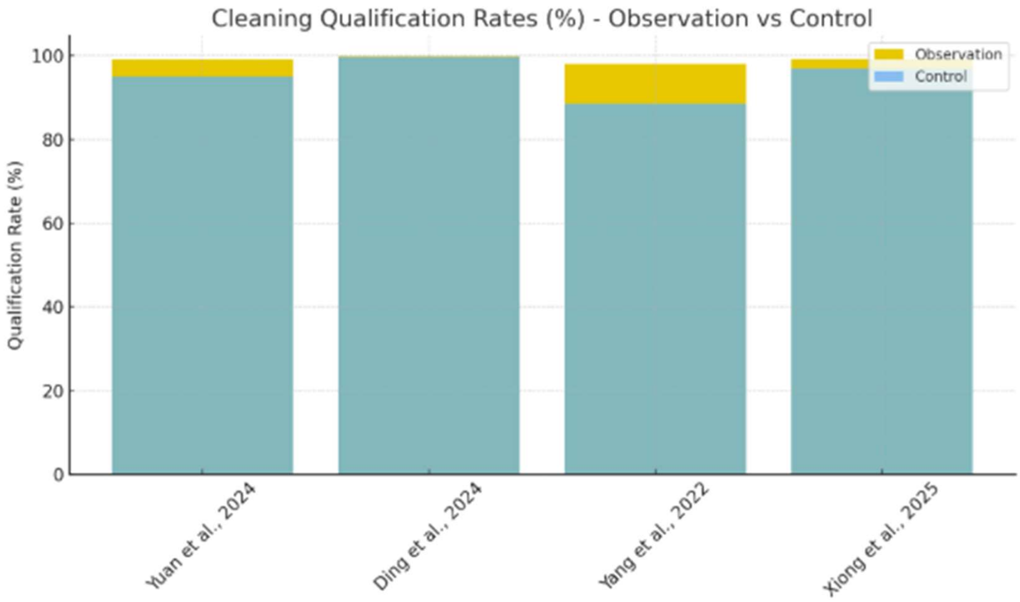


Figure 3: Graphical illustration of %age of cleaning qualification rates as outcome of automated systems

**3). Packaging qualification rate**

Major advantages of automated systems over traditional manual tracking techniques is shown in the graph showing packaging qualification rates (%). With the use of visual management flow diagrams, Yuan et al. (16) showed that packaging qualification increased from 92% in the controls to 96% in the observation group. Using their IoT and RFID-based tracking system, Ding et al. (18) reported almost flawless results, including a significant decrease in processing time per batch (30 minutes to 10 minutes) and an improvement in packaging rates from 99.93% to 99.98%. Yang et al. (21) demonstrated one of the most notable improvements, demonstrating the efficacy of defect management improvement according to JCI standards with packaging qualification rates of 98.67% in the observation group compared to only 81.34% in controls. Similarly, Hu et al. (23) proved important improvements through a quality traceability system, with 96% packaging qualification compared to 66% in manual handling. Overall, these findings suggested that automated systems not only enhance packaging reliability but also strengthen compliance with sterilization protocols, minimize errors, and improve efficiency in CSSDs.



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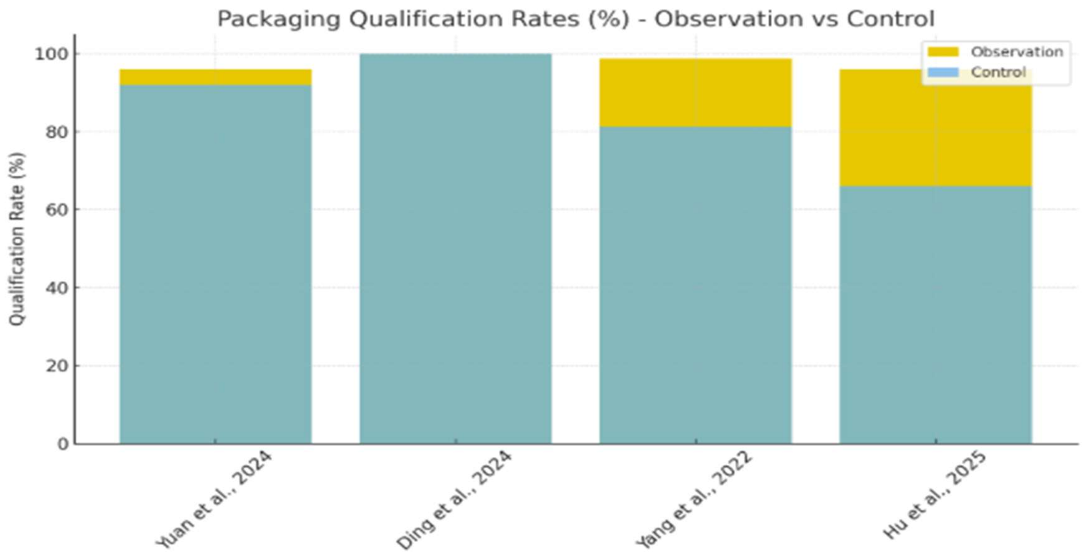


