REVIEW ARTICLE

The epidemiology, pathogenesis, and prevention of peripherally inserted central catheter (PICC)-related bloodstream infections in cancer: A systematic review

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Peripherally inserted central catheters (PICCs) are indispensable for long-term chemotherapy and supportive care in patients with cancer, but PICC-related bloodstream infections (PICCR-BSIs) remain clinically important complications associated with treatment interruption, prolonged hospitalization, excess mortality, and antimicrobial resistance. This review aimed to synthesize current evidence on epidemiology, pathogenesis, diagnosis, and prevention of PICCR-BSIs in cancer patients and to clarify prevention strategies applicable to immuno-compromised oncology settings. A systematic search of PubMed, Embase, and the Cochrane Library was conducted up to 2025, and relevant studies were narratively synthesized. The reported incidence of PICCR-BSIs in cancer patients was approximately 2.0 - 4.0 per 1,000 catheter-days, higher than the 1.0 - 2.1 per 1,000 catheter-days observed in non-cancer populations. In cancer patients, causative pathogens often included multidrug-resistant Gram-negative bacteria and fungal organisms, particularly in patients receiving chemotherapy or experiencing prolonged neutropenia. Pathogenesis reflected the interaction of microbial invasion, biofilm formation, catheter-related factors, and host immunosuppression driven by chemotherapy-induced neutropenia and mucosal barrier injury. Conventional culture-based diagnosis might be insufficient in immunocompromised hosts. Therefore, paired cultures, biomarkers, rapid molecular assays, and resistance profiling should be combined when clinically indicated. Preventive strategies included evidence-based catheter selection, antimicrobial-coated devices, chlorhexidine-based skin antisepsis and dressings, selected lock therapies, strict nursing practice, patient education, and multidisciplinary follow-up. PICCR-BSIs in cancer patients are high-burden, multifactorial infections. A proactive and individualized prevention framework integrating materials science, rapid diagnostics, nursing competency, and multidisciplinary management is essential to reduce infection-related morbidity and mortality without disrupting anticancer treatment.

Keywords: peripherally inserted central catheter; catheter-related bloodstream infection; neoplasms; multidisciplinary team.

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Introduction

The International Agency for Research on Cancer reported that there were approximately 20 million new cancer cases worldwide and 9.74 million cancer-related deaths in 2022 [1]. Contemporary cancer treatment relies on multimodal strategies including surgery, chemotherapy, radiotherapy, targeted therapy, immunotherapy, traditional Chinese medicine, and interventional therapy. International clinical practice guidelines illustrate the importance of

coordinated surgical and systemic treatment pathways in cancer care [2]. Emerging translational approaches such as micro- and nanoplastic-related perspectives on carcinogenesis and therapy [3], proteolysis-targeting chimeras [4], and exosome-based therapeutic platforms [5], have further expanded the therapeutic landscape. Chemotherapy remains a foundational systemic treatment because it can rapidly target disseminated disease and eliminate micrometastatic lesions, although its effect on quality of life and end-of-life care requires careful clinical judgment [6]. In selected cancers, chemotherapy also serves as a backbone for combination strategies with immunotherapy [7]. With rapid advancements in intravenous infusion technology and the increasing technical competence of healthcare professionals, central venous catheterization has become an indispensable component of multidisciplinary cancer care. It enables long-term administration of chemotherapy, parenteral nutrition, and supportive agents, reduces venous irritation caused by vesicant or hyperosmolar drugs, and lowers procedural risks when appropriately managed [8]. Compared with centrally inserted central venous catheters, a peripherally inserted central catheter (PICC) can be placed with less insertion-related trauma, avoids mechanical complications associated with central venous puncture, has practical value in patients for whom central venous access is technically difficult, and supports high-flow infusion, hemodynamic monitoring, and pressure injection when a suitable device is selected. These clinical advantages are supported by studies of PICC use in intensive care populations [9], current infusion therapy standards [10], and scoping evidence on nursing interventions for PICC-related complication prevention [11]. The value of a PICC therefore lies in balancing efficacy, safety, and quality of life by establishing a reliable bridge between high-risk intravenous treatment and fragile venous access conditions. Despite the critical role of PICCs in cancer care, their use is associated with central venous catheter-related bloodstream infection and thrombosis with reported complication rates ranging from 2.27% to 14.73% [12]. Once bloodstream infection occurs, treatment interruption is often unavoidable because patients require immediate diagnostic evaluation, empirical antimicrobial therapy, and catheter removal when clinically indicated. In cancer patients, interruption of anticancer therapy can cause secondary clinical harm, exacerbate antimicrobial exposure, and increase treatment costs. A multicenter study reported that mortality among patients with PICCR-BSI was 1.89 times higher than among those without bloodstream infection [13]. These considerations underscore the need for PICCs that are safe, reliable, cost-conscious, and practical for patients with cancer. Although central line-associated bloodstream infection (CLABSI) guidelines provide an essential framework for catheter infection prevention, evidence specific to cancer patients remains fragmented. This review synthesized current knowledge on PICCR-BSI in cancer patients and proposed a structured prevention and management approach tailored to the oncological setting.

