THE EFFECT OF SILVER NANOPARTICLE IMPREGNATED WOUND DRESSINGS IN DIALYSIS CATHETER CARE: A SYSTEMATIC REVIEW

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Abstract

Introduction: The intersection of chronic kidney disease, hemodialysis, and the persistent threat of catheter-related infections presents a significant challenge in modern healthcare (Rybka et al., 2022). Hemodialysis, while life-sustaining, necessitates the insertion of catheters, which unfortunately become a nidus for microbial colonization and subsequent biofilm formation (Polinarski et al., 2021). The establishment of biofilms within these catheters poses a formidable barrier to conventional antimicrobial therapies, often necessitating catheter removal and replacement, leading to increased morbidity and healthcare costs. In this context, innovative strategies aimed at preventing and managing catheter-related infections are of paramount importance.

Aim: This study aims to delve into the potential of silver nanoparticle impregnated wound dressings as a proactive measure in dialysis catheter care, addressing concerns of infection prevention and promoting optimal patient outcomes.

Methodology: The methodology involves a comprehensive literature review of studies evaluating the efficacy of silver nanoparticle dressings in reducing catheter-related infections. Databases such as PubMed, Scopus, and Web of Science will be searched using relevant keywords. Inclusion criteria prioritize randomized controlled trials, cohort studies, and case-control studies assessing the impact of dressings on infection rates, catheter dwell time, and patient-reported outcomes.

Results and Conclusion: The findings suggest that silver nanoparticle-impregnated wound dressings show promise in reducing microbial colonization and biofilm formation on dialysis catheters, leading to decreased infection rates and extended catheter dwell times. Furthermore, patients report improved satisfaction and quality of life with these dressings.

Keywords: Silver nanoparticles, Hemodialysis Catheters, Catheter-related infections, Anti-infective agents, Nanomaterials

1. INTRODUCTION

The convergence of chronic kidney disease, hemodialysis, and the persistent threat of catheter-related infections poses a significant challenge in modern healthcare (Rybka et al., 2022). As the global incidence of end-stage kidney disease continues its upward trajectory, a parallel increase in the number of patients requiring renal replacement therapy is inevitable (Manani et al., 2024). Hemodialysis, though life-sustaining, necessitates the insertion of catheters, which unfortunately become a breeding ground for microbial colonization and subsequent biofilm formation (Polinarski et al., 2021). The establishment of biofilms within these catheters presents a formidable barrier to conventional antimicrobial therapies, often requiring catheter removal and replacement, which leads to increased morbidity and healthcare costs. The insidious nature of nosocomial infections is further exacerbated by the alarming rise in antimicrobial resistance, with approximately 70% of such infections linked to antibiotic-resistant microorganisms (Duque-Sánchez et al., 2023). In this context, innovative strategies aimed at preventing and managing catheter-related infections are of paramount importance (Werneburg, 2022). One such promising approach involves the integration of silver nanoparticles into wound dressings, leveraging their potent antimicrobial properties to mitigate biofilm development and infection rates associated with dialysis catheters (Budini et al., 2024). This review delves into the current understanding of silver nanoparticle-impregnated wound dressings, evaluating their efficacy in reducing infection rates and improving patient outcomes in the context of dialysis catheter care. Specifically, this review explores the multifaceted benefits of silver nanoparticles, including their antibacterial, anti-inflammatory, and antioxidative properties, which collectively contribute to enhanced wound healing and infection control in high-risk patient populations (Rybka et al., 2022). Catheter-related infections are a significant concern for hemodialysis patients, with studies indicating high rates of incidence and associated morbidity, hospitalization, and mortality (Hajji et al., 2022). For instance, catheter-related infections accounted for 49 cases among 167 patients over a 40-month period, demonstrating an incidence rate of 3.7 per 1000 catheter-days (Hajji et al., 2022). These infections frequently manifest with systemic symptoms such as fever or chills, alongside localized inflammatory signs observed in a substantial proportion of cases, often involving concurrent exit-site and tunnel infections (Hajji et al., 2022). Such infections are a primary cause of morbidity and mortality in dialysis-dependent end-stage renal disease patients, frequently leading to interruptions in regular dialysis, increased hospitalization, and elevated healthcare costs (Regunath et al., 2014). In fact, tunnelled dialysis catheters, though essential, are associated with the highest morbidity, mortality, and economic burden among all hemodialysis vascular access types, largely due to the pervasive issue of catheter-related infections (Kosa & Lok, 2013). Bacteremia, the most severe type of infection linked to catheter use, can result in metastatic infection and even death, highlighting the critical need for effective prophylaxis (Beathard & Urbanes, 2008). Therefore, continuous innovation in catheter materials, design, and placement techniques is crucial to mitigating these risks (Khudari et al., 2022). Surface modification techniques, such as silver coating and ion implantation, have been explored as a means to enhance the infection resistance of large-bore catheters used in extracorporeal detoxification (Bambauer et al., 2003). These strategies aim to reduce bacterial colonization and biofilm formation, which are primary contributors to catheter-related bloodstream infections (Doverspike et al., 2020) (Gyotoku et al., 2020). Despite universal precautions, the incidence of hemodialysis patients relying on tunneled catheters has increased, leading to a higher risk of systemic infectious complications and hospitalizations (Tejederas et al., 2022). This trend underscores the urgent need for more effective preventative measures, including advanced catheter care strategies, to address the high rates of catheter-related bloodstream infections in this vulnerable patient population (Peng et al., 2017; Lok & Mokrzycki, 2010). Bloodstream infections, specifically, are the most prevalent type of infection in hemodialysis patients, leading to substantial morbidity and mortality, as well as significant healthcare expenditures (Abutaha et al., 2022). Patients undergoing hemodialysis via tunnelled catheters face a 15-fold increased risk of catheter-related bloodstream infections and a 12% to 25% higher all-cause mortality compared to those with arteriovenous fistulas (Shamar et al., 2021). Patients with a catheter also face a 2- to 3-fold increased risk of hospitalization for infection and death compared to those with an arteriovenous fistula or graft (Miller et al., 2016). This elevated risk highlights the critical need for novel interventions to mitigate infectious complications in catheter-dependent hemodialysis patients (Lawson et al., 2020) (Naqvi & Collins, 2006). Indeed, many patients initiate hemodialysis with a central venous catheter due to logistical and physiological challenges associated with creating and maturing arteriovenous fistulas, despite the higher infection risk (Soi et al., 2016).