Figure 4: Graphical illustration of %age of packaging qualification rates as outcome of automated systems

Table no. 3: Summary of Key Outcomes of Automated vs. Manual Sterilization Tracking Systems in CSSDs

| Study (Author, Year) | Clinical Satisfaction (%) | Cleaning Qualification Rate (%) | Packaging Qualification Rate (%) | Turnaround Time / Efficiency |
|---|---|---|---|---|
| Yuan et al. [17] | Obs: 99 vs. Ctrl: 90 | Obs: 99 vs. Ctrl: 95 | Obs: 96 vs. Ctrl: 92 | Improved workflow efficiency |
| Zhu et al. [18] | Pre: 75 → Post: 98.4 | – | – | Automated guided vehicles reduced delays |
| Ding et al. [19] | – | Obs: 99.89 vs. Ctrl: 99.59 | Obs: 99.98 vs. Ctrl: 99.93 | Turnaround time: 30 min → 10 min |
| Yang et al. [22] | – | Obs: 98.01 vs. Ctrl: 88.54 | Obs: 98.67 vs. Ctrl: 81.34 | Defect management per JCI improved efficiency |
| Hu et al. [24] | Obs: 65 vs. Ctrl: 55 | – | Obs: 96 vs. Ctrl: 66 | Traceability system reduced errors |
| Xiong et al. [25] | Obs: 99 vs. Ctrl: 91 | Obs: 99.2 vs. Ctrl: 96.9 | – | Improved accuracy and compliance |

Overall, the included studies consistently reported that the implementation of automated tracking systems led to improved instrument cleaning and packaging qualification rates, higher clinical satisfaction, and enhanced operational efficiency, when compared with conventional manual tracking methods.


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## DISCUSSION

This study aimed to evaluate the effectiveness or Outcomes of Smart or automated Sterilization Tracking in Central Sterile Services Departments (CSSDs) by adopting systematic review research approach. This systematic review provided latest evidences about the implementation of smart and automated sterilization tracking systems in Central Sterile Services Departments (CSSDs) and Sterile Processing Departments (SPDs) as it improved multiple outcomes, including instrument cleaning and packaging qualification rates, staff satisfaction, and operational efficiency. Through analysis of 9 included studies and 390,130 instruments/ 32 medical staff members, the findings revealed that clinical satisfaction rates, cleaning qualification rates, packaging qualification rates, and instrument turnout time were improved after the integration of automated sterilization tracking system in clinical settings. Furthermore, the automated solutions, whether RFID-enabled frameworks, IoT sensors, visual flow diagrams, or automated guided vehicles enhanced accuracy and reduced errors compared with conventional manual approaches. All the studies included were of high to moderate quality, as assessed by JBI. Automated sterilization tracking systems directly enhance operating room (OR) turnover by reducing delays associated with missing or unsterile instruments. Faster instrument availability translates into improved workflow efficiency, reduced case delays, and better utilization of OR time. This improvement is critical for hospitals where surgical volume and efficiency directly affect patient flow and financial sustainability.

These findings are consistent with broader trends in the literature, where digital health technologies have been shown to improve quality, traceability, and workflow efficiency in healthcare delivery. For example, prior systematic reviews on digitalization in hospital sterilization or infection control have similarly emphasized the role of smart monitoring in reducing errors and enhancing patient safety. Munir et al., (25) highlighted that RFID and IoT-based systems enhance traceability in surgical workflows, thereby minimizing retained surgical items. Likewise, Whitacre et al., (26) and Piaggio et al., (27) reviewed automation in infection control systems and found significant improvements in compliance and quality assurance. While these reviews were not exclusively focused on CSSDs, they align with the present study in showing the operational and clinical benefits of automation.