Epidemiology of PICCR-BSI in cancer patients

Epidemiological data indicated that the incidence of PICCR-BSI is approximately 1.0 - 2.1 cases per 1,000 catheter-days in non-cancer patients and 2.0 - 4.0 cases per 1,000 catheter-days in cancer patients. A propensity-score-matched analysis found that cancer patients receiving chemotherapy had a higher PICCR-BSI incidence than non-cancer patients [14]. These findings underscore the persistent vulnerability and heightened infection risk of the oncological population. In hematology and oncology practice, updated guideline recommendations emphasized that patients with hematologic malignancies required special attention because profound immunosuppression could increase catheter infection risk [15]. Catheter dwell time and prevention bundle implementation also influenced bloodstream infection risk in central venous access populations [16], and a prior history of PICC placement had been identified as

an independent risk factor in vascular access team practice [17]. Multicenter data also indicated that, in some treatment settings, patients with solid tumors might have a higher observed PICCR-BSI risk than patients with hematological malignancies [18]. Additionally, neutropenic cancer patients with bloodstream infections faced higher mortality risk than those without neutropenia [19]. In non-cancer patients, PICCR-BSI was often caused by Gram-positive bacteria such as coagulase-negative S*taphylococci*, methicillin-resistant *Staphylococcus aureus*, and vancomycin-resistant *Enterococci*. In contrast, cancer patients more frequently experienced infections involving Gram-negative pathogens including *Enterobacterales*, *Acinetobacter baumannii*, and multidrug-resistant *Pseudomonas aeruginosa* [20]. Fungal pathogens also contributed substantially to PICCR-BSI risk in cancer patients with prolonged neutropenia [14]. Cancer patients should therefore be regarded as a high-risk group for PICC-related fungal infection, while PICCR-BSI caused by Gram-negative bacteria could also occur in non-cancer patients under specific clinical conditions [21]. Tailored analysis of causative microorganisms, temporal trends, and drug-susceptibility profiles is necessary to optimize antimicrobial selection and dosing across patient populations and treatment environments. In addition to causative microorganisms, PICC dwell time and insertion frequency influence PICCR-BSI risk. A multicenter cancer cohort showed that PICCR-BSI predictors varied across cancer populations and treatment contexts including solid tumor groups [18]. Another study found that bloodstream infection rates differed according to catheter placement duration after implementation of prevention bundles [16]. A vascular access team study reported that previous PICC placement was the sole independent risk factor for PICC-related bloodstream infection [17]. Consequently, judicious control of catheter dwell time, reinsertion frequency, and individualized vascular access planning is essential for PICCR-BSI prevention.

Pathogenesis and risk factors

1. Microbial invasion pathways

The mechanism of PICCR-BSI can be understood through three interrelated stages including microbial invasion, biofilm formation, and host-pathogen interaction. Microbial invasion occurs mainly through extraluminal, intraluminal, hematogenous, and infusion-contamination routes. The extraluminal route is common soon after insertion. Skin commensals such as coagulase-negative *staphylococci*, *Staphylococcus aureus*, and *Corynebacterium* adhere to the catheter's external surface, bind to adsorbed fibrinogen and fibronectin, migrate toward the catheter tip, and enter the bloodstream. The intraluminal route is particularly important for long-term catheters because organisms from healthcare workers' gloves, the patient's skin, or needleless connectors can enter the lumen during catheter access or drug administration. Residual blood and nutrient-rich infusates within the lumen provide an environment favorable to planktonic growth, and antiseptic barrier caps have been evaluated as one strategy for reducing hub-related contamination [22]. Beyond the lumen itself, surveillance in long-term care settings illustrates that healthcare-associated infections and antimicrobial exposure vary across care environments, reinforcing the need for setting-specific prevention protocols [23]. Hematogenous spread occurs when organisms from distant infection sites seed an implanted catheter through the bloodstream and colonize a pre-formed fibrin sheath. Although less common, contaminated infusate can introduce a high pathogen burden directly into the circulation and may cause fulminant outbreaks.

