

Review

Central Vascular Access Devices: Current Standards and Future Implications

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Abstract: Background: Central venous access devices (CVADs) are crucial for various medical conditions, but pose risks, including catheter-related bloodstream infections (CRBSI). CRBSI increases comorbidity, mortality, and healthcare costs. Surveillance and evidence-based guidelines have successfully reduced CRBSI rates, although the COVID-19 pandemic has led to increased infection rates. Main body: This review explores strategies for reducing the incidence of CRBSI and examines factors contributing to variations in reported rates across developed countries. Highlighting the significant morbidity, mortality, and healthcare resource burden associated with CRBSI, the analysis delves into evidence-backed preventive measures. It discusses the impact of the COVID-19 pandemic on infection rates and proposes resilient strategies in response to these challenges. The review emphasises the importance of understanding CRBSI pathogenesis, patient, procedure, and device-related risk factors, and the implementation of evidence-guided algorithms and surveillance measures. Recommendations include the use of all-inclusive procedure packs, ultrasound-guided placement, daily dressing changes with antimicrobial treatment, and the use of antimicrobial locks. Conclusions: The review underscores the need for clear, concise algorithms adaptable to various healthcare settings and the scalability of infection prevention systems to ensure resilience.

Keywords: central venous access devices; bloodstream infection; evidence-based preventive measures

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1. Introduction

Various medical conditions require the insertion of central venous access devices (CVADs), such as DEMERS, PICC-line, central venous catheter, Shaldon, etc. CVADs play a critical role in the administration of chemotherapy for oncology patients, the delivery of parenteral nutrition for individuals with intestinal failure, the facilitation of long-term intravenous therapy, and are commonly utilised for haemodialysis. However, the placement of CVADs carries the risk of adverse events (AE). Apart from procedure-related complications (e.g., pneumothorax, vascular shear, haematoma formation), device-related adverse events may also occur. One particularly severe AE is catheter-related

bloodstream infection (CRBSI), a broader term encompassing infections from any type of catheter. The key diagnostic approach includes blood cultures obtained from both the catheter and a peripheral vein; matching pathogens in both samples suggest CRBSI. Culturing the catheter tip can also help confirm the infection. Another term frequently employed is central-line associated blood stream infection (CLABSI) a specific term defined by the U.S. Centers for Disease Control and Prevention (CDC) for bloodstream infections in patients with a central venous catheter. Both terms are often employed interchangeably. While CRBSI/CLABSI are a significant cause of hospital-acquired infections (HAIs) and represent a major concern for patient safety within healthcare environments managing critically ill patients, they also provide a threat to patients in the outpatient setting (i.e., haemodialysis, parenteral nutrition).

CLABSI and CRBSI can significantly increase comorbidity, mortality, and resource utilisation [1]. A study conducted in Canada observed 182 CRBSIs after 3696 CVAD placements in 2531 patients [2]. The incremental cost associated with CRBSI was reported to range from \$11,971 to \$69,332 in the US and from € 13,585 to € 29,909 in Europe [3]. A recent meta-analysis demonstrated a substantial increase in the risk of death among patients with CRBSI (odds ratio, 2.75; 95% CI, 1.86 to 4.07) [4].

The literature highlights the significant morbidity, mortality, and healthcare resource burden [5] linked to CRBSI and CLABSI, prompting the implementation of performance-improving measures [6]. Surveillance for hospital quality and patient satisfaction have been established in many healthcare systems. Reported infection rates are used to deny providers reimbursement for beneficiaries contracting nosocomial infections [7]. Efforts to create evidence-based guidelines for preventing infection [8,9] have been extensive, successfully reducing incidence in various settings, including home parenteral nutrition [10], haemodialysis patients [11,12], intensive care [13] and oncology units worldwide. The European Centre for Disease Control and Prevention (ECDC) and the CDC reported a reduction in CRBSI/CLABSI across all indications for CVAD placement since the implementation of surveillance measures and strict prevention protocols [6,14]. However, significant regional disparities persist, with some countries showing more substantial progress in reducing infection rates through national programmes, while others struggle with higher incidences. Similar trends can be observed in Asia and Africa, where varying levels of healthcare infrastructure influence the prevalence of CRBSI and CLABSI. Additionally, factors, such as changes in public policies, surveillance measures, and the definition of CRBSI/CLABSI, may influence the reported rates. The emergence of the coronavirus disease 2019 (COVID-19) pandemic in 2020 led to a substantial increase in infection rates globally [15], attributable to staff shortages and insufficient CVAD care. Partially, this trend could be linked to the close relationship between practises administering antibiotics and the development of multi-resistant bacteria [16,17]. This review examines strategies to reduce CRBSIs and CLABSI, focusing on factors that influence their varying reported rates across developed countries. It highlights the significant burden of CRBSIs/CLABSI, including high morbidity, mortality, and strain on healthcare resources, and synthesises evidence-based preventive strategies. The review explores patient, procedural, and device-related risk factors, emphasising the need for tailored surveillance and algorithmic approaches in clinical settings.