The findings of this study have proven that implication of automated sterilization tracking systems in hospital or clinical settings can improve the outcomes and avoid challenges, caused by manual tracing systems for biomedical instruments. By improving cleaning and packaging qualification rates, automated systems significantly strengthen infection prevention efforts. Fewer errors in sterilization reduce the risk of surgical site infections and hospital-acquired infections. In turn, this enhances surgical safety and contributes to improved patient outcomes, aligning with institutional quality and safety goals. Traceability is another critical advantage, as automated systems provide verifiable digital records of sterilization processes. This not only ensures compliance with regulatory standards but also offers strong documentation in medicolegal contexts, where the ability to demonstrate full sterilization traceability can be pivotal in litigation or audits (28).

The findings highlight that transitioning from manual to smart or automated sterilization tracking systems can significantly improve the quality and safety of instrument reprocessing in CSSDs. For managers, this means prioritizing investments in automation to enhance compliance with sterilization standards, reduce human error, and improve staff satisfaction. However, cost-benefit considerations and implementation feasibility remain critical factors. Initial investments in RFID or IoT-based systems may be substantial, and healthcare managers must weigh these costs against long-term savings from reduced surgical errors, improved efficiency, and fewer hospital-acquired infections. OR professionals can expect more reliable instrument availability, fewer delays, and improved patient safety outcomes due to higher cleaning and packaging qualification rates. Implementing such systems not only optimizes workflow efficiency but also strengthens infection control, ultimately contributing to better surgical outcomes and reduced hospital-acquired infections.

From a global readership perspective, the study's applicability was highlighted for developed countries only (29). The adoption of automation may be slowed in low- and middle-income countries (LMIC) due to resource constraints. However,



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the proven advantages for infection prevention and workflow effectiveness imply that incremental implementation, possibly via hybrid systems, may still yield significant safety improvements in these contexts. Cost-effectiveness and implementation tactics in LMIC situations should be specifically examined in future studies.

The study followed PRISMA guidelines, ensuring transparency and reproducibility of the screening and selection process. By including studies from multiple countries (China, Taiwan, Colombia, USA), the review captured diverse contexts of CSSD automation. Unlike prior reviews that emphasized theoretical benefits, this analysis quantified improvements in cleaning and packaging qualification rates, clinical satisfaction, and operational efficiency (30, 31). Use of the JBI critical appraisal checklist ensured a structured evaluation of methodological rigor, highlighting studies of moderate-to-high quality. To our knowledge, this is the first systematic review specifically targeting **CSSD-focused automated sterilization tracking systems**, filling an important gap in infection control literature.

**There are few limitations of this study despite enormous strengths.** Only nine studies met inclusion criteria, reflecting the emerging nature of this research area. This small pool limits the generalizability of findings. The included studies used diverse technologies (RFID, IoT, AGVs, flow diagrams), making direct comparison challenging and preventing meta-analysis. Six of the nine studies were from China, potentially limiting applicability to other healthcare systems with different infrastructures. Additionally, the meta-analysis of such studies can provide more reliable results but it was not possible due to heterogeneity of interventions/outcomes. Lastly, several studies lacked randomized designs or complete follow-up, introducing potential bias. Some studies reported clinical satisfaction, while others reported only process indicators, making it difficult to synthesize across uniform endpoints.

## CONCLUSION

According to this systematic research, automated and intelligent sterilization tracking systems routinely perform better in CSSDs than traditional manual methods. The data shows definite advantages in terms of raising clinical satisfaction, decreasing human mistake, increasing operational efficiency, and raising cleaning and packaging qualification rates. These results provide insights specific to CSSD and are consistent with previous systematic evaluations in the areas of infection control and healthcare automation. Conclusively, automated sterilization tracking is a vital development to contemporary CSSDs, which directly benefits the safety of surgical operations and more effective operating room operations. The evidence shows that its implementation contributes to a significant improvement in the quality of processing, the satisfaction of staff, and traceability. Thus, automation should be regarded as a strategic aspect that hospital administrators and OR managers should focus on to improve patient safety. Long-term economic and clinical outcomes should be solidified in further multi-center studies. To solidify these findings, the evidence needs to be strengthened by further high-quality, multi-center randomized controlled trials evaluating long-term economic and clinical outcomes. Additionally, cost-effectiveness assessments will be crucial to guide the widespread scaling up of these technologies.