2. Biofilm formation

The formation and maturation of biofilms constitute a central pathological basis for PICCR-BSI, and an estimated 65% of clinical infections are associated with biofilm [24]. Within minutes after catheter insertion, plasma proteins adsorb nonspecifically onto the catheter surface, creating receptors for pathogen adhesins while

impairing immune recognition. The foundational biofilm concept explains how adherent bacterial communities persist on natural and artificial surfaces [25]. In the catheter context, biofilm-associated infection resembles other implant-related infections because organisms embedded in matrix material resist host defenses and antimicrobial exposure [26]. Within several hours, planktonic bacteria attach through van der Waals interactions, hydrophobic effects, and adhesin-mediated binding. Host immune compromise reduces neutrophil and macrophage recognition and phagocytosis, thereby accelerating colonization. Over subsequent days, microorganisms synthesize extracellular polymeric substances composed of polysaccharides, lipids, proteins, and extracellular DNA, forming a three-dimensional matrix. Quorum-sensing pathways then enhance community resilience and resistance to antimicrobial agents, while metabolic heterogeneity produces slow-growing or dormant subpopulations in deeper layers [27]. In *Staphylococcus aureus* biofilm models, these processes have been linked to persistent pathogenicity and potential therapeutic targets [28]. Mature device-associated biofilms act as physical and biochemical barriers, periodically releasing planktonic bacteria and toxins into the bloodstream and contributing to recurrent bacteremia, metastatic complications, and multidrug resistance [29]. These dynamics explain the clinical hallmarks of PICCR-BSI as therapeutic recalcitrance, frequent recurrence, and high antimicrobial tolerance.

3. Host-pathogen interaction in cancer

Among cancer patients, the pathogenesis of PICCR-BSI is amplified by host immune dysfunction. Chemotherapy-induced neutropenia directly weakens innate immune surveillance, while irritant or vesicant anticancer agents can injure the vascular endothelium and increase matrix-protein deposition, providing additional adhesion sites for bacteria [30]. Chemotherapy-associated disruption of oral and gastrointestinal mucosal barriers further promotes hematogenous dissemination of endogenous flora and subsequent catheter colonization. In patients with hematological malignancies, PICCR-BSI is often characterized by profound systemic immunodeficiency, rapid-onset infection, broad pathogen profiles, antimicrobial resistance, poor therapeutic response, and increased mortality. Nursing strategies for PICC use in hematological malignancies should therefore address both infection and thrombosis risks [31]. Systematic evidence also showed that patients with hematological malignancies were vulnerable to PICC-related thrombosis, which might interact clinically with infection risk through fibrin-sheath formation and impaired catheter function [32]. In patients with solid tumors, PICCR-BSI mechanisms are more heterogeneous and depend on tumor histology, anatomical site, treatment regimen, extracellular matrix remodeling, and nutritional status [33]. Regardless of malignancy type, suspected PICCR-BSI requires clinical vigilance, timely diagnostics, and proactive therapeutic intervention.

4. Risk of nursing

In the multidisciplinary prevention of PICCR-BSI in cancer patients, nurses function as frontline procedural operators and essential coordinators of care. Their responsibilities include catheter insertion, maintenance, patient and family education, and interprofessional communication, each of which represents a critical node in the infection-control pathway. A clinical nurse specialist-led neonatal PICC team has demonstrated that expert nursing leadership can reduce central line-associated bloodstream infection and improve cost efficiency [34]. Infusion therapy nursing teams also provide a structured approach to standardizing vascular access practice and evaluating early outcome improvements [35]. During insertion and maintenance, inadequate disinfection, insufficient technical proficiency, and gaps in evidence-based knowledge can directly increase PICCR-BSI risk. Validated nursing knowledge and self-efficacy tools highlight the importance of targeted training in vascular access device management [36]. In the cancer setting,

continuous nursing intervention for patients undergoing tumor chemotherapy with PICC catheterization has been associated with improved care quality and complication control [37]. Timely communication among patients, families, nurses, and multidisciplinary teams is therefore integral to early recognition and prevention of PICCR-BSI.

