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Original Paper

Research Progress on the Risk and Prevention Measures of Peripheral Arterial Catheter Infection in ICU Patients

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Abstract

Peripheral arterial catheter (PAC) is an important assistant method in the treatment of critical patients. However, the related infection risk is significantly underestimated, especially the occurrence of catheter-related bloodstream infections (CRBSI), which also affects the prognosis of patients severely. After literature review, this paper summarized the risk of PAC related infections, PAC retention and maintenance infection prevention measures, and existing problems in PAC related infection research. The progress of intervention measures was collected such as strict adherence to aseptic principles, use of maximum aseptic barrier, selection of arterial puncture site, ultrasound assisted visual puncture, combination of patch and assistant fixation device, shortening of catheter retention period, use of chlorhexidine patch, and regular education and training, to provide scientific and actionable practical guidance for the prevention and control of PAC related infections in clinical practice.

Keywords

Peripheral Arterial Catheter, Infection, Catheter Related Blood Stream Infection, Prevention and Control

1. Introduction

Indwelling peripheral arterial catheter (PAC) is an indispensable auxiliary means in the comprehensive treatment of critically ill patients in intensive care unit (ICU) (Kim, Lilot, Sidhu, et al., 2014), it can continuously, quickly and accurately monitor the changes of patients' arterial blood pressure index,

meet the needs of blood gas sample collection and reduce the pain caused by repeated puncture, which is helpful to improve the work efficiency of medical staff. At present, PAC plays an important role in clinical practice. It is reported that 3 out of every 4 critically ill patients in ICU use PAC. In the United States and Europe, about 8 million and 2.5 million PAC are used for major surgery and intensive care every year, respectively (O'horo, Maki, Krupp, et al., 2014; Reynolds, Dulhunty, Tower, et al., 2013).

With the increasing use of arterial catheters, its complications are becoming more and more obvious. It mainly includes local complications, catheter dysfunction and infection, among which infection is the most serious complication. PAC has been identified as an important source of catheter-associated bloodstream infection (CRBSI). However, compared with central venous catheter (CVC), clinical staff often underestimate the risk of PAC-related CRBSI infection. In addition, due to the lack of authoritative PAC retention and maintenance standards, the operation of medical staff in different regions and medical institutions is not unified, and there are great differences in infection prevention and control measures. Therefore, the purpose of this review is to summarize the evidence of PAC-related CRBSI prevalence and intervention measures to reduce the risk of infection during PAC retention and maintenance, in order to provide scientific and operational evidence-based guidance for clinical practice.

2. Risk of PAC-Related Infections

Previous studies have shown that the risk of PAC infection is relatively low because the implanted blood vessels are arteries with faster blood flow and deeper anatomical positions of arteries than veins. However, the current evidence shows that the incidence of CRBSI caused by PAC is similar to that of short-term CVC (O'horo, Maki, Krupp, et al., 2014), in the United States, there are as many as 50 000 cases of CRBSI caused by PAC every year (Gowardman, Lipman, & Rickard, 2010). A prospective study of 7 ICU conducted in 2010 showed that there was no difference in implantation rates between PAC and CVC, which were 7.9% (11.4/1000 catheter days) and 39.6% (11.1/1000 catheter days), respectively, and CRBSI were 0.68% (1.0/1000 catheter days) and 0.94% (1.09/1000 catheter days), respectively. And the daily risk rate of colonization of PAC increased steadily with the passage of time ($p= 0.008$), but CVC remained stable (Lucet, Bouadma, Zahar, et al., 2010). Several other prospective observational studies have reached similar conclusions (Traoré, Liotier, & Souweine, 2005; Koh, Gowardman, Rickard, et al., 2008; Kluger & Maki, 2000), and suggest that PAC is an under-recognized source of CRBSI. A systematic review conducted in 2006 found that the incidence of CRBSI in PAC was 1.7 pm 1000 catheter days, while the incidence of short-term, non-capsular CVC was 2.7 pm 1000 catheter days (Maki, Kluger, & Crnich, 2006). A meta-analysis conducted in 2014 showed that the risk of PAC for hemodynamic monitoring and CRBSI for peripheral catheterization in hospitalized patients was close to the short-term routine CVC used in ICU (O'horo, Maki, Krupp, et al., 2014). These findings suggest that PAC poses a huge medical burden.

