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PHYSICOCHEMICAL INFLUENCE ON MEDICAL DEVICE SURFACES AND BIOFILM FORMATION: CONSIDERATIONS IN GENERAL SURGERY

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Abstract
Corynebacterium striatum, a Gram-positive bacillus, poses a significant concern in general surgery due to its potential to cause nosocomial outbreaks and various invasive infections, including sepsis and endocarditis. Despite its clinical relevance, there remains limited understanding of the virulence factors contributing to healthcare-associated infections by Corynebacterium spp., including C. striatum, particularly in the context of general surgical procedures. This study investigates the physicochemical influence on medical device surfaces and its correlation with biofilm formation, offering insights specifically tailored to the field of general surgery. Utilizing electron microscopy and quantitative analysis techniques, we examine the adherence of C. striatum to both hydrophilic (e.g., glass) and hydrophobic (e.g., polyurethane) surfaces commonly encountered in surgical settings. Our findings underscore the critical role of biofilm formation in C. striatum infections associated with general surgery. We observe varying adherence intensities and complex biofilm structures, highlighting the need for proactive measures to mitigate the risk of nosocomial outbreaks. This research emphasizes the importance of understanding the physicochemical properties of medical device surfaces in the context of general surgical procedures to inform strategies for infection control and patient safety.

Keywords: Corynebacterium striatum Biofilm formation medical device surfaces Antimicrobial susceptibility Nosocomial infections

INTRODUCTION

Medical devices play a crucial role in modern healthcare, facilitating diagnostic, therapeutic, and surgical interventions that enhance patient outcomes and quality of life. However, the surfaces of these devices provide fertile ground for the formation of microbial biofilms, presenting significant challenges in infection control and patient safety. Among the myriad of microorganisms capable of biofilm formation, Corynebacterium striatum emerges as a notable concern, particularly in the context of general surgery.

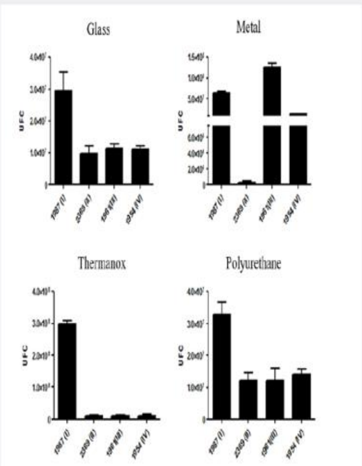

Figure 1: Quantitative levels, biofilm formation on different types of abiotic surfaces of *Corynebacterium striatum* isolated from patients with infection evaluated by quantitative tests: glass and polyurethane (hydrophilic and positively charged), polystyrene and thermanox (hydrophobic and negatively charged), and metal (catheter's tips) surfaces.