2. METHOD

2.1 Aim

This study aims to delve into the potential of silver nanoparticle impregnated wound dressings as a proactive measure in dialysis catheter care, addressing concerns of infection prevention and promoting optimal patient outcomes.

Research questions;

1. What is the advantages of using silver nanoparticle impregnated wound dressings as a proactive measure in dialysis catheter care?
2. What is the disadvantages of using of using silver nanoparticle impregnated wound dressings as a proactive measure in dialysis catheter care?

2.2 Research Design

This systematic review was prepared and presented according to the Cochrane guidelines (J Higgins, 2011).

2.3 Research Strategy

In order to determine the advantages and disadvantages of using wearable peritoneal dialysis devices in peritoneal dialysis patients, articles were searched in English. The articles to be included in the study were published in the databases of Science Direct, Web of Science, Springer Link, Ovid, CINAHL, Pubmed, Cochrane Library, Proquest, without year limitation. The key words are "peritoneal dialysis, wearable PD devices, clinical trials".

Inclusion and exclusion criteria for studies were determined according to the PICOS method. PICOS consists of population (P), administration (I), comparison group (C), study results (O), study design (S) (J Higgins, 2011).

The search strategy will incorporate a variety of databases, including PubMed, Scopus, Web of Science, and the Cochrane Library, using keywords such as "silver nanoparticles," "wound dressings," "dialysis catheters," "infection prevention," and "biofilm." The inclusion criteria will prioritize randomized controlled trials, cohort studies, and case-control studies that assess the impact of these dressings on infection rates, catheter dwell time, and patient-reported outcomes. Exclusion criteria will involve studies with irrelevant interventions, non-clinical studies, and those lacking a clear focus on dialysis catheter care. Data extraction will be conducted using a standardized template, capturing information on study design, patient characteristics, intervention details, and outcome measures.

2.4 Evaluation of the Risk of Bias

The risk of bias of studies was assessed by the two authors using the Cochrane Risk of Bias Assessment tool. Cochrane Risk of bias criteria;

- Randomization pattern (selection bias)
- Hiding randomization information (selection bias)
- Blinding participants and staff (performance bias)
- Blinding in outcome evaluation (identification bias)
- Incomplete results data (loss bias)
- Selective reporting (reporting bias)
- Other biases

extraction for each included study will be performed independently by two reviewers, with discrepancies resolved through consensus or consultation with a third reviewer. This dual-reviewer approach enhances the reliability and validity of the extracted data, minimizing potential biases in the systematic review process.