5. Other risk factors

Catheter-related and care environmental factors also influence PICCR-BSI risk. Material composition is clinically relevant because rough or hydrophobic catheter surfaces may promote microbial adhesion, while smoother or modified surfaces may reduce initial attachment without eliminating late infection mediated by fibrin sheath and biofilm formation [24, 29]. Current infusion standards and oncology infection guidelines emphasize that catheter lumen number, insertion site, maintenance quality, and the local care environment should be incorporated into vascular access planning and surveillance [10, 15]. The number of PICC lumens is particularly important because a propensity-score-matched analysis found lumen number to be independently associated with PICCR-BSI risk in cancer and non-cancer populations [14]. Antimicrobial coatings, inpatient management standards, and device selection should therefore be assessed together rather than considered as isolated technical variables.

Diagnostic technology

Clinical studies indicate that PICCR-BSI symptoms in cancer patients are often atypical and that causative microorganisms can be difficult to identify. Conventional microbiological diagnosis relies on paired blood cultures with catheter-source infection suggested when catheter-drawn blood cultures become positive at least two hours earlier than peripheral blood cultures followed by Gram staining for preliminary classification [38]. This approach is necessary but insufficient for cancer patients when rapid therapeutic decisions are required. Once a blood culture becomes positive, prompt notification of the clinical team, rapid species identification by matrix-assisted laser desorption/ionization time-of-flight mass spectrometry, and detection of key resistance genes by real-time polymerase chain reaction (PCR) or gene-chip methods can provide early direction for empirical antimicrobial treatment. Imaging techniques may also be used when complications such as thrombosis, abscess, septic embolism, or metastatic infection are suspected [39]. Combining biomarkers with microbiological testing represents a contemporary rapid diagnostic strategy. Procalcitonin (PCT) often increases during bacterial infection and has a relatively short half-life, allowing dynamic monitoring of treatment response and support for antimicrobial discontinuation decisions. However, PCT elevation may be attenuated in localized, viral, or fungal infections, and some malignancies may produce PCT [39]. C-reactive protein (CRP) is a conventional inflammatory marker that can rise rapidly during infection and can be monitored dynamically, but its low specificity limits standalone interpretation because levels may also increase after surgery, trauma, or tumor-related inflammation [39]. Emerging biomarkers such as soluble triggering receptor expressed on myeloid cells-1 (sTREM-1) and presepsin have potential value in early infection assessment, but variability in cancer patients currently precludes their use as standalone diagnostic tools [40]. In suspected PICCR-BSI among cancer patients, diagnostic evaluation should clarify the underlying cancer type and current immune status, collect paired peripheral and catheter blood cultures before antimicrobial administration whenever feasible, measure PCT and CRP concurrently, and use advanced molecular methods when rapid pathogen identification or resistance profiling is clinically necessary. A clinical score incorporating calcitonin gene-related peptide, programmed death-1, and programmed death-ligand 1 has been proposed for PICC-related bloodstream infections in breast cancer [20], while a nomogram has been developed for patients with hematologic malignancies [41]. Nanopore

Table 1. Comparison of different catheter materials.

Material type	Representative materials	Clinical advantages	Clinical limitations
First-generation: Traditional	Polyurethane [43, 45]	High strength; resistant to kinking [43, 45]	Higher baseline biofilm risk when unmodified [43, 45]
	Silicone [45, 46]	Excellent biocompatibility and comfort for long-term use [45, 46]	Soft material; thicker walls may limit flow [45, 46]
Second-generation: Surface-modified	Hydrophilic/hydrogel-coated polyurethane or silicone [44]	Reduces mechanical irritation and may lower phlebitis risk [44]	Limited long-term antimicrobial protection [44, 45]
Third-generation: Antimicrobial-coated	Chlorhexidine/silver sulfadiazine [43, 45]	Active bactericidal effect with sustained surface release [43, 45]	Weak antifungal activity; limited efficacy against some non-fermenters [43, 45]
	Minocycline/rifampin [43, 45]	Broad-spectrum bactericidal activity, especially against Gram-positive bacteria [43, 45]	Potential risk of localized bacterial resistance [45]
	Benzalkonium chloride [43]	Anti-biofilm activity; suitable for selected high-risk patients [43]	High cost and limited widespread clinical data [43, 47]
Special/Composite coatings	Heparin, silver ions, platinum composites [46, 47]	Combines anti-infective and antithrombotic functions [46, 47]	Primarily high-end products; cost and clinical evidence remain limiting factors [47]

