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A Review of Risk Factors Analysis and Bundle Prevention and Control Strategies for Pediatric PICC Catheter-related Bloodstream Infections

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Abstract: The peripherally inserted central catheter (PICC) for children is widely used in clinical treatment due to its advantages, such as long-term indwelling and convenient operation. However, the incidence of catheter-related bloodstream infection (CRBSI) is significantly higher than that in adults, which seriously threatens the lives of children and increases the medical burden. This paper systematically reviews the risk factors and prevention and control strategies of PICC-CRBSI in children. Studies have shown that the high incidence of CRBSI in children is closely related to the following factors: the children's own factors, operation and management factors, and pathogen diversity. Aiming at the above risks, the article puts forward a bundled prevention and control strategy, including professional training of personnel, strengthening aseptic technology, standardizing catheter maintenance, and establishing an infection monitoring and early warning mechanism. Through the synergistic effect of multi-dimensional intervention measures, the incidence of CRBSI can be effectively reduced, providing an evidence-based basis for the safe management of vascular access in children. This paper aims to provide a systematic prevention and control framework for clinical practice and calls for further research to optimize strategies and reduce CRBSI-related complications in children.

Keywords: Pediatric catheter-related bloodstream infection; Risk factors; Bundle intervention; Infection prevention and control

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1. Introduction

In recent years, peripherally inserted central catheters (PICCs) have been increasingly used in pediatric clinical treatment. As an important vascular access technology, PICCs have become a key medical tool for chemotherapy in children with tumors, nutritional support for critically ill children, and neonatal care due to advantages such as long-term indwelling, convenient operation, and stable fixation [1–2]. Relevant data show that the utilization rate of PICCs in neonatal intensive care units has continued to increase over the past decade [3]. However, this technology

still faces severe challenges in clinical practice: the complexity of pediatric-specific vascular conditions (such as smaller vessel diameter and poor elasticity), immature immune function development (especially the immature reticuloendothelial system in premature infants), and insufficient standardization of nursing operations collectively constitute high-risk factors for catheter-related bloodstream infections (CRBSIs). Studies have shown that the incidence of CRBSIs in pediatric patients is significantly higher than that in adults, severely threatening the safety of children and significantly increasing the medical burden [4–5].

Research on the prevention and control of pediatric PICC-related infections presents two notable characteristics: firstly, risk factor studies mostly focus on single dimensions, such as microbiological characteristics or nursing operation levels, lacking systematic analysis of multidimensional interactions; secondly, prevention and control strategies often adopt isolated measures, failing to form a scientifically integrated bundle intervention system. It is noteworthy that due to significant differences in the immune system between children and adults, their ability to combat bacteria is poor, thus increasing the risk of catheter infection. This article aims to review the risk factors of pediatric PICC-related CRBSI, explore corresponding prevention and control measures and bundle management strategies, and provide references for formulating key interventions to reduce their occurrence risk.

2. Characteristics of pediatric PICC-CRBSI: Incidence and pathogenic characteristics

PICC-CRBSI poses significant clinical harm in neonatal and preterm infant intensive care, with its pathogenic characteristics and risk factors having attracted extensive attention. A study by Yan Hu et al. reported that the incidence of neonatal PICC-CRBSI was as high as 10.62%, with low birth weight, indwelling time ≥21 days, low Apgar score, and femoral artery insertion identified as major risk factors. Common CRBSI pathogens included Escherichia coli and Staphylococcus aureus [6]. Yan-ping Xu et al. reported a CRBSI incidence of 1.46 cases per 1,000 catheter-days in neonates, with common pathogens such as Klebsiella pneumoniae. The risk of PICC-induced CRBSI decreased with increasing gestational age [7]. Jeongmin Shin et al. reported a CRBSI rate of 1.3 cases per 1,000 catheter-days in neonates, identifying major contributing factors as prolonged catheter indwelling, unnecessary catheter insertion, extremely low birth weight, and immunodeficiency [8]. Shu-Chun Chu et al. reported a CRBSI rate of 6.36 cases per 1,000 catheter-days in extremely low birth weight infants, with pathogens primarily including coagulase-negative staphylococci, while gram-negative bacteria and Candida albicans were also relatively common. Risk factors associated with CRBSI included gestational age, birth weight, and PICC indwelling time [9].

It can be seen that the incidence of CRBSI varies significantly among pediatric populations, but extremely low birth weight infants and preterm infants face a higher infection risk. Key risk factors include low birth weight, prolonged catheter indwelling, and specific puncture site selection. Common pathogenic spectra cover *E. coli*, *S. aureus*, coagulase-negative *staphylococci*, gram-negative bacteria, *C. albicans*, and *K. pneumoniae*.