## REFERENCES

1. Garg A. Central sterile services department (CSSD). In: Monitoring Tools for Setting up The Hospital Project: Department-wise Planning. Springer; 2023:505-525. doi:10.1007/978-981-99-6663-9_15
2. Fusco SDFB, Spiri WC. Analysis of quality indicators of central sterile supply departments at accredited public hospitals. Texto Contexto Enferm. 2014;23(2):426-433. doi:10.1590/0104-07072014001570013
3. Basu D, Bhattacharya S, Mahajan A, Ramanan VR, Chandy M. The importance of the central sterile supply department in infection prevention and control. Infect Control Hosp Epidemiol. 2014;35(10):1312-1314. doi:10.1086/678072



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4. Bodane MSR, Jarad R, Moholkar N, Suryavanshi P, Yadav M, Bhavsar D. The study of quality control in CSSD. Int J Adv Res Sci Eng. 2018;7(4):32-38. Accessed from: https://ijarasem.com/admin/img/32_The.pdf
5. Yazid NA. Development of automated visual tracking system for surgical instruments [Master's thesis]. University of Malaya; 2016. Accessed from: http://studentsrepo.um.edu.my/6854/
6. Rutala WA, Weber DJ. Disinfection, sterilization, and control of hospital waste. In: Bennett JE, Dolin R, Blaser MJ, editors. Mandell, Douglas, and Bennett's Principles and Practice of Infectious Diseases. 8th ed. Elsevier; 2014:3294-3309.
7. Stergiou GS, Alpert B, Mieke S, Asmar R, Atkins N, Eckert S, et al. A universal standard for the validation of blood pressure measuring devices: Association for the Advancement of Medical Instrumentation/European Society of Hypertension/International Organization for Standardization (AAMI/ESH/ISO) Collaboration Statement. Hypertension. 2018;71(3):368-374. doi:10.1161/HYPERTENSIONAHA.117.10237
8. Hung LH, Wu ZJ, Yan CH, Chen CL. Internet of things and autonomous robots to develop intelligent solutions for sterilization and disease prevention. Eng Proc. 2025;89(1):25. doi:10.3390/engproc2025089025
9. Al-Janabi S, Alkaim A. An innovative electronic sterilization system (S-vehicle, NaOCI.5H2O and CeO2NP) for epidemic areas by virus Covid-19 manage remotely using mobil application. In: AI and IoT for Sustainable Development in Emerging Countries. Chapman and Hall/CRC; 2022:195-204. doi:10.1201/9781003307822-22
10. Sivayamini L, Venkatesh C, Venkatesh B, Sunil K, Surendra P, Reddy NSK. SOBOT: Design and development of UV sterilization ostensible doctor robot for clinical purposes based on IoT. In: 2024 International Conference on Recent Innovation in Smart and Sustainable Technology (ICRISST); 2024. doi:10.1109/ICRISST59181.2024.10921946
11. Aljamali NM, Abdullabass HK, Jawad AM, Alfatlawi IO, Jawd SM. Review on types of automatic sterilization systems in hospitals. Int J Ind Biotechnol Biomater. 2020;6(1):15-21.
12. Ohashi K, Ota S, Ohno-Machado L, Tanaka H. Smart medical environment at the point of care: Auto-tracking clinical interventions at the bed side using RFID technology. Comput Biol Med. 2010;40(6):545-554. doi:10.1016/j.compbiomed.2010.03.007
13. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi:10.1136/bmj.n71
14. Schardt C, Adams MB, Owens T, Keitz S, Fontelo P. Utilization of the PICO framework to improve searching PubMed for clinical questions. BMC Med Inform Decis Mak. 2007;7(1):16. doi:10.1186/1472-6947-7-16
15. Munn Z, Barker TH, Moola S, Tufanaru C, Stern C, McArthur A, et al. Methodological quality of case series studies: an introduction to the JBI critical appraisal tool. JBI Evid Synth. 2020;18(10):2127-2133. doi:10.11124/JBISRIR-D-19-00099
16. Yuan C, Yang X. Application of visual management in enhancing work quality within the central sterile supply department. Altern Ther Health Med. 2024;30(11):126-130.