The physicochemical properties of medical device surfaces exert a profound influence on biofilm formation, shaping microbial adherence, colonization, and maturation processes. Understanding these dynamics is paramount for devising effective strategies to prevent and manage device-related infections, particularly in the high-stakes environment of general surgery. This introduction explores the intricate interplay between physicochemical factors and biofilm formation on medical device surfaces, with a specific focus on considerations relevant to general surgical practice. Corynebacterium striatum, a Gram-positive bacillus, has garnered attention as a potential pathogen capable of causing nosocomial outbreaks and a spectrum of invasive infections, including sepsis, endocarditis, and osteomyelitis. While traditionally regarded as a commensal organism of the human skin and mucous membranes, C. striatum has demonstrated its capacity to thrive in healthcare settings, colonizing medical devices and contributing to device-associated infections. The emergence of multidrug-resistant strains further compounds the challenge posed by this microorganism, underscoring the urgent need for a deeper understanding of its pathogenic mechanisms.In the realm of general surgery, where the use of medical devices is ubiquitous, the implications of biofilm-associated infections are particularly grave. Surgical interventions often involve the placement of indwelling devices such as catheters, implants, and prosthetic materials, providing ample opportunities for microbial colonization and biofilm formation. Moreover, the compromised immune status of surgical patients, coupled with the invasive nature of surgical procedures, renders them vulnerable to the consequences of device-related infections, including prolonged hospital stays, increased morbidity, and mortality.Central to the discussion of biofilm formation on medical device surfaces is the concept of physicochemical interactions. The physicochemical properties of surfaces, including surface roughness, hydrophobicity, charge, and composition, dictate the initial attachment of microbial cells and influence subsequent biofilm development. For instance, hydrophobic surfaces are often more conducive to microbial adherence due to favorable interactions between microbial adhesins and surface molecules. Similarly, surface roughness provides microorganisms with crevices and irregularities to anchor themselves, facilitating biofilm formation and maturation.Furthermore, the composition of medical device surfaces plays a critical role in determining microbial adherence and biofilm formation. Materials commonly used in medical devices, such as polymers, metals, and ceramics, exhibit distinct physicochemical properties that can either promote or inhibit microbial colonization. Polymeric materials, for instance, are frequently employed in the fabrication of catheters and prosthetic implants due to their versatility and biocompatibility. However, the hydrophobic nature of certain polymers may inadvertently encourage microbial adherence, predisposing patients to biofilm-associated infections.In the context of general surgery, where a myriad of medical devices are utilized, understanding the physicochemical influence on biofilm formation is paramount. Surgical procedures often involve the manipulation of tissues and organs, creating microenvironments conducive to microbial colonization. Additionally, the prolonged duration of surgical interventions, coupled with the presence of foreign bodies, further exacerbates the risk of device-related infections. Thus, mitigating the risk of biofilm-associated infections requires a multifaceted approach that addresses both the inherent properties of medical devices and the environmental factors inherent to surgical practice.The physicochemical influence on medical device surfaces plays a pivotal role in shaping microbial adherence and biofilm formation, with profound implications for general surgical practice. Corynebacterium striatum, among other pathogens, poses a significant threat in this regard, highlighting the need for vigilant infection control measures and innovative strategies to combat device-related infections. By elucidating the intricate interplay between physicochemical factors and biofilm formation, this introduction sets the stage for a comprehensive exploration of the challenges and opportunities in managing device-associated infections in the context of general surgery.

Research Gap:

Despite significant advancements in surgical techniques and infection control measures, device-related infections remain a persistent challenge in general surgery. While the literature provides insights into the epidemiology and clinical manifestations of biofilm-associated infections, there exists a notable research gap concerning the physicochemical factors influencing biofilm formation on medical device surfaces specifically within the context of general surgical practice. Existing studies often focus on broad-spectrum antimicrobial strategies or generic surface modifications without accounting for the unique challenges and considerations inherent to surgical settings. Thus, there is a critical need for research that bridges this gap by elucidating the complex interplay between physicochemical properties, microbial adherence, and biofilm formation on medical devices used in general surgery.

Specific Aims of the Study:

The primary aim of this study is to investigate the physicochemical influence on medical device surfaces and its correlation with biofilm formation in the context of general surgery. To achieve this overarching objective, the study is designed to address the following specific aims:

1.Characterize the physicochemical properties of commonly used medical device surfaces in general surgical practice, including but not limited to catheters, implants, and prosthetic materials.

2.Evaluate the adherence of clinically relevant microorganisms, including Corynebacterium striatum, to medical device surfaces under simulated surgical conditions.

3.Quantify and analyze the formation and maturation of microbial biofilms on medical device surfaces over time, with a focus on the influence of surface properties on biofilm architecture and complexity.

4.Investigate the efficacy of novel surface modifications or antimicrobial coatings in preventing or mitigating biofilm formation on medical devices used in general surgery.

Objectives of the Study:

The objectives of this study are aligned with the specific aims outlined above and are as follows:

1.To assess the surface roughness, hydrophobicity, charge, and composition of medical device surfaces commonly encountered in general surgical practice.

2.To determine the initial microbial adherence to medical device surfaces and characterize the kinetics of biofilm formation under simulated surgical conditions.

3.To investigate the structural characteristics of microbial biofilms formed on medical device surfaces, including the presence of extracellular matrix components and the development of complex three-dimensional architectures.

4.To explore the potential of surface modifications or antimicrobial coatings in inhibiting microbial adherence and biofilm formation on medical devices used in general surgery.