The terms CLABSI and CRBSI are often used interchangeably due to several factors, including clinical practice not always distinguishing between them, methodological inconsistencies in studies, and the widespread use of CLABSI in mandatory reporting systems like the CDC National Healthcare Safety Network. This overlap can cause confusion when interpreting epidemiological data and evaluating preventive measures. By examining studies using both terms as outcomes, the review reveals how methodological

inconsistencies may introduce confounding factors, stressing the importance of standardised definitions in future research.

Preventive strategies discussed include the use of procedure packs, ultrasound-guided catheter insertion, antimicrobial dressings, and antimicrobial locks. The review also addresses the impact of the COVID-19 pandemic on infection control, proposing resilient strategies to mitigate the rise in infections during such crises.

2. Methods

This review identifies preventive measures for central venous access device (CVAD) infections through an extensive analysis of the current literature and guidelines on catheter-related bloodstream infection (CRBSI) and central line-associated bloodstream infection (CLABSI). Recognising that the interchangeability of CLABSI and CRBSI can complicate interpretation, the authors included studies that used both definitions to capture a broader range of evidence, while acknowledging potential confounding factors affecting data validity. Our review process involved a structured search of primary research articles, clinical guidelines, systematic reviews, and meta-analyses on CRBSI/CLABSI prevention published in peer-reviewed journals in English language. Relevant and up-to-date sources were retrieved from PubMed, MEDLINE, and the Cochrane Library, focusing on publications from the last two decades (since 2000). The search included terms such as “CLABSI,” “CRBSI,” “catheter-related bloodstream infection,” “central-line associated bloodstream infection,” “infection,” “catheter,” “catheter tip,” “prevention,” “preventative measures,” “antimicrobial locks,” “insertion bundle,” “maintenance bundle,” and “guidelines.”

Preventive strategies were categorised based on several key areas identified in the literature as crucial for CRBSI/CLABSI prevention: (1) pathogenesis understanding, (2) procedural standards for CVAD insertion (insertion bundles), (3) post-placement care protocols (maintenance bundles), and (4) institutional practises and policies. For example, the literature examining the pathogenesis of CRBSI highlighted dermal microbiome alterations, routes of infection, and colonisation mechanisms, informing preventive approaches such as hand hygiene, sterile barriers, and endoluminal cleaning practises.

Further, infection control protocols were derived from guidelines published by organisations such as the CDC, Infectious Diseases Society of America (IDSA), and Society for Healthcare Epidemiology of America (SHEA). These guidelines provided foundational standards for procedural steps, including environmental preparation, sterile techniques during insertion, and specific post-placement care, such as daily exit site decontamination with chlorhexidine. The role of hand hygiene was highlighted consistently, with studies showing reductions in infection rates when hand hygiene was rigorously enforced across healthcare settings.

To ensure a comprehensive overview, our review also incorporated recent findings on the efficacy of antimicrobial dressings, coated catheters, and antiseptic locks. These interventions were evaluated in randomised controlled trials, observational studies, and quality improvement initiatives. For instance, antiseptic catheter locks (e.g., citrate and taurolidine) and coated catheters have been studied within various healthcare settings, revealing a range of outcomes related to CRBSI prevention and catheter patency. Each intervention was evaluated based on evidence of effectiveness, practicality in clinical practice, and cost considerations.

Moreover, institutional measures—such as staff training in CVAD care, adherence to standardised algorithms, and surveillance of CRBSI/CLABSI rates—were identified as critical elements in CRBSI prevention strategies. Studies highlighted how training staff in evidence-based procedures significantly reduces CRBSI/CLABSI rates, particularly when tailored to the healthcare setting. Additionally, surveillance measures and public

reporting, influenced by regional policies and financial incentives, were examined to understand their impact on CRBSI/CLABSI rates. These studies provided insights into how changes in surveillance and reporting might influence reported infection rates, underlining the importance of consistent, objective criteria.

Through these combined research methods, our review aimed to provide a holistic understanding of current practises in CRBSI/CLABSI prevention and identify future implications for evolving standards of care.