3. In-depth analysis of risk factors for pediatric PICC-CRBSI

3.1. Patient-specific factors

3.1.1. Physiological developmental characteristics

Children's developmental status directly affects immune system function. Extremely low birth weight (<1000g) leads to immature immune system development and poor resistance. Additionally, the thin stratum corneum and

fragile barrier function make it more prone to infection during invasive procedures [10]. Therefore, extremely low birth weight is typically a high-risk factor for CRBSI. In a clinical study by Pan Jinzhou et al., the incidence of CRBSI in neonates with birth weight <1000g reached 58.8% [11]. Furthermore, studies have shown that the smaller the gestational age of newborns, the higher the infection risk, with preterm infants <28 weeks facing the highest risk [12]. This may be associated with mechanical barrier defects due to immature development.

3.1.2. Disease and treatment status

Relevant studies indicate that children with chronic underlying diseases such as metabolic disorders, tumors, and heart diseases have a higher risk of CRBSI [13]. Among these groups, some children require long-term use of broad-spectrum antibiotics due to their conditions, which can cause dysbiosis, suppress beneficial bacteria, and facilitate colonization by drug-resistant or opportunistic pathogens, increasing the risk of secondary infection [7]. Additionally, children unable to meet energy needs through oral intake often rely on long-term PICC for total parenteral nutrition support. During nutrient solution preparation, high-osmolar components (such as glucose and amino acids) may alter the intravascular hemodynamic environment, promoting microbial adhesion and biofilm formation. Incomplete catheter flushing may also leave residual fluid as a breeding ground for bacterial proliferation [14].

3.2. Operational and management factors

3.2.1. Risks in catheter insertion

The standardization of catheter insertion directly affects the incidence of catheter-related infections. Before insertion, healthcare providers' failure to strictly follow hand hygiene protocols is a critical risk factor, as hands are often the direct route of infection. A survey covering 21 tertiary hospitals showed that 11 (52.3%) had inadequate hand hygiene compliance [15]. During insertion, operator inexperience is a significant risk factor. For example, inexperienced operators may cause repeated punctures, leading to vascular wall injury, subcutaneous hematoma, and weakened local anti-infection ability, allowing bacteria to invade vessels and cause bloodstream infections. Studies have shown that catheters inserted by less experienced personnel are more prone to bacterial colonization and CRBSI compared to those inserted by senior nurses, highlighting the importance of standardized training and operational protocols [16–17]. Additionally, inexperienced operators are prone to mishandling during the operation process when facing severe crying in newborns, resulting in insufficient skin disinfection, promoting skin flora migration and adhesion to the catheter surface, and finally invading through the puncture site. Neonatal crying, unstable positioning, and vascular collapse due to hypothermia increase operational difficulty, prolonging insertion time. Repeated insertion after initial failure extends exposure time of sterile items (e.g., catheter packs, dressings), increasing contamination risk, mainly via microbial contamination of catheters through exposed instruments or operator gloves [18].

3.2.2. Catheter maintenance defects

Good catheter care is crucial for preventing CRBSI, with any oversight potentially causing infection. Dressings and infusion connectors are two key risk factors in maintenance. For dressings, delayed replacement of contaminated dressings, non-sterile operations, or loose dressings can lead to local bacterial colonization and bloodstream entry via the catheter site. Infusion connectors are critical pathways for bacterial entry: needleless connectors, due to structural design, may facilitate microbial invasion and intraluminal contamination—bacteria on

skin or connector surfaces can contaminate the lumen when connecting infusion devices [19]. Inadequate connector disinfection allows bacteria to migrate along the catheter lumen, causing infection. Studies also show that high-frequency connector changes increase infection risk, as frequent replacements expose the catheter lumen to air, enabling microbial colonization [20].

3.2.3. Catheter dwell time

Catheter dwell time is a recognized independent risk factor. Prolonged dwell time increases the risk of biofilm formation on the catheter surface, significantly raising infection rates. After insertion, patient movement may cause mechanical friction between the catheter and vascular wall. If dwell time exceeds 20 days, CRBSI incidence significantly increases [21]. Dwell time correlates with higher mortality and infection recurrence rates; thus, clinical assessment for unnecessary catheter removal and shortened dwell time is essential to reduce risk [22].

3.2.4. Puncture site selection

Anatomical structures, skin flora distribution, nursing difficulty, and local environment vary by puncture site, influencing infection rates. Yan Hu et al. found that femoral vein insertion in neonates had a significantly higher CRBSI risk than other sites [6]. Key reasons include: (1) The femoral vein area near the perineum is prone to contamination, with high skin bacterial density; (2) Lower limb/femoral sites are harder to keep clean and dry, increasing nursing difficulty and infection risk; (3) Blood flow velocity and dwell time at different sites affect bacterial colonization and infection.

4. Construction and implementation of bundle prevention and control strategies

In the prevention and control of pediatric peripherally inserted central catheter-related bloodstream infections (PICC-CRBSI), bundle strategies represent an effective approach. Their core lies in the combined implementation of multiple evidence-based measures covering the entire process of catheter insertion, maintenance, and removal, systematically reducing infection risks.