**CC-BY 4.0 Licensed**

17. Zhu Y, Gu H, Ren X, Wang Y, Qian Y. Application of automated guided vehicle and sterilization monitoring report in disinfection and sterilization process. Supply of Disinfection. 2024;3(2):67-74. doi:10.11910/j.issn.2791-2043.2024.2.03
18. Ding W, Yang Y, Tian Q, Wang Y, Zhang Y, Wu Z. Development of automated visual quality tracking information system for central sterile supply department based on IoT technology. In: Fourth International Conference on Biomedicine and Bioinformatics Engineering (ICBBE 2024); 2024. doi:10.1117/12.3044370
19. Hung LP, Chen KY, Hsieh NC, Chen CL. Using internet of things to improve the sterilization process for surgical instruments in healthcare. J Internet Technol. 2020;21(6):1811-1819. doi:10.3966/160792642020122106022
20. Gonzalez-Palacio M, Moncada SV, Luna-delRisco M, Gonzalez-Palacio L, Montealegre JJQ, Orozco CAA, et al. Internet of things baseline method to improve health sterilization in hospitals: An approach from electronic instrumentation and processing of steam quality. In: 2018 13th Iberian Conference on Information Systems and Technologies (CISTI); 2018. doi:10.23919/CISTI.2018.8399370
21. Yang L, Xun Q, Xu J, Hua D. Application of the defect management improvement mode under Joint Commission International standard to improve the instrument cleaning and disinfection effect and management quality in the central sterile supply department: a randomized trial. Ann Transl Med. 2022;10(3):137. doi:10.21037/atm-21-6610
22. Ma X, Yang K, Reeves P, Yu S. RFID-based healthcare workflow management in sterile processing departments. In: IISE Annual Conference Proceedings; 2012. doi:10.1109/scc.2012.81
23. Hu Y, Yu J, Yang H, Chen L. The effects of quality traceability systems on shared medical community disinfection centers. Sci Rep. 2025;15(1):16396. doi:10.1038/s41598-025-00882-x
24. Xiong J, Jiang W, Wan W, Zuo L, Tu P, Rao DX. Improving precision instrument cleaning with a quality control module: implementation and outcomes. Front Public Health. 2025;13:1553113. doi:10.3389/fpubh.2025.1553113
25. Munir T, Akbar MS, Ahmed S, Sarfraz A, Sarfraz Z, Sarfraz M, et al. A systematic review of internet of things in clinical laboratories: Opportunities, advantages, and challenges. Sensors. 2022;22(20):8051. doi:10.3390/s22208051
26. Whitacre T. The role of robots and smart environments in infection prevention and control (IPC) systems: a systematic review. Infect Control Today. 2023;27(4):NA-NA.
27. Piaggio D, Zarro M, Pagliara S, Andellini M, Almuhini A, Maccaro A, et al. The use of smart environments and robots for infection prevention control: a systematic literature review. Am J Infect Control. 2023;51(10):1175-1181. doi:10.1016/j.ajic.2023.03.005
28. Sookavatana P, Usawalertkamol B, Mongcolpitakkul S, Usawalertkamol T, Pacharapha A. TSS: Traceability Software Solution, A Medical Equipment Sterilization Process Trace-Back System. In: 2023 20th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON); 2023. doi:10.1109/ECTI-CON58255.2023.10153208
29. Garg A, Dewan A. CSSD. In: Manual of Hospital Planning and Designing: For Medical Administrators, Architects and Planners. Springer; 2022:321-331. doi:10.1007/978-981-16-8456-2_29



**CC-BY 4.0 Licensed**

30. Yao W, Chu CH, Li Z. The adoption and implementation of RFID technologies in healthcare: a literature review. J Med Syst. 2012;36(6):3507-3525. doi:10.1007/s10916-011-9789-8

31. Fayad M, Yahiaoui R, Auber F, Pidoux H, Hild O, Picaud F, et al. Traceability of surgical instruments: a systematic review. Appl Sci. 2025;15(3):1592. doi:10.3390/app15031592

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- **Harvard**: Mannan, H.A. and Green, K., 2025. Outcomes of smart or automated sterilization tracking in central sterile services departments (CSSDs): A systematic review. *The Operating Room Global Journal (TORGJ)*, **1**(1). Published 23 October. Available at: https://doi.org/10.64573/torgj2509002

- **Vancouver**: Mannan HA, Green K. Outcomes of smart or automated sterilization tracking in central sterile services departments (CSSDs): A systematic review. *The Operating Room Global Journal (TORGJ).* 2025 Oct 23;1(1). https://doi.org/10.64573/torgj2509002

- **MLA (9th edition)**: Mannan, Hafiz Abdul, and Kevin Green. “Outcomes of Smart or Automated Sterilization Tracking in Central Sterile Services Departments (CSSDs): A Systematic Review.” *The Operating Room Global Journal (TORGJ)*, vol. 1, no. 1, 23 Oct. 2025, https://doi.org/10.64573/torgj2509002

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