targeted sequencing with pathogen-specific primers also illustrates the potential of molecular rapid diagnostic testing for bloodstream infections [42].

Prevention strategies

1. Technology-driven interventions

Different PICC materials and surface antibacterial coatings have a significant impact on PICCR-BSI prevention. Traditional PICC materials mainly include silicone and polyurethane, whereas contemporary catheters increasingly incorporate surface-modified or antimicrobial-coated functional materials. A systematic review and meta-analysis indicated that PICC materials and designs could affect catheter-related complications [43]. Hydrophilic biomaterial and hydrogel catheter concepts aim to reduce mechanical complications by improving surface interactions [44]. A Cochrane review emphasized that comparative evidence on PICC design and material remained clinically important but heterogeneous [45]. A randomized comparison of PICC materials provided direct clinical evidence that material properties influenced catheter outcomes [46]. Cost-effectiveness modeling further suggested that the economic value of PICC types varies across healthcare settings [47] (Table 1). Catheter material selection should be based on evidence, patient-specific risk, anticipated dwell time, infusion characteristics, and cost-effectiveness. Because cancer patients often combine immunosuppression, repeated vascular access needs, chemotherapy-related endothelial injury, and prolonged catheter exposure, unmodified first- or second-generation materials may be insufficient for patients at high infection risk. In such patients, active antimicrobial-coated catheters may be prioritized when institutional

Table 2. Comparison of different skin disinfectants.

Skin disinfectant type	Clinical advantages	Clinical limitations
2% chlorhexidine gluconate in alcohol	Maximally reduces infection risk when not contraindicated [48]	Contraindicated in neonates and chlorhexidine-allergic patients [10, 48]
Povidone-iodine	Alternative when chlorhexidine is contraindicated [48]	Slower bactericidal action [48]
70% alcohol	Alternative to chlorhexidine or iodine for selected patients [48]	Strong skin irritation; unsuitable for chemotherapy-induced dry skin [48]

Table 3. Comparison of different dressing.

Dressing type	Clinical advantages	Clinical limitations
Transparent semipermeable film	Breathable, waterproof, allows visualization [10]	Limited antimicrobial efficacy [49]
Chlorhexidine gluconate dressing	Provides up to 7 days of local antimicrobial activity [49]	Contraindicated in chlorhexidine-allergic patients [49]
Gauze dressing	Excellent absorbency for oozing or fragile skin [10]	Requires frequent changes and may increase infection risk if prolonged [10, 49]

policy, antimicrobial stewardship considerations, and cost allow. In addition to catheter material, pre-insertion skin antisepsis, post-insertion dressing selection, and locking strategy materially affect PICCR-BSI prevention. Evidence-based aseptic techniques during vascular access procedures are a core foundation for reducing bloodstream infection, which include alcoholic chlorhexidine, povidone-iodine, and alcohol-based alternatives [48] (Table 2). Chlorhexidine-based dressings provide localized antimicrobial activity and have been reviewed as an evidence-based strategy for catheter-related bloodstream infection prevention [49] (Table 3), while lock solutions and intraluminal prevention options including antimicrobial lock therapy [50], locking solutions in critical care [51], and antiseptic barrier caps [52] target hub contamination, biofilm formation, and high-risk long-term catheter use (Table 4). These measures should be integrated rather than used as isolated interventions. The options summarized above are most applicable to long-term, non-critically ill patients with indwelling catheters, but cancer patients require additional individualized evaluation. Skin condition after chemotherapy or radiotherapy, allergy history, anticipated neutropenia, pathogen epidemiology, catheter material compatibility, and antimicrobial stewardship should guide selection of disinfectants, dressings, and lock solutions to reduce PICCR-BSI risk while avoiding preventable toxicity or device damage.

