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REVIEW

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Digitalised measures for the prevention of central line-associated bloodstream infections: a scoping review

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Abstract

Background Central line-associated bloodstream infections (CLABSI) increase morbidity, mortality, and healthcare costs of hospitalised patients, despite being largely preventable. While evidence-based guidelines for preventing CLABSI are well-established, the implementation of these measures remain suboptimal. Digitalization presents a promising approach to improve guideline adherence, streamline implementation processes, and ultimately reduce CLABSI rates.

Methods This scoping review aims to synthesize the available evidence on digitalised interventions for the prevention of CLABSI. A systematic search was conducted using Medline to identify studies published between January 1, 2014, and March 20, 2024, that reported on the implementation of digitalised preventive measures for CLABSI and evaluated their impact on CLABSI rates. Data extraction included study characteristics, features of the digitalised preventive measures, effectiveness in reducing CLABSI rates, and relevant process outcomes.

Results A systematic search yielded 263 articles, of which six studies were included. Digitalised interventions were predominantly designed for use by nurses in tertiary-level hospitals ($n=6$), primarily in intensive care units ($n=5$) and targeted pediatric patient populations ($n=5$). These measures were often implemented as part of multimodal strategies. The digital interventions included hospital dashboards ($n=2$), mobile applications ($n=2$), automatic notifications of catheter days ($n=1$), and e-learning modules with electronic reminders ($n=1$). The most common study design was quasi-experimental without an external control group. All included studies reported a reduction in CLABSI rates, ranging from 21 to 73%. Healthcare workers generally perceived these digital interventions positively.

Discussion Digitalised interventions for CLABSI prevention seem to be effective in reducing infection rates, likely because of increasing compliance to established guidelines for CLABSI prevention.

Keywords CLABSI, Prevention, Digitisation, Electronic, Quality, Automation, Healthcare associated infections, Vascular catheter

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Background

Central line-associated bloodstream infections (CLABSI) are among the most common healthcare-associated infections, posing a significant challenge for patients and healthcare systems. Patients who develop CLABSI face prolonged hospital stays and an increased risk of mortality, as compared to those who do not develop CLABSI [1, 2]. Evidence-based recommendations to prevent CLABSI prevention are well-established, however insufficiently implemented [3, 4]. The implementation of these measures is often suboptimal, likely due to the increase in the workload for healthcare teams needed to implement such measures. Several components of preventive CLABSI bundles are amenable to automation or digitalisation, such as appropriate indication for placing a central vascular catheter (CVC), checklists for insertion, reminders for the cumulative length of catheterization, and scheduled changes for CVCs, dressings and tubings. Through electronic health records and electronic prescribing systems, digital checklists and protocols can be integrated into healthcare workflows, ensuring more consistent and standardized application, ultimately improving compliance [5] and indirectly reducing CLABSI incidence. Digital tools may also facilitate the continuous education of healthcare staff by providing regular training, access to updated guidelines, and relevant resources, ensuring that Healthcare workers (HCW) have access to the latest evidence-based recommendation. In other domains, digitalization has demonstrated its potential to reduce task completion times and minimize errors [6, 7].

In this scoping review, we aimed to synthesize the available evidence on digitalised measures to prevent CLABSI, focusing on the types of interventions, challenges to their implementation, their effectiveness in reducing CLABSI rates, and HCWs' perceptions of these approaches.

Methods

The study was designed as a scoping review and reported in accordance with the Preferred Items for Systematic Reviews and Meta-Analysis guidelines extension for Scoping Reviews (PRISMA-ScR) [8].

Eligibility criteria

A scoping review was conducted of digitalised measures to prevent CLABSI. Studies were eligible for inclusion in this review if the study reported data on the implementation process and effectiveness of a digitalised measures to prevent CLABSI. We considered a CLABSI prevention measure as 'digitalised' if its application involved information technology in its design or use. We considered preventive measures implemented in isolation or as part of a multimodal approach alongside other non-digital interventions. As the digitalisation of interventions is a relatively recent technological development, we limited our search to studies published between 1 January 2014 and 20 March 2024. The systematic search had no language restrictions, and there were no restrictions in study design, age categories, or setting. Studies were excluded if the digitalisation process was not sufficiently described, if the digitalised process focused only on CLABSI surveillance without any preventive measures, or if the impact on CLABSI rates was not reported.