3. Preventive Measures of PAC Indwelling Infection

3.1 Strict Adherence to Hand Hygiene and Asepsis

Strict hand hygiene and standardized aseptic practices are essential in all clinical operations. Hand hygiene is the most direct, cost-effective and efficient measure to prevent and control hospital-acquired infections. Strict adherence to hand hygiene is the key to preventing the occurrence of CRBSI. The Centers for Disease Control and Prevention (CDC) Guidelines for the Prevention of Endovascular Catheter-Related Infections (O'grady, Alexander, Burns, et al., 2011) suggests key points for hand hygiene: hand hygiene should be performed before and after evaluating the site of catheterization, during catheterization, after removing gloves from the tube, before and after catheter maintenance, and before and after contacting the patient's skin. Hand hygiene should be performed before and after assessing the site of catheter placement, during catheter placement, after removing gloves for catheter placement, before and after catheter maintenance, and before and after contact with the patient's skin.

3.2 Use of Standard Sterile Barriers

Using standard aseptic barrier in medical operation, using aseptic barrier can reduce the colonization of microorganisms and reduce the risk of CRBSI, which is one of the important means to prevent infection in clinic. The maximum aseptic barrier (MSB) refers to the operator wearing aseptic clothing, sterile gloves, hat, surgical mask and patient body covering aseptic treatment towel; standard aseptic barrier (SSB) refers to the operator wearing surgical cap, surgical mask, aseptic gloves and operating site covered with aseptic treatment towel. A number of studies have suggested that (Dong, Liu, Duan, et al., 2017; Card, Piersa, Kaplon, et al., 2023) MSB increases the consumption of sterile surgical clothes and sterile single, increases medical burden and prolongs catheterization time, while SSB has more economic benefits, and there is no difference between the occurrence of CRBSI and the maximum aseptic barrier. CDC (O'grady, Alexander, Burns, et al., 2011) of the United States recommends that different levels of protective barrier measures be taken according to the insertion of different types of catheters. Central ductus arteriosus (including the insertion site of axillary artery and femoral artery) for central vascular catheter insertion, MSB preventive measures are recommended, while peripheral vascular catheter insertion is recommended to use SSB.

3.3 Ultrasound-assisted Help Improves Tube Placement Efficiency

Ultrasound-assisted catheterization to improve catheterization efficiency is a hot topic in recent years. According to a review (Brass, Hellmich, Kolodziej, et al., 2015), ultrasound-assisted catheterization can help increase the success rate of 10%—80%, and greatly reduce the failure rate of puncture, shorten the puncture process, reduce the exposure time of puncture points in the air, and reduce mechanical complications by 50%. The current literature shows that compared with anatomical marker technology, the mechanical complications are reduced by 50%. Ultrasound imaging may improve in terms of safety and quality. Several meta-analyses have determined that ultrasound-guided use significantly contributes to the success and proper placement of ductus arteriosus, affecting indwelling time, overall function, and infection outcome (Bhattacharjee, Maitra, & Baidya, 2018; Moussa Pacha,

Alahdab, Al-Khadra, et al., 2018). Buetti (2020) recommends that ultrasound guidance be added to routine catheterization.