4.1. Core elements of bundle management

4.1.1. Personnel specialization

Personnel specialization serves as the foundational guarantee for constructing and implementing bundle strategies. PICC insertion and maintenance involve complex procedures (e.g., puncture techniques, aseptic barriers, catheter fixation), requiring execution by a systematically trained professional team (e.g., PICC insertion team). By establishing a dedicated PICC task force, all operators and maintainers are ensured to possess corresponding qualifications and receive regular professional training to enhance technical proficiency and emergency response capabilities. Thus, personnel specialization ensures that insertion and maintenance are performed by trained healthcare providers, reducing infection risks from operational errors [23].

4.1.2. Strengthening aseptic techniques

Enhanced execution of aseptic techniques is a critical link in infection prevention and the first line of defense to disrupt the infection transmission chain. Strict adherence to the maximum aseptic barrier principle during insertion—including wearing sterile gowns and using large sterile drapes—minimizes pathogen invasion [24]. Additionally, skin disinfectant selection is vital: disinfectants containing chlorhexidine alcohol (>0.5%) significantly improve

disinfection efficacy. Chlorhexidine alcohol exhibits stronger bacteriostatic ability, providing prolonged skin protection and remarkably reducing local infections and bacterial colonization [25].

4.1.3. Standardized catheter maintenance

Standardized daily catheter maintenance is equally indispensable. Normalized maintenance operations can effectively reduce local contamination, thereby lowering infection risks [26]. Dressings should be changed according to standard cycles (e.g., weekly for transparent dressings) and replaced immediately if contaminated or loose. Meanwhile, adopting pulse flushing techniques and heparinized saline positive pressure sealing during infusion and catheter sealing helps clear residual substances, effectively preventing biofilm formation and reducing infection rates.

4.1.4. Infection monitoring and early warning

To achieve early identification and rapid intervention, a sound infection monitoring and early warning mechanism must be established. Continuous tracking of infection occurrences identifies high-risk patients and operational links for early intervention and continuous improvement [23]. Daily assessment of catheter necessity in children, combined with clinical manifestations such as fever and elevated C-reactive protein (CRP), determines whether catheter removal is required. Suspected infections should immediately trigger confirmation procedures, including catheter tip culture and bilateral blood culture to improve diagnostic accuracy. Furthermore, using information technology to set infection warning indicators helps shorten response time and enhance overall prevention efficiency.

4.2. Synergistic effects of core elements

Bundle management represents an evidence-based systematic intervention model, with its core lying in the scientific integration and simultaneous implementation of multiple key prevention strategies. This strategy features: (1) all core elements are evidence-based rather than single empirical operations; (2) simultaneous execution of all elements instead of isolated measures; (3) monitoring data driving strategy optimization to form an "implementation-monitoring-improvement" cycle. In pediatric PICC-CRBSI prevention practice, personnel specialization ensures operational standardization, strengthened aseptic techniques cut off infection sources, standardized maintenance reduces dwell-time risks, and monitoring/early warning enables dynamic management. The synergy of elements constructs a three-level prevention system: front-end prevention (insertion), process control (maintenance), and terminal disposal (infection response), thus minimizing CRBSI incidence.

5. Conclusion

In summary, pediatric PICC-CRBSI poses a significant challenge in pediatric clinical treatment, with notably higher incidence rates among extremely low birth weight infants and preterm infants. Key risk factors include patient-specific conditions (e.g., low birth weight, immunodeficiency, long-term dependence on total parenteral nutrition) and operational/management defects (e.g., inadequate hand hygiene, unskilled catheter insertion, prolonged dwell time, inappropriate puncture site selection). Studies have shown that dwell time >14 days, femoral vein puncture, and nursing oversights (e.g., contaminated dressings, incomplete infusion connector disinfection) are high-risk factors for infection, with pathogens primarily including coagulase-negative *staphylococci*, *Escherichia coli*, and *Staphylococcus aureus*. To address these issues, bundle prevention and control strategies

establish a three-level prevention system—"front-end prevention-process control-terminal disposal"—through professional personnel training, strengthened aseptic practices (e.g., chlorhexidine alcohol-based disinfectants), standardized catheter maintenance (pulse flushing, positive pressure sealing, regular dressing changes), and dynamic monitoring-early warning mechanisms, effectively reducing CRBSI incidence. Future research should prioritize multicenter studies to clarify the combined effects of prevention measures, explore novel antibacterial materials and coating technologies, and enhance long-term follow-up of pediatric CRBSI to optimize strategies, reduce infection-related complications, and provide evidence-based support for safe pediatric vascular access management.

Disclosure statement

The authors declare no conflict of interest.

Author contributions

Ruizhi Huang: Responsible for the conceptualization and design of the review, led the literature retrieval and analysis, and made multiple revisions and polishing to the full text.

Shuang Zhang: Participated in the conceptualization, mainly responsible for data collation and interpretation, as well as the writing of partial chapters.

Jialin Ye: Responsible for overall project management and coordination, ensuring smooth communication and collaboration within the team, and conducted the final review of the full text.

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