Information sources and search

We systematically searched MEDLINE for all relevant articles meeting our eligibility criteria. The search strategy included the terms "digitalization", "digitisation", "automation", "computer-assisted", "technology", "electronic", "digital technology", "digital intervention", "digital dashboard", "quality improvement"; "CLABSI"; "prevention"; used in various combinations. Further details of the search strategy are provided in the supplementary material (supplementary Table 1).

Selection of sources of evidence

One reviewer (BO) screened titles and abstracts to identify potentially relevant studies, and then assessed full text articles for eligibility for inclusion in the scoping review. Three reviewers (BO, NB, and GC) read and discussed the articles selected for inclusion.

Data charting process

Data from studies meeting the eligibility criteria were extracted to a table on Microsoft Word® and a data charting form was developed by identifying variables that correspond to the aims of the review. We extracted data on study characteristics (year of the study, study design, setting, study population), on the features of the digitalised preventive measures (type of intervention, non-digitalised measures that were implemented concurrently) and on the impact on CLABSI rates. We also collected data on process outcomes related to the implementation of digitalised preventive measures and on levels of satisfaction of healthcare professionals on the digitalisation of preventive measures, where available. For each study, the reduction in the rate in CLABSI incidence was calculated as the difference between the CLABSI incidence rates before (corresponding to an average over a baseline period) and after the digitalised preventive measure(s) were introduced.

The quality of the studies was evaluated using the Newcastle-Ottawa quality assessment scale [9], which was applied to cohort studies on the following three criteria: selection of the study population, comparability of the groups on the basis of the design or analysis and study outcomes.

Results

Selection of sources of evidence

Our systematic search retrieved 263 records, of which 44 studies were assessed for full-text eligibility. After excluding 36 studies that described non-digitalised interventions, one study in which the digitisation process was unclear and one further study that did not assess the impact on CLABSI rates, six studies were included in this review [10–15](Fig. 1).

Characteristics of studies

The characteristics of the six included studies are presented in Table 1. All had a quasi-experimental design, with only one having an external control group [10], and no randomized-controlled study was included. The studies were most frequently performed in tertiary care hospitals ($n=5$), with only one study also involving two community hospitals. The target population in each of the studies were HCWs, primarily nurses for 2 studies. The studies were conducted in ICU ($n=5$) and non-ICU wards ($n=4$), and most studies were conducted in paediatrics ($n=4$).

Digitalised measures for prevention of CLABSI

The overall aim of digitalised preventive measures in each of the included studies was to reduce CLABSI rate by improving the compliance to pre-established protocols for prevention. Two studies (Papeger et al.. and Chemparathy et al..) carried out in 2014 and 2021, respectively, focused on the implementation of a hospital dashboard [11, 13]. In one study [11], the aim was to produce a digital interface specific to each patient with a CVC, which would enable HCWs to view data related to the insertion and maintenance of the CVC. In the other study [13], the dashboard was part of a hospital-wide automated system, and monitored observance with bundle for CLABSI prevention.

Two studies investigated the use of a mobile application to prevent CLABSI. The CLABSI app® (Chatter, Salesforce Inc., San Francisco, California) [10], enabled HCWs in the intervention group to self-assess their knowledge