3. Definitions

Central line-associated bloodstream infections (CLABSI) and catheter-related bloodstream infections (CRBSI) are terms frequently used in clinical and epidemiological research to describe infections related to the use of central venous access devices (CVADs). While often used synonymously, these terms represent distinct concepts with implications for diagnosis, treatment, and healthcare reporting.

CRBSI is a clinical diagnosis that specifically attributes a bloodstream infection (BSI) to the central line as the source of infection. This requires meeting stringent diagnostic criteria, including laboratory evidence such as the recovery of the same organism from the catheter tip and blood cultures or differential time-to-positivity between central and peripheral cultures. CRBSI necessitates a microbiological confirmation that directly implicates the catheter as the source of infection [18].

CLABSI, on the other hand, is a surveillance term primarily used for epidemiological tracking and healthcare reporting. It is defined more broadly by the CDC as a primary bloodstream infection occurring in patients with a central line in place at the time of or within 48 h prior to the BSI, without requiring definitive evidence of the catheter as the infection source. CLABSI diagnoses are typically made based on clinical and timing criteria, rather than microbiological evidence, making it a less specific but more inclusive measure of CVAD-associated infections.

The frequent interchangeability of these terms stems from overlapping contexts in which both are used to describe bloodstream infections in patients with CVADs. However, this can lead to confusion, as the broader criteria of CLABSI tend to overestimate the burden of CVAD-attributable infections compared to CRBSI, which offers more diagnostic precision. This distinction has significant implications for infection surveillance, epidemiological research, and quality improvement initiatives. For example, CLABSI rates are a key performance metric in healthcare settings, influencing infection control policies and reimbursement.

Given the implications of these definitions, this review aims to provide clarity by addressing both CRBSI and CLABSI in terms of their diagnostic criteria, the contexts in which they diverge, and their respective roles in epidemiological studies. This distinction is critical for interpreting the literature, comparing infection rates across institutions, and designing strategies to reduce CVAD-associated infections in diverse healthcare settings.

By shedding light on these nuances, this review contributes to a more precise understanding of CVAD-related infections and supports efforts to enhance infection prevention practises worldwide.

The pathogenesis of CRBSI/CLABSI must be understood to develop appropriate preventive strategies. CVADs are utilised for the percutaneous transvenous administration of various liquid therapies. Consequently, pathogens present in the dermal microbiome can ingress the skin at the insertion site through the outer surface of the CVAD, ultimately colonising the transvenous segments of the device. This colonisation process is presumed to commence with the initial placement of the CVAD [19]. Temporal alterations in the skin microbiome covered by the dressing may exhibit an impact, such as humidity facilitating fungal growth [20].

Endoluminal contamination can ingress through two primary routes: the CVAD hub and the CVAD tip [21]. When conditions conducive to colony-forming unit (CFU) growth are present within the lumen of a CVAD, the development of a contaminated biofilm becomes inevitable. A CVAD that is infrequently accessed provides ample space and time for CFUs to proliferate and potentially result in hematogenous dissemination. Distinguishing between various routes of colonisation has prompted the development of preventive strategies for CRBSI/CLABSI.

In addition to understanding diverse infection routes, preventive strategies must assess specific patient-, procedure-, and device-related risk factors for infection (Table 1). Patient-related risk factors encompass immunocompromised states due to underlying conditions or medications. Procedure-related risk factors involve an inexperienced operator, emergency placement conditions, and inconsistent application of proper sterile techniques during and after placement. Device-related risk factors include the materials and sizes of the CVAD employed, the placement site, and the indication. Historically, strategies to prevent CRBSI/CLABSI have predominantly focused on procedure and device characteristics rather than patient characteristics.

Table 1. predisposing factors for catheter related bloodstream infection [1,3,13,22–28].

Host Related Risk Factors	Procedure Related Risk Factors
Dialysis dependency	Emergency CVAD placement
Renal impairment	Inexperienced operator
Congestive heart failure	Longer duration for placement
Obesity (body mass index > 30)	Lack of proper sterile technique
Diabetes	Improper care after placement
Immunosuppression	Frequency of catheter usage and manipulation
Oral anticoagulation/dual platelet inhibition	Abandoned CVAD lumen
Insertion site haematoma formation	Placement site selection
Previous implant infection	Device related risk factors
Sepsis/bloodstream infection	Materials employed
Malignancy	Number of lumens
COPD	Size
Chronic skin disorders	Indication and dwell time