3.4 Carefully Choose Antibacterial Catheter

Regardless of the type of catheter, it can disrupt the skin barrier, which in turn elevates the risk of catheter infection. Antimicrobial catheters have emerged as a solution and continue to be replaced as the public becomes more aware of the serious consequences of infection. There are many kinds of antibacterial coated catheters in clinic, among which the catheters containing chlorhexidine and silver sulfadiazine are the most prominent (Slaughter, Kynoch, Brodribb, et al., 2020; Bouadma, Karpanen, & Elliott, 2018). Chlorhexidine and silver sulfadiazine have good germicidal effect and synergistic effect, which can effectively inhibit the occurrence of bacterial colonization and infection, but because of the high price of antibacterial catheter and the possibility of tolerance, clinical use is not recommended. At the same time, the overall research scale of antibacterial coated catheter is small, and the quality level is not high, so larger-scale and high-quality randomized trials are still needed to provide evidence.

3.5 Preferred > 0.5% Chlorhexidine Disinfectant

In medical practice, catheter placement inevitably compromises skin integrity and breaks its natural protective barrier. Given that catheter-related bloodstream infections (CRBSI) are often caused by microorganisms via the extraluminal route, the selection and use of disinfectants during operation is of particular importance. The correct selection and rational use of disinfectants is decisive in preventing the occurrence of such infections. The application scenarios of different kinds of disinfectants are different. Chlorhexidine can change the integrity of bacterial cell wall and has strong germicidal properties for many types of microorganisms (Boyce, 2019). It has been proved to be the most effective disinfectant. In 2011, CDC issued in the United States recommended the use of disinfectants containing CHG in the prevention of catheter-related bloodstream infections. In 2021, the National Health Commission of China issued the guidelines for the Prevention and Control of Vascular Catheter-related infections (2021),which clearly recommended the use of disinfectants containing more than 0.5% CHG for local skin disinfection at the puncture site. In 2017, the U.S. Food and Drug Administration (FDA) issued a formal warning against CHG, noting the existence of a rare but serious allergic reaction and the increased incidence of such reactions in recent years. Therefore, when considering the use of CHG disinfectant, it is necessary to monitor patients' tolerance to CHG. Patients with severe allergies can use iodine tincture or 70% ethanol instead.

2.6 Reasonable Selection of Catheterization Location

In recent years, a number of studies have confirmed that the occurrence of CRBSI is closely related to the puncture site (Han, Yao, Eun, et al., 2023; Pitiriga, Bakalis, Theodoridou, et al., 2023). Compared with the radial artery, the risk of blood flow infection through femoral artery catheterization is 1.94 times higher, and the selection of femoral artery should be avoided during puncture (Luo, Wang, Gao, et al., 2016). In 2016, the American Infusion Nursing Association issued guidelines for the practice of Transfusion Therapy, which recommended that adults should choose percutaneous puncture, followed

by brachial artery and dorsalis pedis artery. However, the choice of puncture site should be combined with the actual situation of patients.

3.7 Use Assistive Tools to Help Secure the Catheter

Accidental catheter removal and displacement may disrupt continuous 5-flow dynamic monitoring and cause severe bleeding and infection threats to the patient. The failure of a large number of ductus arteriosus is related to improper application and fixation (Timsit, Bouadma, Ruckly, et al., 2012). Traditional suture methods have been shown to increase the risk of CRBSI (Gorski, Hadaway, Hagle, et al., 2021). The new type of auxiliary fixation equipment is becoming more and more mature, and the body surface catheter fixation devices such as Sile buckle are often used for central venous catheters such as CVC, PICC and so on. A new clinical application of cyanoacrylate glue (CG) has been reported as a feasible, safe and effective method for fixing peripheral, central venous and arterial ductus arteriosus from newborn to adult.CG reduces bleeding at the insertion site and inhibits the risk of bacterial growth and CRBSI (Nicholson & Hill, 2019; Prince, Solanki, Varughese, et al., 2018). In clinical practice, clinicians should carefully evaluate the applicability of various fixation options. In addition to the application of the primary dressing, the use of secondary fixation devices should be considered to further enhance catheter stability. Preventing microbial colonization due to potential catheter displacement reduces the risk of secondary CRBSI.