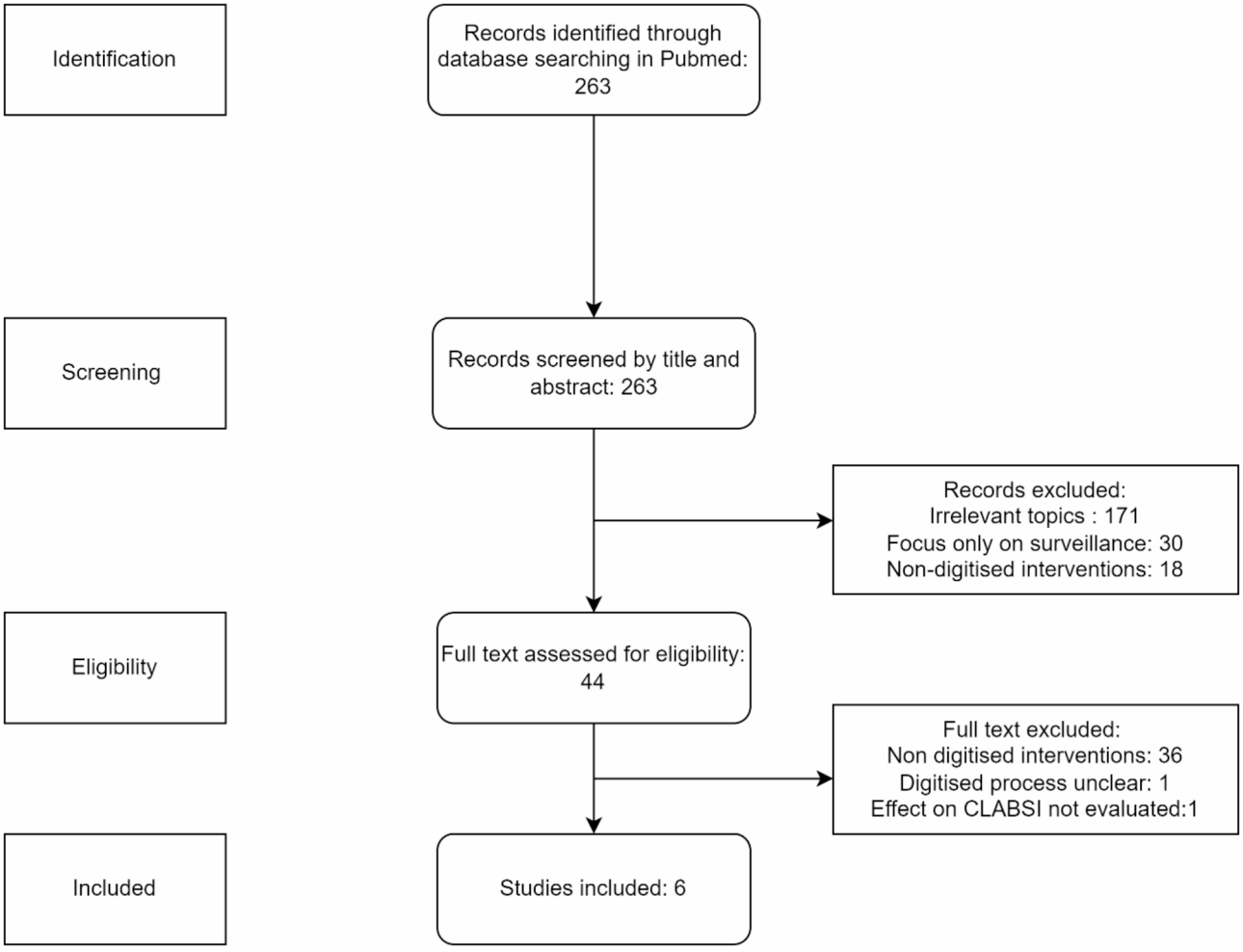

Fig. 1 Study flow diagram

Table 1 Study characteristics

Study (first author, year)	Study period; baseline duration (B); intervention duration (I)	Settings	Study population	Digitalised CLABSI prevention intervention
Engel et al., 2023	2018–2021, B = 24 months, I = 14 months	3 hospitals: 1 university hospital and 2 community hospitals (34 units, 983 beds)	HCWs in adult and paediatric acute care wards	An e-learning module on CHG bathing (background on the evidence and short video) was available for HCW. An electronic reminder in the EHR for daily CHG bathing created a worklist task for nurses and nursing assistants.
Hugo et al., 2022	2017–2021 ; B = 12 months ; I = 27 months	1 quaternary care, pediatric academic hospital (7 inpatient units, 364 beds)	Nurses in paediatric ICU and non-ICU wards	A digital application (Rounds+®) assisted nurses during CVC maintenance rounds by documenting key bundle elements, including line access, dressing changes/port needle insertions, and cap changes. A dedicated nurse recorded observations in the app and marked any protocol deviations as "done with correction" when the deviation was addressed in real-time.
Chemparathy et al., 2021	2015–2019 B= 30 months; I = 15 months	1 pediatric academic hospital (395 beds)	HCWs (physician and nurses) in paediatric ICU and non-ICU wards	An automated hospital-wide CLABSI bundle adherence system was implemented via a dashboard. The dashboard was integrated into the EHR and provided visual representations of bundle-adherence rates across units and bundle elements. Adherence calculations were based on data entered by nursing staff into the EHR during bundle checks.
Orwol et al., 2018	2014–2015 ; B = 12 months ; I = 12 months	1 pediatric academic hospital	Nurses working in paediatric ICU and non-ICU wards	The application (CLABSI App®) served as a self-assessment tool for CVC care. It integrated just-in-time microlearning with in-line explanations of institutional CLABSI prevention bundle elements, on-demand video demonstrations, and visualization of self-reported compliance. Users could compare their performance to unit-wide aggregates, and the app supported customized teams and competitions across shifts and units.
Pageler et al., 2014	2009–2012 ; B = 23 months; I = 4 months	1 PICU (24 beds) in an academic pediatric hospital	HCWs in PICU	An electronic dashboard was integrated into the EHR with a specific interface for each patient to highlight critical clinical data and ensure compliance with evidence-based best practices for CVC insertion and maintenance. The page displayed actionable items, color-coded visual indicators for compliance, and an integrated checklist combining elements of pediatric-specific CVC insertion and maintenance bundles for CLABSI prevention. The checklist was dynamically linked to nursing and physician documentation, displaying only relevant components and providing educational links to support clinician decision-making. In addition, an electronic multipatient dashboard was displayed in the PICU.