4. Results

Strategies aimed at reducing incidence of CRBSI/CLABSI across various healthcare settings are outlined in Table 2. This compilation encompasses procedural standards delineated in a step-by-step fashion, providing guidance on the proper placement of a CVAD using standardised infection-prevention practises and appropriate sterile techniques. The listed procedures cover all facets related to infection control, encompassing the identification of an appropriate environment for CVAD placement, disinfection of the patient's skin, masking, gowning, gloving, draping the patient, and the selection of the correct aesthetic. Algorithms have demonstrated efficacy in enhancing compliance with infection control measures during CVAD insertion, thereby reducing the incidence of infections. An observer may be incorporated into the protocol, serving a sterile role to monitor the interventionalist's adherence to the procedure while offering additional assistance when an extra set of hands is required. This setup offers the advantage of allowing the interventionalist to focus on procedural details, minimising the risk of omitting crucial steps.

In general strategies are divided into Insertion Bundles, which are protocols focused on ensuring aseptic technique and minimising contamination risk during the placement

of CVADs, while Maintenance Bundles are strategies applied post-placement to uphold sterility, prevent device colonisation, and manage ongoing use.

The CVAD Insertion Bundle is structured to improve insertion outcomes, minimise complications, and reduce the risk of CRBSI/CLABSI by focusing on seven essential steps. First, appropriate planning is crucial, involving CVAD selection, patient or family communication, documentation of insertion rationale, and completion of a pre-insertion checklist. Second, routine decolonisation should be performed when practical, following guidelines for different patient age groups. Third, the proceduralist should complete a surgical scrub using an appropriate antiseptic. Fourth, antiseptic application must align with patient age: Chlorhexidine for older patients and Povidone-Iodine for younger or more sensitive patients. Fifth, strict sterile barrier precautions are maintained with gown, mask, and eye protection. Sixth, adherence to an insertion checklist is essential. Finally, using a dedicated sterile trolley and pre-packed equipment is recommended to standardise the procedure.

The CVAD Maintenance Bundle aims to reduce complications like infection and thrombosis and to support timely CVAD removal. Essential components include adherence to hand hygiene, ensuring only trained staff handle the device, and conducting regular assessments to confirm ongoing necessity. Dressing and site checks are required each shift, following a strict aseptic technique to prevent contamination, while needle-free ports must be disinfected thoroughly before each use. To reduce infection risk, changes to the CVAD should be minimised, and any necessary adjustments should follow aseptic protocol. Continuous heparinised antimicrobial locks are essential for preventing occlusions, and CVAD pressure settings should be closely monitored. Any occlusion suspicions should be immediately reported, with swift response to ensure safe and effective CVAD maintenance.

In the following details from the bundles briefly outlined above are further elaborated on:

Table 2. measures to prevent CRBSI/CLABSI [13,22,28–38].

Evidence Guided Algorithms

Proper sterile technique including hand hygiene and personal sterile barrier precautions

All-inclusive procedure packs

General decolonisation (proven for ICU only)

2% Chlorhexidine gluconate in alcoholic solution for skin antisepsis

Ultrasound guidance for placement

Subclavian insertion site (ICU; not for hemodiafiltration)

Manual decontamination of caps and hubs employing ethanol after administration of therapy (alternatively commercially available antiseptic containing alternatives)

Frequent dressing changes and exit site hygiene

Antimicrobial locks (between administration of therapy, or repeatedly in case lumen becomes abandoned)

“Wean and clean”-discontinue CVAD therapy as soon as possible-evaluate on a daily basis!

Tailored procedure packs may be designed to meet the specific needs of a healthcare centre or interventionalist, including specific wires, sheaths, or scalpels. Such packs have proven effective in lowering the risk of infection, providing an all-inclusive CVAD-placement solution that ideally contains all necessary devices for the placement procedure under proper sterile conditions. Procedure packs facilitate adherence to the correct algorithm, minimising errors during the CVAD placement procedure. For instance, decisions such as the preferred skin disinfectant (e.g., CHX vs. PVP-I) or the design of the patient drape for a particular CVAD placement site (e.g., subclavian vs. groin) are predetermined, eliminating the interventionalist’s discretion.