4. PAC Maintenance Infection Prevention Measures

4.1 Choose the Type of Application According to the Patient's Condition

The selection and replacement of dressings occupies a central place in clinical care. In order to promote efficient observation of conditions, sterile transparent dressings have become a widely adopted clinical solution. With the deepening of medical research, various new types of dressings are emerging, such as silver-containing antimicrobial dressings, CHG-containing dressings and high-adhesion dressings. Among them, CHG-containing dressings are particularly effective in preventing CRBSI, and the types of CHG dressings, CHG-impregnated sponges, and CHG gel dressings can effectively reduce the risk of arterial and central venous catheter infections, including CRBSI, by as much as 60% (Buetti, Ruckly, Schwebel, et al., 2020), the CDC guideline strongly recommends CHG-containing dressings as the first choice for preventing the risk of infection in indwelling catheters. However, given its high price, this type of dressing is not widely and routinely used in China. Therefore, clinical caregivers need to take into account the risk of infection and affordability of patients, and reasonably select the dressing.

4.2 Avoid Routine Replacement of Ductus Arteriosus

Some previous studies have suggested that regular replacement of catheters can help reduce the risk of CRBSI. However, with the further deepening of research, more and more studies believe that frequent operation will increase the possibility of bacterial colonization and increase the risk of CRBSI because of non-standard aseptic technology. At the same time, a number of studies have shown that there is no difference in the risk of CRBSI between regular replacement of ductus arteriosus and clinical

indications. At present, the unified consensus is that under the premise of aseptic operation, when there is no clinical indication, the ductus arteriosus should not be routinely replaced.

4.3 Implement Cluster Nursing

In the course of clinical practice, given the diversity of timing of CRBSI, the effect of only one measure to control the occurrence of bloodstream infections may not be ideal, therefore, to improve the effectiveness of prevention and control of multiple evidence-based conceptual interventions of cluster care has emerged.

Cluster nursing was first put forward by the American Institute of Health Promotion (IHI) in 2001. Based on the evidence-based concept, it combines clear and effective nursing measures to provide patients with a scientific and perfect combination of nursing programs. The cluster nursing program has been used twice in the United States, and the successive implementation of the two activities has helped many hospitals in the United States to reduce the incidence of CRBSI by 6% or even close to zero (Soni, Rogers, Valenti, et al., 2008), reduce the incidence of CRBSI by about 25000 cases, save 414 million US dollars for US medical insurance and save as many as 6000 lives. After 10 years of observation after the introduction of the cluster care program in the Netherlands, it was found that the incidence of CRBSI decreased from 4 ‰ to 1.6 ‰, and the risk of CRBSI in ICU was significantly reduced by 50%. Then, under the premise of ensuring compliance > 80%, the risk of infection can be reduced by 68% (Van Der Kooi, Smid, Koek, et al., 2023). According to the US CDC, the implementation of cluster nursing intervention has helped reduce the incidence of CRBSI in the United States by at least 46%. IHI recommends five measures to prevent the occurrence of CRBSI, such as hand hygiene, maximum sterile barrier, skin disinfection, selection of catheterization location and catheter evaluation. However, the medical level varies in different countries and regions, and clinical medical staff should combine the characteristics of our department on the basis of the guidelines to form a set of cluster nursing programs suitable for their own situation.

4.4 Receive Regular Education and Training

Regular education and training can improve the core competence of clinical medical staff by enhancing knowledge, compliance and attitude in academic and clinical environment, thus affecting future nursing practice and patient safety. Savage proved that by using vascular pathway teams to provide peer-to-peer education, the incidence of CRBSI has been reduced by 90% (Savage, Lynch, & Oddera, 2019). Savage by educating and training clinical nurses, scholars such as Sisley have reduced the incidence of CRBSI from 1.4% to 0.4%. Education helps clinical workers provide scientific and detailed basic knowledge and standard operation, and improve compliance and operational compliance (Star, Lindsey, Reese, et al., 2023). The occurrence of nosocomial infection is closely related to the knowledge level of staff (Ni, Chen, Chen, et al., 2023). The American CDC guidelines clearly point out that the education and training of medical staff is the primary measure to prevent and control CRBSI. Clinical workers should receive regular education and training, constantly improve and standardize clinical operation, and ensure the safety of patients.