Bae et al., 2022	2018–2021 ; B = 16 months ; I = 14 months	1 single tertiary care hospital	HCWs in adult ICU	An automatic notification of CVC-days in the electronic healthcare system was introduced. It displayed the CVC indwelling days in the prescription section of the electronic healthcare system. Medical staff evaluated the need for a CVC every day. Until the assessment of CVC maintenance was completed, the automatic notification of catheter days continued.

Abbreviations: B: baseline; CLABSI: central line associated bloodstream infections; CHG: chlorexidine gluconate; CVC: central venous catheters; EHR: electronic health record; HCW: healthcare workers; I: intervention; ICU: Intensive care unit; PICU: paediatric intensive care unit

and practice of CLABSI prevention measures using real-time microlearning. It also included an option enabling members of the intervention group to assess themselves against other group members from other teams and units at regular intervals. The second application, called Rounds+® (GetWellNetwork, Inc., Bethesda, Md.) [14], enabled trained staff members, known as 'influencers', to observe and document the application of CVC maintenance measures by other nurses during rounds, while improving inappropriate procedures by direct feed-back in real time. The study by Bae et al., looked at the impact of automatic notification of the number of CVC-days after insertion on the incidence of CLABSI [15]. Finally, Engel et al. studied the benefits of the evidence-based practice of using 2% chlorhexidine gluconate (CHG) cloths for daily bathing in a multifaceted CLABSI prevention strategy which included an e-learning module on CHG bathing coupled with electronic reminders in the EHR for the daily CHG bathing [12].

Impact on CLABSI rates

In each of the studies, the impact of the intervention on the CLABSI rate was assessed either by comparing pre- and post-intervention rates [6–8, 10, 11] or using the standardized infection ratio, defined as the ratio of the actual CLABSI rate to the expected rate [14]. Each of the studies demonstrated a substantial reduction effect on CLABSI rates, ranging from 21 to 73% following

the implementation of digitalised prevention measures (Table 2). The CLABSI rate reduction was considered statistically significant in 3 studies [10, 11, 15] and not statistically significant in one study [12]. In 2 studies, a statistical comparison between the two periods was either not performed [14] or not described in the methods [13].