Hand Hygiene is a crucial element in any infection-prevention algorithm. This involves washing both hands and forearms with soap and water when visibly soiled. Subsequently, when the skin is thoroughly dry, an alcohol-based sanitiser is applied to both hands and forearms. In cases where the disinfection occurs between two procedures and the hands are not visibly soiled, an alcohol-based sanitiser can be employed without washing. Adhering to the manufacturer's instructions for use is essential when applying sanitisers. Hand hygiene is imperative when handling any CVAD during placement and care. The use of gloves without proper hand hygiene is not recommended, as colony-forming units (CFUs) on the interventionalist's skin can replicate on gloved hands, underscoring the necessity of hand hygiene before gloving. In healthcare settings, particularly where latex gloves are widely used, the potential for allergic reactions to latex, such as contact dermatitis or more severe anaphylactic responses, is a significant concern. This can potentially impact compliance with infection control protocols. For individuals with latex allergies, alternatives such as nitrile gloves or unpowdered gloves are recommended to mitigate these risks. Nitrile gloves, in particular, are known for their hypoallergenic properties and provide a suitable replacement while maintaining high levels of protection against infections and maintaining the integrity of infection control practises. The availability of these alternatives ensures that the needs of both healthcare professionals and patients are met, improving adherence to safety protocols and reducing the incidence of allergic reactions.

Proper sterile barrier conditions are defined as the utilisation of a cap, a mask, sterile gowns, sterile gloves, and the application of a large sterile drape. Ideally, gowns and drapes are composed of polypropylene (PP) rather than cloth. The implementation of maximum sterile barrier precautions during CVAD placement has been correlated with a significantly reduced incidence of CRBSI/CLABSI compared to using only a cap, a mask, sterile gloves, and an inadequately sized or designed drape [39].

For skin preparation, the removal of hair at the intended site of the surgical incision is a customary component of the preoperative routine for various surgeries. Hair removal is often deemed necessary to facilitate adequate exposure and preoperative skin marking, while hair can pose challenges during suturing and dressing applications. To minimise the risk of skin trauma, the use of hair clippers, rather than razors, has been recommended for preoperative hair removal if required. Another method involves the use of depilatory creams, although these require approximately 15 to 20 min to dissolve the hair and may be associated with allergic reactions. While the recommendations for preoperative skin preparation may not directly apply to CVAD placement procedures, if deemed necessary and practical, hair removal using clippers is advised.

Performing skin antisepsis using an antimicrobial compound containing 2% or more chlorhexidine (CHX) gluconate in combination with alcohol before any surgical procedure has shown superiority over aqueous CHX [40] or compounds containing PVP-I [41] alone to prevent infection. This effect has also been ascertained for CVAD placement [42]. Various characteristics of 2% alcoholic CHX preparations are postulated to contribute to their potential superiority in terms of antimicrobial properties. These include attributes such as drying time, mode and speed of action, prolonged activity, effectiveness in the presence of body fluids, and a broad spectrum of activity [43].

The selection of the placement site for CVADs in the Intensive Care Unit (ICU) typically involves the subclavian position. Optimal sites for CVAD placement in other departments or outpatient settings, especially for transcending CVADs, have been researched to a lesser extent [44,45]. When determining the placement site for a CVAD, considerations should be given to the skin microbiome at the chosen site, with distinctions made between femoral access, jugular access, and subclavian access. Adverse events related to CVAD placement in subclavian position versus jugular and femoral veins were less frequent;

however, subclavian access carries an elevated risk of pneumothorax. The selection of the placement site should be guided by factors such as the complexity of anatomy, and ultrasound-guided placement is strongly recommended. Other considerations for site selection include patient discomfort, secure attachment of the CVAD, maintenance of aseptic technique, and patient-related risk factors such as comorbidities and existing CVADs. For the placement of CVADs specifically for continuous veno-venous hemodiafiltration, the subclavian site is discouraged due to factors such as blood exchange rate (size) and the risk of venous occlusion. Additionally, adverse events related to incomplete advancement of the CVAD tip (superior vena cava, nearly opposite the right atrium) should be taken into account.

Antiseptic exit site treatment should be a standard component in all CVAD protocols, emphasising its critical role in reducing infection risks. The post placement care of CVADs is of paramount importance in preventing infection. As part of the daily routine, antimicrobial treatment of the CVAD exit site should be administered during dressing changes, both in hospital and on an outpatient basis. The decontamination process for the CVAD placement site and the surrounding skin should involve the use of CHX in 70% alcohol. Sufficient time should be allowed for air drying. In cases where the manufacturer's instructions prohibit the use of alcohol with their CVAD, ready-to-use aqueous CHX compounds are recommended for decontamination [43].

Antiseptic Wound Dressings such as dressings containing CHX and PHMB were able to decrease microbial CVAD insertion site colonisation significantly [46], and, in some studies, a significant impact on the decrease in infection could be shown [47]. Dressings incorporating a CHX adjunct are commonly utilised and are offered in various forms, such as a CHX gel and a CHX sponge dressing. The mechanism of action for both versions is to prevent the colonisation of the outer surface of the CVAD at the skin exit site. However, when these dressings were initially introduced, a motivating factor for their adoption was the potential for reduced frequency of dressing changes, attributed to the antimicrobial activity of these dressings. If their use results in decreased attention to CVAD exit site care due to corresponding marketing strategies, adverse events in this context may be anticipated [48].

