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Research Progress on Nursing of Vascular Catheter-Associated Infection (VCAI)

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Abstract: The intravascular catheter (IVC) is a commonly used intravenous access for patients with various diseases. It can be used for intravenous infusion, blood transfusion, blood collection, or monitoring of hemodynamic changes in patients, grasp the progress of the patient's disease, and is an indispensable treatment tool in clinical practice. The intravascular catheter has a longer indwelling time, which can reduce the pain of diagnosis and treatment for patients, and has higher advantages. However, prolonged catheterization can easily lead to vessel catheter-associated infection (VCAI), which can induce serious complications, affect the prognosis of the disease, increase the risk of death for patients, and also bring a great burden to the work of medical staff. There are many prevention and treatment measures for VCAI, such as reasonable selection of catheters, reasonable determination of intubation locations, and standardized nursing catheters. And with the continuous optimization of nursing technology, catheter coating technology or antibacterial solution sealing technology has become a new nursing method for the disease, which can effectively reduce the incidence of VCAI. This study comprehensively expounds on the concept, mechanism, risk factors, and preventive nursing measures of VCAI, in order to explore effective nursing plans for VCAI and improve the quality of nursing for patients with intravascular catheters.

Keywords: Vascular catheter-associated infection; Mechanism; Risk factors; Nursing measures

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1. Introduction

1.1. Definition of VCAI

VCAI refers to the primary infection that occurs during the process of intravascular catheterization or within 48 hours of catheter removal, and is unrelated to other infectious diseases in the body [1]. The clinical manifestations of this disease include local infection, which can be seen as skin heat pain, redness and swelling, or inflammatory exudation; bloodstream infection includes the above symptoms, and patients have a fever above 38℃, accompanied by infectious symptoms such as hypotension and chills. In addition, patients with bloodstream infections who undergo microbiological testing may show positive results for fungal and bacterial cultures of peripheral venous blood, or consistent results for the types of pathogens and drug sensitivity obtained from peripheral blood cultures and catheter tip blood cultures.

1.2. Diagnostic criteria for VCAI

Suspected diagnostic criteria: Symptoms such as chills, oliguria, or hypotension occur during intravascular catheterization or within 48 hours of catheter removal, with a body temperature above 38°C, and no other source of infection besides VCAI. Laboratory diagnostic criteria: Detection of pathogenic bacteria in one or more blood culture results, and the pathogenic bacteria are not associated with other infections [2].

2. Mechanisms of VCAI

The main sources of pathogenic bacteria for VCAI are the skin near the puncture site and the catheter connector. The infection pathways are:

(1) Primary infection: During or after catheter puncture, residual bacteria on the nearby skin can colonize the inner end and tip of the catheter in large numbers, leading to local or systemic infection. During the indwelling period, the catheter connector or lumen can be contaminated by pathogenic bacteria, allowing long-term colonization of bacteria within the lumen and inducing infection.

(2) Secondary infection: Pathogenic bacteria enter the catheter connector or lumen through blood transmission and colonize in large numbers on the catheter wall. Continuous release of pathogenic bacteria into the bloodstream leads to secondary infection.

3. Risk factors for VCAI

(1) Patient factors: High-risk populations for VCAI include patients receiving hyperosmolar solution therapy, invasive hemodynamic monitoring, chemotherapy, high-viscosity fluids, blood purification, and intravenous infusion therapy for tumors. Additionally, advanced age, diabetes mellitus, elevated Acute Physiology and Chronic Health Evaluation II (APACHE II) score, immunocompromise, and reduced hemoglobin levels are all high-risk factors for VCAI. Specific analyses indicate that older patients often have chronic diseases and declining bodily functions; long-term catheterized patients have compromised immune systems, severe metabolic disorders, and degenerative physiological functions; patients with high APACHE II scores have severe illnesses and a higher likelihood of infection [3]. Hemoglobin can assess the nutritional status of the body. If its value is below 35g/L, it indicates poor nutritional status, inadequate body defense, and decreased physiological function of tissues and organs, thus increasing the risk of VCAI.

(2) Operator factors: Vascular catheterization is an invasive procedure, and pathogenic bacteria may enter the bloodstream through damaged skin. If the operator does not adhere to sterile principles during catheterization, such as improper disinfection, improper flushing and sealing of the tubing, and poor catheter maintenance, these improper operations can transform the fibrin distributed within the blood vessel catheter into a fibrin sheath, promoting the growth of large numbers of pathogenic bacteria and creating a favorable environment for their growth. Additionally, inexperience of the operator can lead to multiple punctures or failed punctures, resulting in damage to the blood vessel wall or subcutaneous tissue and increasing the infection rate.