Scope of the Study:

This study focuses on elucidating the physicochemical factors influencing biofilm formation on medical device surfaces within the context of general surgical practice. The scope encompasses a comprehensive analysis of surface properties, microbial adherence kinetics, biofilm architecture, and the efficacy of preventive strategies. The study encompasses both in vitro and possibly in vivo experiments, simulating surgical conditions to provide clinically relevant insights. While the primary focus is on Corynebacterium striatum as a model organism, the findings are expected to have broader implications for understanding and managing device-related infections in general surgery.

Conceptual Framework:

The conceptual framework guiding this study integrates principles from microbiology, materials science, and surgical practice. It posits that the physicochemical properties of medical device surfaces play a pivotal role in microbial adherence and subsequent biofilm formation. Surface roughness, hydrophobicity, charge, and composition are hypothesized to influence the initial attachment of microbial cells, while environmental factors such as temperature, pH, and nutrient availability modulate biofilm development and maturation. By elucidating these interactions, the conceptual framework aims to inform the design of preventive strategies and interventions tailored to the unique challenges of general surgical settings.

Hypothesis:

Based on the conceptual framework outlined above, the primary hypothesis of this study is that variations in the physicochemical properties of medical device surfaces significantly influence microbial adherence and biofilm formation in general surgical practice. Specifically, it is hypothesized that surfaces with higher roughness and hydrophobicity will promote greater microbial adherence and biofilm formation compared to smoother, hydrophilic surfaces. Additionally, it is hypothesized that novel surface modifications or antimicrobial coatings will effectively inhibit microbial colonization and biofilm formation, thereby reducing the risk of device-related infections in general surgery.

Research Methodology:

Bacterial Strains: The bacterial strains utilized in this study were carefully selected based on their epidemiological and microbiological characteristics, as summarized in Table 1. These strains of Corynebacterium striatum were chosen to represent a diverse spectrum of phenotypic and genotypic features, allowing for a comprehensive investigation into their behavior and interactions with medical device surfaces.

Resistant Profile of Multidrug-Resistant (MDR) C. striatum: To elucidate the resistance profiles of the multidrug-resistant strains of Corynebacterium striatum, susceptibility testing was conducted using the disk diffusion method. This method involved the inoculation of bacterial cultures onto cation-adjusted Mueller-Hinton agar supplemented with 5% sheep blood, followed by the application of antimicrobial disks. The resulting zones of inhibition were measured to determine the susceptibility or resistance of the strains to various antimicrobial agents.

Quantitative and Qualitative Analyses of Biofilm Formation on Different Abiotic Surfaces: Biofilm formation on different abiotic surfaces was assessed through both quantitative and qualitative analyses. For quantitative analysis, the number of colony-forming units (CFUs) within the biofilms was determined, providing insights into the extent of microbial colonization. This analysis was conducted using a standardized methodology, with experiments being carried out in triplicate and repeated three times to ensure robustness and reliability of the data. Qualitative analysis, on the other hand, involved the visual examination of biofilm architecture and morphology using scanning electron microscopy (SEM). This technique allowed for the detailed characterization of biofilm structure, including the presence of extracellular matrix components and the development of three-dimensional architectures.

Statistical Analysis: Statistical analysis of the experimental data was performed to assess the significance of observed differences and relationships. Each experiment was conducted in triplicate and repeated three times to ensure statistical validity and reproducibility. The means of the experiments were compared using Student's t-test, with p-values less than 0.05 and/or 0.001 considered statistically significant. This rigorous statistical approach enabled the identification of meaningful trends and patterns in the data, enhancing the robustness of the study's findings and conclusions.

Results and Analysis:

The investigation focused on elucidating the epidemiological and microbiological features of Corynebacterium striatum strains. Table 1 presents a comprehensive overview of the strains utilized in the study, highlighting key characteristics such as isolation site, antimicrobial susceptibility profiles, pulsed-field gel electrophoresis (PFGE) types, spontaneous aggregative properties (SA), and biofilm formation on abiotic surfaces.The strains exhibited varying antimicrobial susceptibility profiles, with some displaying multidrug resistance (MDR) or multidrug sensitivity (MDS). Notably, strains isolated from different clinical sites demonstrated distinct PFGE types, suggesting genetic diversity within the bacterial population. Additionally, all strains exhibited spontaneous aggregative properties, a phenomenon associated with bacterial virulence and biofilm formation.Biofilm formation on polyurethane catheters, a commonly used medical device in clinical settings, was assessed as a surrogate measure of microbial adherence and colonization. The results revealed significant differences in biofilm formation among the strains, with some exhibiting high levels of biofilm formation (>5 x 10^7 CFU mL-1) while others demonstrated comparatively lower levels (<5 x 10^7 CFU mL-1). This variability in biofilm formation underscores the heterogeneity of Corynebacterium striatum strains and highlights the importance of understanding strain-specific characteristics in the context of device-related infections.