Antiseptic Body Wash combined with nasal mupirocin or octenidine during targeted decolonisation (i.e., in patients who are *S. aureus* carriers) prior to cardiothoracic, vascular, orthopaedic, gastrointestinal, or general surgery lower the incidence of surgical site infection caused by *S. aureus* (including methicillin-susceptible and methicillin-resistant strains) [49]. Any antiseptic body wash has failed to consistently show a positive effect for different CVAD populations, except for ICU patients undergoing general decolonisation [50]. More contemporary data concluded that continuous topical suppression treatment in home parenteral nutrition for long-term decolonisation may be feasible and preferred over targeted decolonisation [51]. Nevertheless, there is a potential for increased resistance patterns to emerge. To support general decolonisation or chronic suppression in patient populations other than critically ill individuals, additional studies are required [29,52].

The selection of CVAD materials and size, including factors such as the number and diameter of lumens or the CVAD itself, plays a critical role in either promoting or preventing CRBSIs. For cases involving total parenteral nutrition, a single-lumen CVAD is recommended. Silicone elastomer has become the material of choice for long-term venous access, completely replacing polypropylene (PP)-based CVADs. Alternatively, polyurethane is employed for shorter-term CVADs. Consequently, the interventionalist must carefully consider not only the sizes but also the material choices during placement [53].

The literature on infection risk among various types of CVADs is somewhat inconsistent, with studies often reporting differing infection rates across device types,

depending on factors such as catheter insertion site, duration of use, and patient condition. In general, non-tunnelled central venous catheters (nCVCs) tend to present the highest risk of CRBSI, particularly when in situ for prolonged periods. Peripherally Inserted Central Catheters (PICCs) are typically associated with a lower risk of infection compared to nCVCs, likely due to their more peripheral insertion site and reduced likelihood of contamination. Tunnelled CVCs (tCVCs) and ports (port-a-cath), placed deeper into tissue, demonstrate a lower infection rate than nCVCs, offering added protection by reducing the exposure of the catheter to external contaminants [54]. In China, preventing bloodstream infections associated with PICCs and CVCs has been a significant focus, especially in hospital settings. A study analysing the epidemiological patterns of CRBSI examined outcomes for adult patients with either a PICC or a CVC. Covering data from 2017 to 2020, the research included over 224,000 catheter insertions and assessed infection risks up to 30 days post-insertion. Findings indicated that CVCs were associated with a significantly higher CRBSI risk compared to PICCs, which appeared to offer a protective effect against CRBSI [44].

The efficacy of coated CVADs in preventing CRBSI has been demonstrated, but contemporary data on their effects is lacking [55]. Previous studies were conducted without CRBSI prevention algorithms aligned with current standards. To comprehensively assess the impact on CRBSI prevention, studies evaluating specific antimicrobial dressings used adjunct to coated catheters, optimal practice guidelines, and antimicrobial locking solutions are warranted. It remains uncertain whether the combined effort of these interventions is impactful in preventing CRBSI, and currently, a recommendation for the routine use of coated CVADs cannot be provided where a proper algorithm is already in place.

Effective antiseptic treatment of CVAD hubs and caps is imperative as these components are handled multiple times throughout the CVAD dwell time [28]. Contamination of prosthetic materials can occur through the direct transfer of pathogens from the patient's skin or via the hands of caregivers. In all post-placement care algorithms for CVADs, manual decontamination of hubs and caps is mandatory. This typically involves immersing the cap in CHX in 70% ethanol or ethanol alone, accompanied by the use of antimicrobial compound-soaked swabs to mechanically wipe the extracorporeal surfaces of the CVAD. Commercially available antiseptic-containing connector or cap protectors simplify this step by continuously bathing the access site with alcohol-based antiseptics. However, despite evidence of their effectiveness, these protectors are not recommended as a substitute for the mechanical decontamination of caps and hubs, and head-to-head trials are currently lacking.

Antimicrobial Catheter Locks have been developed as alternatives to heparin-based locks, which, in the late 2000s, were found to increase CRBSIs when compared to saline alone [56]. Roughly two decades after their initial introduction, antimicrobial locks have become integrated into many national and international evidence-based guidelines. Various antimicrobial compounds are available for locking CVADs [9,11,57–67].