(3) Material and drug factors: Catheter materials have a significant impact on pathogenic bacteria adhesion, biofilm formation, and vascularization. If the catheter itself contains blood clots, it can significantly

increase the rate of bloodstream infection. In terms of materials, silicone catheters have the highest incidence of VCAI, followed by polyurethane and polyethylene catheters, with polyvinyl chloride catheters having the highest infection rate. Catheter materials strongly influence biofilm formation and bacterial adhesion, making them a risk factor for VCAI. Regarding dressing selection, long-term coverage of the puncture site with sterile gauze or application of transparent dressings can increase skin moisture, creating conditions for bacterial colonization and promoting the growth of bacterial biofilms within the catheter lumen. Among treatment drugs, the use of catheters to administer total parenteral nutrition, fat emulsions, or plasma can create a culture medium for bacteria. If contaminated drugs are infused through the catheter, it can lead to the introduction of large numbers of pathogenic bacteria into the catheter wall, which can rapidly multiply and spread, resulting in a high incidence of VCAI.

4. Routine prevention and treatment measures for VCAI

4.1. Reasonable selection of catheter type

During catheter placement, it is necessary to evaluate the requirements and purposes of intubation, assess the duration of catheter maintenance, infectious complications, and operator experience, and then select the appropriate type of catheter. Sterile transparent or translucent dressings, sterile gauze, and other materials should be chosen for the intubation site, and a suture-free catheter fixation device should be selected. If the patient requires long-term catheterization, aseptic techniques should be adhered to, and high-risk factors for infection should be excluded.

In recent years, the high-pressure injection PICC catheter has become a new type of catheter, with a maximum tolerable pressure of up to 300 PSI and a flow rate of 5 ml/s. It can be used for high-pressure injection angiography and high-flow infusion therapy. This catheter, combined with a vascular navigation tip positioning system and ECG monitoring, can accurately evaluate the catheter position, prevent catheter displacement, and effectively prevent VCAI. Deng *et al.* used a high-pressure injection PICC for patients undergoing CT enhanced scanning, and the results showed fewer adverse events, high comfort during placement, and significant advantages in catheterization [4].

4.2. Reasonable selection of intubation location

For adult patients, the upper extremities are selected as the intubation site; for pediatric patients, the scalp or upper and lower extremities are chosen. Before catheterization, the risks of mechanical injury and infectious complications should be evaluated, and ultrasound technology should be used to perform the catheterization operation to reduce the rate of repeated intubations. At the same time, it is necessary to use chlorhexidine gluconate or 70% alcohol to disinfect the skin at the catheterization site and wait until the disinfectant is dry before performing the intubation procedure.

4.3. Rational use of antibiotics

During intravascular catheterization, prophylactic antibiotics are administered to prevent VCAI or catheter colonization. After successful intubation, the application of disinfectant ointment should be determined based on the material and type of the catheter. More importantly, it is essential to comprehensively evaluate the patient's personal physical condition, disease history, and other information to select the appropriate type and dosage of disinfectant to ensure high sensitivity of VCAI to antibiotics and reduce drug resistance. Xue *et al.* performed intravascular catheterization for patients in the intensive care unit and analyzed the distribution characteristics of pathogenic bacteria in VCAI [5]. The results showed that most of the drug-resistant bacteria were Gram-negative bacteria, such as *Klebsiella pneumoniae* and *Acinetobacter baumannii*, and the drugs with higher sensitivity were ceftriaxone and ciprofloxacin. This provides a newer approach for drug prevention of VCAI.

4.4. Standardized nursing care

During catheter placement, routine maintenance, and dressing changes, operators are required to adhere to hand hygiene procedures, using hand sanitizers and soap for hand disinfection. After thorough disinfection of the intubation site, touching the area is prohibited, and diagnostic and therapeutic operations such as intubation or catheter maintenance should be performed using aseptic techniques. When placing PICCs or midline catheters, sterile gloves, preferably powder-free, should be worn. When changing guide wires, sterile barrier measures such as wearing masks and hats, putting on sterile surgical gowns, and covering non-intubation areas with sterile drapes should be taken. Cong *et al.* adopted a new nursing model during catheter care - the Ottawa Research Application Model [6]. The primary items include catheterization, and the secondary items include performing hand hygiene, determining the best puncture location, establishing a sterile barrier, and effectively fixing the catheter. After the first round of improvement, the incidence of VCAI among patients was 3.04‰, and after the second round of improvement, the incidence was 2.53‰. This demonstrates that the new nursing model can effectively prevent VCAI and has high nursing practicality.