2. Enhanced professional skills

In addition to technical innovation, strengthening the professional competence of nursing staff is essential. Nursing education should enhance specialized knowledge and ensure proficiency in catheter insertion, flushing, dressing changes, connector disinfection, complication recognition, and patient instruction. Self-management education integrated with nursing has been shown to improve outcomes among cancer patients with PICC placement [53]. Home-care nursing guidance further emphasizes the need for accurate device identification, evidence-based clinical management, and consumer support for adults living with PICCs or midline catheters at home [54]. Commentary on self-management education highlights the practical importance of nurse-led education for cancer patients with PICCs [55]. Field training studies also show that targeted education can improve

Table 4. Comparison of different lock solutions.

Lock solution	Clinical advantages	Clinical limitations
70% ethanol	Low cost; disrupts lipid membranes and biofilms [50, 51]	May degrade catheter material and increase fracture risk [50, 51]
Antibiotic lock	High-concentration local bactericidal activity for selected high-risk cases [50, 51]	Resistance risk; requires antimicrobial stewardship [50, 51]
Sodium citrate	Anticoagulant with potential antimicrobial and anti-biofilm activity [51]	Limited evidence for infection prevention [51]
Targeted antibiotic lock	Targets multidrug-resistant Gram-negative bacteria and persistent biofilm infections [50, 51]	Reserved for selected emergencies; requires expert supervision [50, 51]

nurses' knowledge and self-efficacy in vascular access device management [56]. As frontline caregivers, nurses reduce patient anxiety, improve adherence, communicate real-time clinical changes to multidisciplinary teams, and provide practical feedback for evaluating emerging technologies in routine care.

3. Procedural and behavioral measures

Cancer patients frequently rely on long-term vascular access devices, making infection prevention highly dependent on the management capacity of patients and caregivers. Multilingual, visually supported PICC home-care manuals and structured catheter self-management training should therefore address dressing assessment, puncture-site surveillance, hand hygiene, hub protection, activity modification, and early identification of fever, chills, erythema, swelling, drainage, or catheter dysfunction. Implementation research on PICC appropriateness guidelines shows that institutional barriers and facilitators must be addressed for consistent practice change [57]. A co-designed PICC booklet evaluated with consumers provides an example of how patient-centered education can improve the relevance and usability of home-care information [58]. A dedicated telemedicine or web-based follow-up platform can complement written education by enabling real-time consultation, remote guidance, and early escalation for suspected catheter complications. An integrated model combining patient education, telehealth support, nurse-led surveillance, and multidisciplinary decision-making may reduce PICCR-BSI incidence and healthcare costs by preventing avoidable complications and readmissions.

Future studies

While diagnostic approaches for PICCR-BSI in non-oncological populations have matured, cancer patients present distinct diagnostic challenges. The immunological and pathophysiological milieu of cancer limits the diagnostic performance of conventional biomarkers and standard culture-based modalities. Future research should prioritize rapid point-of-care diagnostics, multiplex resistance detection, and integrated risk-stratification models that combine clinical metadata, catheter characteristics, immune status, and microbial profiling. Parallel advances in antimicrobial catheter coatings, skin antisepsis, dressing technologies, and lock solutions have improved prevention opportunities. Next-generation smart catheters and nano-functionalized surfaces, particularly those engineered for controlled local antimicrobial release and real-time biofilm sensing, may further reduce infection risk. Translational success will require both demonstrable clinical efficacy and economic viability to ensure accessibility across diverse healthcare settings. Nevertheless, technological superiority cannot compensate for deficiencies in aseptic technique during catheter insertion and maintenance. Sustainable infection reduction requires daily management systems, standardized operational guidelines, and

dedicated multidisciplinary teams that include infectious disease, oncology, pharmacy, microbiology, radiology, infusion therapy, and nursing specialists. Hospital- and community-based follow-up initiatives are also necessary to facilitate early detection, prompt intervention, and optimized outcomes. PICCR-BSI in cancer patients therefore represents a complex interaction of device, pathogen, and host factors. A proactive, evidence-based, and multidisciplinary prevention strategy is essential to reduce infection risk without compromising anticancer treatment outcomes. Future efforts should focus on personalized prevention, rapid diagnostics, and innovative biomaterials tailored to immunocompromised hosts.

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