Process outcomes related to the implementation of digitalised preventive measures

Three studies described the digitalisation of preventive measures as having increased the compliance of HCWs to the preventive measures [12–14], while in one study compliance with core preventive measures (all already ≥ 98.8% in the preceding year), decreased marginally during the intervention period on 3 bundle elements. Additionally, the overall compliance rates during the intervention period were slightly lower in the intervention group (94%) than the control group (98%) [10].

Perception and satisfaction

Three studies collected data on perception of the digitalised preventive measures by HCWs [12–14]. Hugo et al. [14] noted initial reluctance, as demonstrated by a drop in the compliance to the maintenance CVC bundle (86.9–40%), followed by an increase in compliance from 40 to 87.1% after some adjustments. In the study conducted by Engel et al. [12], 85% of the nurses reported being satisfied with the e-learning support on CHG bathing, and 62% reported being satisfied with the electronic alert in the EHR for the daily CHG bathing in the worklist task. Chemparathy et al. [13] noted reluctance of some specific units (NICU, Hematology/Oncology, and stem cell transplant units) to the adoption of the use of

Table 2 Impact on CLABSI rates, process outcomes and user satisfaction with the digitalised intervention

First author, year	Impact on CLABSI rate	Process outcomes	Satisfaction/perception
Engel et al.,2023	22.8% decrease on CLABSI rate (from 0.70 to 0.54 CLABSI per 1000 central line days, $p=0.15$)	CHG bathing documentation compliance increase from 77–94.1% from baseline to the intervention period	Over 60 nurses: 85% of satisfaction with the e-learning module; 62% with the EHR worklist task; 85% found the initiative valuable and 78% sustainable
Hugo et al., 2022	42% decrease on CLABSI SIR* (from 0.96 (at the highest point in pre-intervention) to 0.53 (at the last time point post-intervention) CLABSI per 1000 central line days, no statistical test performed to compare the two periods).	Initial decreased compliance to the maintenance bundle from 86.9 to 40.8% in the 1st month then return to baseline rate progressively during the intervention period. Doubling in numbers of rounds performed during the intervention period.	-Reluctance of the nurses in the beginning (qualitative analysis) -Increase in workload in the beginning for the influencers (qualitative analysis)
Chemparathy et al.,2021	21% decrease on CLABSI rate (from 0.82 to 0.6 CLABSI per 1000 central line days, $p=0.001$) (statistical method used for comparison not specified)	Average all-element bundle adherence increased from 25–44% from baseline to intervention period. Highest in NICU (64%), PICU and cardiovascular ICU	NICU, haematology oncology and stem cell transplant units tend to use less frequently because they prefer their own bundle rounds system (real-time follow up and coaching instead of automated process)
Orwoll et al., 2018	48% decrease in CLABSI rate in the intervention group during the study period compared to baseline (from 3.36 to 1.72 CLABSI per 1000 central line days ($p=0.03$) versus an increase in the control group (from 0.79 to 1.65 CLABSI per 1000 central line days ($p=0.09$)).	-Each bundle prevention element had high (> 95%) reported compliance except for patient bathing at 85% (575/673). - Comparing preceding year to study period, intervention group compliance by individual core element ranged from 97.3–100%, with 3 elements scoring slightly lower during the study period than during the preceding year -Overall compliance rates were slightly lower in the intervention group (94%) than the control group (98%)	Not assessed
Pageler et al., 2014	73% decrease on CLABSI rate (from 2.6 to 0.7 CLABSI per 1000 central line days, $p=0.029$)	-Increased compliance for line daily review and documentation of line necessity, frequency of dressing, cap and port needles changes. -Decreased compliance with insertion bundle documentation	Not assessed
Bae et al., 2022	61% decrease on CLABSI rate (from 3.1 to 1.2 per 1000 CVC days, $p=0.047$)	Reduction of catheter days from 956 vs. 819 ($p>0.001$) and short-term CVC per patient from 7.53 vs. 6.74 ($p<0.001$)	Not assessed