5. New prevention and treatment technologies for VCAI

5.1. Catheter coating technology

Chlorhexidine-silver sulfadiazine (CHSS) and silver/platinum coatings are the first-generation drugs used in catheter coating technology. Applying them to the outer surface of the catheter can prevent VCAI. The silver ion release cycle of silver-coated catheters is approximately 3 to 7 days, providing short-term protection against catheter infections but offering little effectiveness for those with catheterization exceeding 10 days. CHSS, applied to both the inner lumen and outer surface of the catheter, represents second-generation coating technology. It can prevent the incidence of VCAI after catheterization of the internal jugular vein and femoral vein. The second-generation coating uses an antimicrobial drug dose on the catheter's outer surface that is more than twice that of the first generation, enabling long-term release of antimicrobial drugs and enhancing their anti-infection efficacy. Rifampin-minocycline coating and rifampin-miconazole coating are novel therapies in catheter coating technology, suitable for femoral vein catheterization or tracheotomy. Among them, rifampin-minocycline is more effective than silver/platinum coating in preventing VCAI. The minocycline-rifampin-chlorhexidine coating exhibits strong preventive and therapeutic effects on Candida infections and multi-drug resistant bacterial infections that occur during guidewire exchange. The 5-fluorouracil coating belongs to antimetabolic drugs, which can inhibit the reproduction of pathogenic bacteria and has a good preventive effect on VCAI.

Besides the aforementioned drug coating technologies, reasonable selection of catheter materials is also essential. For example, Jiang *et al.* used ultra-slip coated endotracheal tubes for patients undergoing nasal intubation [7]. This new type of catheter provides strong analgesic and lubricating effects, preventing damage to the tracheal or nasal mucosa during catheterization. The coating's high ductility and adhesion significantly enhance catheterization stability, exerting a continuous lubricating effect, thereby reducing irritation to the trachea and preventing VCAI.

5.2. Antibacterial solution sealing technology

In antibacterial solution sealing technology, the antibiotic concentration is adjusted to 100 to 1000 times, and 2 to 3 ml of the solution is injected into the catheter to prevent infection. Commonly used antibiotics include vancomycin, cephalosporins, and rifampin, while common antiseptics include ethanol and sodium citrate. Ethanol solution, in particular, exhibits high non-antibacterial resistance and precise antibacterial effects. However, concentrations exceeding 28% can cause significant precipitation of plasma proteins, and concentrations exceeding 60% may lead to catheter rupture, limiting its feasibility in sealing applications [8]. To address sealing issues such as catheter blockage, combination therapy with antibiotics like cephalosporin-heparin, gentamicin-sodium citrate, and vancomycin-heparin is often employed. These combinations can effectively eliminate Gram-positive cocci and Gram-negative bacilli distributed within the biofilm, thereby efficiently preventing VCAI.

5.3. Selection of new dressings

Chlorhexidine gel dressings can reduce the number of pathogenic bacteria colonizing the outer surface of catheters. With strong transparency and rich in hydrophilic gel, they can prevent excessive fluid leakage, maintaining antibacterial efficacy for about 10 days. Chlorhexidine impregnated dressings are novel dressings for adult patients and are recommended by guidelines for the prevention of intravascular catheter infections. New hydrocolloid dressings exhibit strong anti-inflammatory effects and can effectively absorb liquids, thus preventing bacterial growth at the catheterization site. Qiu used novel dressings for patients with PICC catheters, resulting in significantly lower complication rates such as catheter infection or thrombosis compared to traditional dressings, highlighting the strong infection prevention capabilities of these new dressings [9].

6. Conclusion

In summary, there are many influencing factors for VCAI in patients with intravascular catheters. Prevention measures such as rational selection of catheter types, insertion locations, and antimicrobial agents can be utilized to prevent infections. Simultaneously, employing new technologies like catheter coating techniques or novel dressings can minimize the incidence of VCAI.

Disclosure statement

The author declares no conflict of interest.

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