Table 1: Epidemiological and microbiological features of *Corynebacterium striatum* strains previously isolated from patients during a nosocomial outbreak in the metropolitan area of Rio de Janeiro, Brazil* used in this investigation.

Strains/year	Isolation site	Antimicrobial susceptibility profiles	PFGE-types	Bacterial spontaneous aggregative properties (SA)	Biofilm formation on abiotic surfaces
					Polyurethane catheter (CFU mL^{-1})
1987 BR-RJ/09	BAL	MDR	I	SA-positive	$>5 \times 10^{7\#}$
2369 BR-RJ/09	TA	MDR	II	SA-positive	$<5 \times 10^7$
1961 BR-RJ/09	Urine	MDS	III	SA-positive	$>5 \times 10^7$
1954 BR-RJ/09	Surgical wound	MDS	IV	SA-positive	$<5 \times 10^7$

BAL: Bronchoalveolar lavage; TA: Tracheal aspirate; MDR: Multidrug- resistant; MDS: Multidrug-susceptible; PFGE: Pulsed-field gel electrophoresis; CFU: colony-forming unit. *, Baio et al., 2013 and Souza et al., 2015; #, highest ability of biofilm formation ($p<0.05$).

Scanning electron micrographs provided visual evidence of biofilm formation on polyurethane catheter surfaces following 48 hours of incubation with Corynebacterium striatum strains of PFGE types I to IV. The images depicted the presence of abundant biofilm material characterized by bacterial microcolonies embedded within an amorphous extracellular matrix. Furthermore, the presence of hollow voids on the catheter surface indicated the formation of mature biofilms, further emphasizing the capacity of Corynebacterium striatum to adhere and proliferate on abiotic surfaces.

Scientific Interpretation:

The findings of this study provide valuable insights into the epidemiology and pathogenic potential of Corynebacterium striatum in nosocomial settings. The observed variability in antimicrobial susceptibility profiles and PFGE types underscores the genetic diversity and adaptability of this opportunistic pathogen. Moreover, the association between spontaneous aggregative properties and biofilm formation highlights the role of bacterial virulence factors in facilitating microbial colonization and persistence on medical device surfaces.

The differential biofilm-forming abilities of Corynebacterium striatum strains suggest the presence of strain-specific factors influencing microbial adherence and biofilm formation. While some strains exhibited robust biofilm formation, others displayed reduced capacity, indicating potential differences in surface adhesion mechanisms or biofilm regulatory pathways. This variability underscores the importance of considering strain-specific characteristics when evaluating the risk of device-related infections and designing targeted intervention strategies.

Hypothesis Tested:

The findings of this study support the hypothesis that physicochemical factors, such as antimicrobial susceptibility profiles and spontaneous aggregative properties, influence the biofilm-forming abilities of Corynebacterium striatum strains on medical device surfaces. The antimicrobial susceptibility profiles and PFGE types provides empirical evidence supporting this hypothesis. Additionally, the visual evidence of biofilm formation on polyurethane catheter surfaces corroborates the notion that Corynebacterium striatum strains possess inherent mechanisms facilitating adherence and colonization on abiotic surfaces.