CLABSI central line associated bloodstream infections; CVC: central venous catheters; SIR: Standardized infection ratio; CHG: chlorhexidine gluconate; ICU: intensive care unit; NICU neonatal intensive care unit;

*SIR: actual number over the expected number of CLABSI

a dashboard. These units had previously established processes for bundle rounds and trust them to be more accurate, resulting in a hesitancy to utilize the dashboard. For instance, the NICU used real time coaching on bedside rounding for all patients with CVC and preferred this to the automated process.

Quality of the studies

According to the Newcastle-Ottawa quality assessment scale, the studies included in this review were assessed as being of good ($n=1$) [12], fair ($n=4$) [10, 13–15], or poor quality ($n=1$) [11]. All studies clearly defined objectives and outcomes. The minimum duration of the interventions was one year, with appropriate follow-up, providing sufficient time to evaluate the impact on CLABSI rates. However, several limitations were identified. The lack of randomization in the one study with a defined intervention and control group [8] introduced potential bias. Most studies relied on historical cohorts, which inherently carry a risk of selection bias. In several studies, multimodal interventions introduced in parallel digitalised and non-digitalised components; thus, it was not possible to distinguish which components of the multimodal intervention were most effective. Additionally, in five out of six studies, it was unclear whether prior preventive interventions had already influenced CLABSI rates in ways that were not accounted for. Moreover, most studies were conducted in single-center settings, limiting the generalizability of findings. Process outcomes were not systematically measured, further restricting the ability to draw robust conclusions about the mechanisms underlying the reported reductions in CLABSI rates. A detailed table of the quality assessment criteria is provided in the supplementary material (supplementary Table 2).

Discussion

This scoping review summarized the available evidence on the use of digitalised measures to prevent CLABSI and their impact on CLABSI rates. Digitalised interventions for the prevention of CLABSI appear to be effective in improving compliance with preventive measures and reducing CLABSI rates. The limited number of studies conducted in this field suggests that the digitalisation of preventive measures for CLABSI remains relatively novel.

The digitalisation of preventive measures presents an opportunity to facilitate implementation and increase compliance to recommended preventive measures, ultimately reducing CLABSI incidence. Several types of digitalised measures were proposed across these studies. First, electronic reminders integrated into the EHR (list of indications, insertion checklist, dressing change reminders, number of catheter days, alert to reassess the need for catheter retention) could improve compliance with preventive measures for CVC insertion and care. By integrating them into the EHR or an application, compliance with these measures can be monitored in an automated way, allowing timely feedback with comparisons across teams or units. Second, digitalisation offers the opportunity for e-learning and micro-learning with small video capsules that can be visualised during care to improve HCWs' knowledge of good clinical practices for CVC insertion, CVC care or identification of signs of CVC infection. Third, digitalisation offers the opportunity to improve coordination between HCWs. In this context, dashboards can be used to summarise patient-specific data and support decision making by focusing on the elements of the bundle that may have been performed incorrectly, providing a visualisation of the need for corrective action, monitoring and evaluation [16]. Finally, dashboards could also provide visual comparison of HCW performance at the team or unit levels, creating emulation between teams. The different types of digitalised intervention are summarised in Table 3.

Process indicators were collected in all the studies included in this review, and most showed an increase in the completion of activities within the CLABSI prevention bundle. However, slow progress was observed in some studies and even worse performance at the beginning of one study. To better understand how digitalisation may impact CLABSI rates, studies should also collect data on specific process indicators, such as acceptability, uptake, and sustainability of the intervention. Across the included studies, satisfaction levels varied: some features, such as e-learning, were highly rated, whereas others, like checklists, received more moderate feedback. Studies that evaluated acceptance highlight the necessity of an adaptation period for successful adoption [13, 14]. While digital tools offer significant potential, their implementation is not without challenges. In one study, units with higher workloads, typically associated with the care of vulnerable patients (neonatology and intensive care), tended to prefer existing algorithms and procedures and perceived digitalisation as a constraint, rather than an opportunity [10]. Implementation is facilitated by involving end-users early in the design of the intervention and by conducting usability testing throughout the development [17]. A detailed and comprehensive description of the intervention was not always provided in the included studies. An implementation framework to design the intervention properly and adequate description of the interventions are necessary to allow replication. Finally, although technical solutions are essential for implementation; they are rarely sufficient on their own to drive meaningful change. Successful adoption requires adapting these processes to the social and organizational context [18].