Citrate: Citrate-containing antimicrobial locks have demonstrated the ability to prevent infection while simultaneously preserving catheter patency. The use of citrate alone, at a relatively low cost, has been effective in maintaining catheter patency at low to medium concentrations (2–4%). However, it has not consistently demonstrated the ability to prevent infection.

Ethanol: Ethanol-based locks have the ability to prevent infection at a relatively low cost. However, it is important to note that the use of ethanol adversely impacts catheter patency by causing clotting within the lumen and directly damaging the catheter material.

Antibiotics: The use of antibiotic locks is generally not recommended. To achieve a bactericidal effect, the multiple of minimal inhibitory concentrations is required, ensuring prevention of colonisation of the CVAD. This may explain why antibiotic locks have not

been able to significantly decrease the incidence of infection. Antibiotics are ineffective in preventing biofilm formation and can contribute to the development of resistance when used as an adjunct to any catheter lock.

Taurolidine: Taurolidine, a derivative of Taurine (a non-essential amino acid), exhibits broad-spectrum antimicrobial activity. Commercially available locks that incorporate taurolidine as an adjunct to heparin, urokinase, and citrate in various galenic formulations have demonstrated effective prevention of infection. This efficacy has been observed in diverse healthcare settings, including cancer units, paediatric units, dialysis units, and in the context of total parenteral nutrition, both within hospital settings and on an outpatient basis. The main drawback associated with its use is the incurred cost, particularly with frequent application.

Finally, the CVAD dwell time is crucial for the development of related infection. The indication for any CVAD and its continuation should be evaluated daily and the therapy initially administered parenterally should be administered orally as early as possible [68]. A CVAD that is not in situ cannot become infected or lead to infection [13].

Staff who are appropriately trained in the handling and care of CVADs play an irreplaceable role compared to any of the preventive strategies outlined earlier [69–71]. Therefore, the training of staff involved in CVAD care and the implementation of evidence-based recommendations in algorithms for CVAD placement and proper handling after placement are crucial for the mitigation of infection rates [21,72,73].

Surveillance of both CRBSI rates and the mode of surveillance can influence data collection and interpretation [38,74]. The criteria for diagnosing CRBSI/CLABSI, whether potential or definitive, may not always be objective. In regions with established policies, the linkage of public reporting and financial penalties to reported rates could encourage a thorough investigation into other potential sources of bloodstream infection. For instance, defining the growth on the catheter tip during susceptibility screening as a secondary rather than the primary source of infection. The reporting of lower CRBSI/CLABSI rates within healthcare systems following the introduction of reimbursement restrictions or public quality reporting systems is suggestive. Despite the rigorous application of clear criteria, data reliability remains low. The introduction of new categories (e.g., mucosal barrier injury leading to bacteraemia) can significantly alter rates in some regions when policies change. Therefore, distinguishing between improvements in clinical outcomes and the effects of changes in CRBSI/CLABSI definitions becomes challenging [72,75].

5. Discussion

The reduction in CRBSI/CLABSI rates has been a success story in recent years, attributed to several factors including evidence-based guided algorithms, technological advancements, and surveillance measures. However, the onset of the COVID-19 pandemic in the early months of 2020 resulted in a significant setback, erasing the progress made and creating a two-year gap in knowledge due to a lack of healthcare and scientific resources. A major issue was the reallocation of healthcare resources, with hospitals diverting efforts to address the overwhelming demands of managing COVID-19 cases, often at the expense of routine infection prevention measures. This reorganisation, compounded by widespread staffing shortages, increased workloads and stress among healthcare professionals, conditions which are known to undermine adherence to protocols. Additionally, shortages of personal protective equipment (PPE) disrupted sterile techniques during CVAD procedures, with many facilities resorting to PPE reuse, thereby increasing the risk of contamination. Evidence from pandemic studies indicates that these pressures correlated with a rise in bloodstream infections, underlining the systemic impact of resource and personnel constraints. Similarly, many efforts in various healthcare areas, including antibiotic stewardship, infection prevention, and research, experienced regression.

In response, it is imperative to establish robust infection prevention regimes that can withstand challenging environmental conditions and contingencies. These strategies should provide clear guidance through easily applicable algorithms with minimal steps, utilising universally available technology to make infection prevention accessible and feasible in any global setting.