4.5 Shorten Indwelling Time of Catheter

There are no standardized criteria for the length of time an arterial catheter should be left in place, and prolonged catheter retention is positively associated with an increased risk of microbial colonization, which may lead to the development of infections. Therefore, medical staff should evaluate the necessity of indwelling catheter every day and pull out unnecessary catheters as soon as possible; there is no guarantee that the indwelling time of ductus arteriosus under aseptic condition should not exceed 48 hours (Wang, Han, Yuan, et al., 2020).

5. Problems with Current Research on PAC Infection Prevention and Control

5.1 The Importance of Sensory Control of PAC has not been Paid Attention to

In the studies of endovascular catheters in the past 10 years, most of the studies focused on how to reduce the incidence of complications caused by CVC, but few studies focused on PAC. The importance of ductus arteriosus did not attract the attention of medical workers in clinical practice, and even ignored ductus arteriosus to cause blood flow infection when the clinical work was busy. The United States conducted a nationwide survey on the prevention of infection of ductus arteriosus in ICU. The results show that when ICU doctors place PAC catheters, only 44% of doctors use the preventive measures recommended by CDC, and even 15% of doctors use aseptic protective barrier (Cohen, Carino, Heffernan, et al., 2015). Cui and other Chinese scholars conducted a survey on nurses' knowledge and time of preventing CRBSI in our country. The results showed that Chinese nurses generally lacked awareness of preventing CRBSI (Yuan, Wang, Xiao, et al., 2022). Xiao and other scholars (2022) conducted a survey on nurses' knowledge of keeping PAC unobstructed. The study concluded that Chinese nurses lacked relevant knowledge of maintaining PAC, and there were great differences between clinical practice and related standards. The cross section of the Beijing area shows that although most of the nursing operations of the nurses in the Beijing area are in line with the recommendations of the guidelines, more than half of the nurses believe that indwelling PAC will not cause infection, and that the maintenance and replacement of PAC is only a routine, regardless of whether it meets the clinical indications for catheter replacement (Yuan, Wang, Xiao, et al., 2022).

5.2 There is no Unified Standard for Sensing and Control Measures

Globally, the development of medical standards among different countries and regions shows an uneven trend. At the same time, the base of medical personnel is huge, and there are significant differences in their comprehensive quality. Even within the same hospital, the operations of medical staff in different departments are different, leading to a greater variability of infection prevention and control measures at the individual level. The survey in 2021 shows that the perceptual control measures of ICU nurses to PAC are mainly based on nursing routine and clinical experience, and lack of scientific theoretical guidance (Yuan, Xiao, Wang et al., 2021). The difference between indwelling and maintenance operation not only increases the difficulty of prevention and control of nosocomial infection, but also increases the possibility of complications of PAC-related infection, increases the

difficulty of treatment, and hinders the rehabilitation process of patients. Therefore, it is extremely important to scientifically standardize the prevention and control measures of clinical PAC infection.

6. Summary

PAC-associated CRBSI has become a burden in healthcare that cannot be ignored. Although some guidelines, expert consensus and evidence summaries on CRBSI have mentioned infection prevention measures during PAC retention and maintenance, they are mostly brief and lack specific, implementable and comprehensive standards. At the same time, clinical workers have not paid enough attention to the importance of PAC infection prevention and control, which to a certain extent increases the risk of patient infection and healthcare burden.

PAC infection prevention and control is not only related to the life safety and health of patients, but also an important part of improving the quality and safety of healthcare. Therefore, we call on clinical medical staff and researchers to focus more attention on peripheral arterial catheters and carry out more research in various aspects, and through continuous research and practice, we are expected to provide patients with safer and more effective medical services.

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