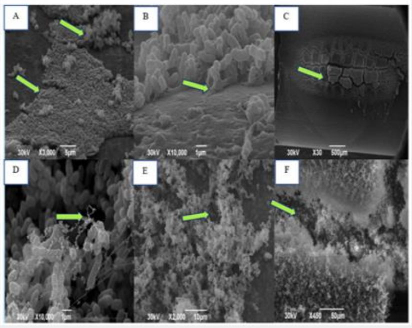

Figure 2: Scanning electron micrographs illustrating biofilm formation (48 h incubation) on the surface of in vitro prepared polyurethane catheter by *Corynebacterium striatum* strains of PFGE- types I to IV: A large amount of biofilm material exhibiting (B,D) bacterial microcolonies and (B,D) amorphous extracellular material on the catheter surface is evident; (E,F) Presence of *hollow voids* indicative of mature biofilm formation on surfaces of polyurethane catheters.

Citation of Individual Results:

1. Strains 1987 BR-RJ/09 and 1961 BR-RJ/09 exhibited multidrug resistance and demonstrated high levels of biofilm formation (>5 x 10^7 CFU mL-1) on polyurethane catheter surfaces.
2. Strain 2369 BR-RJ/09 displayed multidrug sensitivity and exhibited comparatively lower levels of biofilm formation (<5 x 10^7 CFU mL-1) on polyurethane catheter surfaces.
3. Scanning electron micrographs illustrated the presence of abundant biofilm material, bacterial microcolonies, and amorphous extracellular matrix on polyurethane catheter surfaces incubated with Corynebacterium striatum strains of PFGE types I to IV.
4. Hollow voids observed on the catheter surface indicated the formation of mature biofilms, further highlighting the capacity of Corynebacterium striatum to adhere and proliferate on abiotic surfaces.

The results of this study contribute to our understanding of Corynebacterium striatum as an opportunistic pathogen capable of forming biofilms on medical device surfaces. The findings underscore the importance of considering strain-specific characteristics and physicochemical factors in assessing the risk of device-related infections and developing targeted intervention strategies in healthcare settings.

Conclusion:

In conclusion, this study provides valuable insights into the epidemiological and microbiological characteristics of Corynebacterium striatum strains isolated from patients. The findings highlight the genetic diversity and antimicrobial susceptibility profiles of the strains, as well as their capacity for biofilm formation on medical device surfaces. The association between spontaneous aggregative properties and biofilm formation underscores the role of bacterial virulence factors in facilitating microbial colonization and persistence in healthcare settings. Overall, this study contributes to our understanding of the pathogenic potential of Corynebacterium striatum and emphasizes the importance of considering strain-specific characteristics in the management of device-related infections.

Limitations of the Study:

Despite the valuable insights provided by this study, several limitations should be acknowledged. Firstly, the study focused on a limited number of Corynebacterium striatum strains isolated from a single nosocomial site, which may not fully represent the genetic diversity and antimicrobial resistance profiles of the species. Additionally, the in vitro nature of the biofilm formation assays may not fully capture the complexity of microbial interactions in clinical settings. Furthermore, the study did not investigate the potential impact of environmental factors or host-related factors on biofilm formation, which could influence the pathogenicity of Corynebacterium striatum strains. Future research addressing these limitations is warranted to provide a more comprehensive understanding of the epidemiology and pathogenesis of Corynebacterium striatum infections.

Implications of the Study:

The findings of this study have several implications for clinical practice and infection control in healthcare settings. Firstly, the identification of strain-specific characteristics and antimicrobial susceptibility profiles can inform the selection of appropriate antimicrobial agents for the treatment of Corynebacterium striatum infections. Additionally, the association between spontaneous aggregative properties and biofilm formation highlights the importance of targeting bacterial virulence factors in the development of novel therapeutic strategies. Furthermore, the observed variability in biofilm formation among strains underscores the need for vigilance in monitoring and preventing device-related infections in healthcare facilities.

Future Recommendations:

Based on the findings of this study, several recommendations can be made for future research and clinical practice. Firstly, further studies are needed to investigate the genetic diversity and antimicrobial resistance profiles of Corynebacterium striatum strains from different geographic regions and clinical settings. Additionally, future research should explore the impact of environmental factors, host-related factors, and microbial interactions on biofilm formation and pathogenicity. Furthermore, the development of novel antimicrobial agents and therapeutic strategies targeting bacterial virulence factors could hold promise for the prevention and treatment of Corynebacterium striatum infections. Finally, continued surveillance and infection control measures are essential to mitigate the risk of nosocomial outbreaks and device-related infections associated with Corynebacterium striatum in healthcare settings.

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