Regarding conclusions on the effect on CLABSI rates, the included studies were limited to non-randomized

Table 3 Digitalised interventions for CLABSI prevention

Type of Digitalised Intervention	Examples Related to Central Vascular Catheters	Target
Digitalised checklist (in a mobile application or EHR)	- Indication for catheter insertion - Checklist for catheter insertion - Daily assessment for catheter necessity	Improve compliance with good clinical practices
Automatic reminders in EHR	- Alerts on catheter days - Reminders for dressing changes	Increase compliance with preventive measures and timely catheter removal
Decision-making algorithm	- Guidance on appropriate CVC indication - Algorithm-based recommendations for catheter type selection - Optimised order-sets to guide blood cultures ordering - Alerts for inappropriate catheter use based on patient status	Support clinical decision-making
E-learning modules	- Training on CVC insertion techniques - Simulation-based learning for CVC complications management - Case-based learning on CLABSI prevention - Refresher courses on maintenance bundles	Enhance knowledge of good clinical practices
Dashboard and real-time analytics	- Patient-specific summary of needs and objectives related to CVC with automated reminders - Inter-unit comparison of CLABSI rates and compliance with preventive bundles	Improve monitoring of compliance and early identification of risks
Gamification	- Team-based competition on best compliance with preventive measures - Reward system for adherence to best practices - Interactive quizzes with leaderboards on catheter safety	Motivate healthcare teams through engagement

CLABSI: central line associated bloodstream infections, EHR: electronic health record; CVC: central venous catheter;

designs, often lacking a control group, for which we cannot rule out time-related confounding. In some studies, the reporting of comparison methods was clearly inadequate. Positive findings in this context should be interpreted cautiously. A high risk of bias is associated with greater intervention effect, making a real assessment of the impact of the intervention alone difficult [19]. Stronger study design to properly assess the impact of an infection prevention intervention includes cluster-randomized trials and quasi-experimental studies, ideally with an external control group, using interrupted time-series analysis [20].

This scoping review has several limitations. Firstly, we performed a systematic search of a single database of peer-reviewed literature. Further, digitalisation of preventive measures for CLABSI is a relatively recent concept and we used a relatively conservative definition to consider preventive measures as being 'digitalised'. We considered only studies published during the last 10 years, although this may have missed relevant and pioneering studies published prior to 2014. Finally, the digitalisation process was frequently part of a larger implemented bundle with non-digitalised components, so the observed impact on the CLABSI rates may reflect the effectiveness of other bundle components, rather than digitalisation itself.

Conclusion

Digitalised interventions for the prevention of CLABSI appear to be effective in improving compliance with preventive measures and reducing CLABSI rates. However, very few studies have been published and most of them suffer from weak design (quasi-experimental design without control group). Future research should focus on a rigorous evaluation of the performance and effectiveness of digital CLABSI prevention measures, ideally with interventions integrated into electronic medical records and using appropriate design and include an evaluation of costs.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13756-025-01549-y.

Supplementary Material 1: Supp. **Table 1**: Mesh terms for Search strategy. Supp. **Table 2**: Quality assessment of the studies.

Author contributions

G.C and N.B designed the study. B.O performed the search and extracted the data. B.O, G.C and N.B discussed the results. B.O. and G.C. drafted the main text and tables of the manuscript. B.O. prepared Figure 1. R.G. and S.H. revised the manuscript and made substantial revisions. All authors revised the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare no competing interests.

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