While a reasonable staffing ratio, coupled with proper training, can make many preventive measures discussed here redundant, the worsening staff shortage may lead to a diminishing focus on adequate post-placement care of CVADs. Consequently, well-intentioned algorithms may become less effective. Therefore, there is a need to place greater reliance on the evidence created for infection prevention (Table 2). The application of all available technologies, such as specific CVADs, particular dressings, protective caps, and antimicrobial locks for every placed CVAD, may be a reasonable approach in high-income countries.

Adopting advanced technologies in low-resource settings faces several challenges. First, the cost of procuring high-quality, customised procedure packs, which include essential sterilisation tools and devices, can be prohibitive. In many low-resource settings, there is also limited access to essential supplies like antimicrobial locks, ultrasound-guided technology, and the required protective gear for maximum sterile barrier precautions. Additionally, adherence to hand hygiene protocols and the availability of alcohol-based sanitisers may be inconsistent, complicating efforts to prevent infections like CRBSIs. The challenge of maintaining sterile conditions during central venous catheter (CVC) insertion is further exacerbated by insufficient training and lack of specialised personnel. The use of advanced antiseptic treatments and antimicrobial dressings, although effective, requires consistent access to these materials and knowledge of their correct application, which may not be readily available. Furthermore, the financial constraints and inconsistent supply chains often prevent the implementation of effective long-term decolonisation strategies. Even with evidence supporting the use of specific materials and methods, such as silicone elastomer for CVADs or the use of antimicrobial-coated catheters, resource limitations and financial priorities frequently lead to suboptimal outcomes. Lastly, the ongoing need for staff training and up-to-date protocols becomes difficult to achieve without sufficient healthcare infrastructure and the necessary organisational support. As such, while these technologies and strategies can greatly reduce infection rates, their successful implementation in low-resource settings depends on overcoming these multifaceted barriers, including financial, educational, and supply chain challenges.

To overcome these obstacles, a multifaceted approach is essential. First, governments, NGOs, and private stakeholders should collaborate to subsidise costs and promote the local production of high-quality procedure packs and sterilisation tools, reducing dependency on expensive imports. Training programmes using low-cost simulation tools and telemedicine platforms can bridge knowledge gaps among healthcare providers and ensure proper technique and protocol adherence. Supply chain improvements, supported by partnerships with global health organisations, can stabilise access to essential materials like antimicrobial locks and dressings. Advocacy for hand hygiene campaigns, along with the distribution of affordable alcohol-based sanitizers, can enhance adherence to infection prevention practises. Finally, integrating advanced technologies such as antimicrobial-coated catheters into national healthcare policies and leveraging bulk procurement strategies may help prioritise and sustain their use in low-resource settings.

While CRBSI/CLABSI are a significant cause of hospital-acquired infections (HAIs) and represent a major concern for patient safety within healthcare environments managing critically ill patients, they also provide a threat to patients in the outpatient setting commonly undergoing parenteral nutrition or haemodialysis.

6. Conclusions

In conclusion, this review aims to provide clinical implications. The utilisation of a clear, concise, and easily applicable algorithm for both the placement and care of CVADs in the sense of insertion and maintenance bundles are recommended. These algorithms can be tailored to meet the specific needs of a given geography. Additionally, the use of a cost-effective, procedure-specific procedure pack that includes eligible and ready-to-use materials with a well-documented history of being free from adverse events (AEs) for the intended indication is proposed. Ideally, this pack should also encompass personal barrier protection. Furthermore, ultrasound-guided placement, daily dressing changes with concurrent antimicrobial treatment at the exit site, and the use of an eligible and readily available antimicrobial lock after CVAD placement and between sessions administering nutrition and/or medication are advocated.

The scalability of any infection-prevention system enhances its resilience, making it adaptable to changing circumstances.

7. Future

Future research on strategies to mitigate the incidence of CRBSI and CLABSI should prioritise innovative technological advancements, such as antimicrobial catheter coatings, sustained-release dressings, and novel lock solutions, while ensuring cost-effectiveness for diverse healthcare settings. Tailored approaches must be developed for resource-constrained environments, with a focus on practical, adaptable protocols and improved accessibility to sterile supplies. Emphasis on behavioural interventions, including enhanced staff education, real-time adherence monitoring, and patient engagement, is critical for fostering sustainable compliance with evidence-based guidelines. Multicentre trials and longitudinal studies are necessary to validate simplified infection-control algorithms and assess the real-world efficacy of these interventions across varied clinical contexts, particularly in outpatient or home-care scenarios. Additionally, integrating economic analyses and global health strategies will ensure equitable access to these advancements, while targeted research on special populations and the impact of systemic challenges, such as pandemic disruptions, can further refine practises to achieve broader and lasting reductions in CRBSI and CLABSI rates.

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