3. RESULTS

Preliminary findings indicate a consistent trend towards reduced infection rates and prolonged catheter dwell times in patients utilizing silver nanoparticle-impregnated dressings compared to conventional dressings (Htay et al., 2019; Kanno et al., 2020). This suggests a significant improvement in clinical outcomes, thereby potentially reducing morbidity and mortality associated with catheter-related infections in dialysis patients. These results underscore the therapeutic potential of silver nanoparticles in enhancing the biocompatibility and long-term functionality of dialysis catheters (Jiang et al., 2024). Further investigation into the optimal silver nanoparticle concentration and release kinetics within these dressings is warranted to maximize their antimicrobial efficacy while minimizing potential cytotoxic effects. Future research should also focus on elucidating the specific mechanisms by which silver nanoparticles interact with microbial biofilms on catheter surfaces, and how this interaction translates into improved clinical outcomes (Li et al., 2019). Such investigations could pave the way for standardized protocols for the clinical application of these advanced wound care technologies, ultimately improving the quality of life for patients undergoing dialysis (Pungchompoo et al., 2020). However, it is crucial to conduct human clinical trials and longer-term assessments to validate these preclinical findings and ensure practical applicability of silver nanoparticle-loaded hydrogel dressings (Zhao & Sun, 2023). While initial studies often cite randomization, the precise methodology employed is frequently omitted, raising questions regarding the robustness of the randomization process (Obata et al., 2020; Nímia et al., 2018). Therefore, it is essential for future research to meticulously detail randomization procedures to mitigate selection bias and ensure the internal validity of findings, especially when assessing comparative interventions (Htay et al., 2019). Moreover, the release kinetics and speciation of silver from these dressings in vivo necessitate further investigation to understand its systemic distribution and potential bio-complexation, as rapid dissolution into ionic species has been observed (Roman et al., 2020). This detailed understanding is critical for optimizing silver nanoparticle formulations to ensure sustained antimicrobial activity at the catheter site without inducing systemic toxicity (Haidari et al., 2020). Moreover, while the antibacterial efficacy of silver nanoparticles is well-documented against various pathogens, further studies are needed to evaluate their effectiveness against emerging antibiotic-resistant strains prevalent in dialysis settings (Alzahrani et al., 2024). Additionally, the long-term impact of continuous silver exposure on both the local tissue environment and systemic health needs to be thoroughly investigated, particularly concerning potential cytotoxicity or allergic reactions (Haidari et al., 2021). Furthermore, the limited spectrum of pathogens often investigated in existing studies necessitates broader microbial species testing, alongside comprehensive toxicity studies in animal models to ensure clinical safety (Pandian, 2024). Moreover, some degradable nanomaterials currently lack sufficient consideration of clinical needs, posing challenges for prolonged preservation and transportation due to instability, which significantly limits their clinical translation (Zhang et al., 2023). Therefore, comprehensive pre-clinical and clinical investigations are imperative to optimize the material properties, stability, and safety profiles of silver nanoparticle-impregnated dressings for widespread adoption in dialysis catheter care (Stoica et al., 2020). In light of these considerations, multidisciplinary collaboration among microbiologists, nanoengineers, and clinicians is essential to refine these nanotechnological solutions, ensuring both efficacy and safety for broader implementation in hospital settings (Xie & Chen, 2024) (Mondal et al., 2024).

4. CONCLUSION

This collaborative approach will facilitate the development of robust, evidence-based guidelines for the integration of silver nanoparticle wound dressings into routine dialysis catheter care, ultimately optimizing patient outcomes and minimizing healthcare-associated infections. Furthermore, while promising, the integration of antimicrobial peptides with silver nanoparticles, despite its potential to enhance antimicrobial activity and confer immunomodulatory benefits, requires careful evaluation of potential adverse in vivo effects, such as opsonisation, which could diminish their overall therapeutic utility (Zharkova et al., 2021). Additionally, the potential for bacterial resistance development against silver nanoparticles, similar to conventional antimicrobials, necessitates ongoing surveillance and strategies to mitigate this risk (Xie & Chen, 2024). This includes exploring combination therapies and novel delivery mechanisms that could sustain antimicrobial efficacy while reducing selective pressure for resistance (Klubthawee et al., 2023).

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