The Influence of Electricity on The Biofilm of Bacteria: A Literature Review

Fadli Januar[1], Eko Budi Koendhori[2]

[1] fadli.januar-2020@fk.unair.ac.id
[1] Faculty of Medicine, Universitas Airlangga, Surabaya 60132, Indonesia
[2] Department of Clinical Microbiology, Dr. Soetomo General Hospital, Universitas Airlangga, Surabaya 60312, Indonesia

Abstract

This literature review explores the role of low voltage electricity on the biofilm of the bacterium, focusing on the impact of electricity on bacterial cells and biofilms. The review begins with an overview of biofilm formation, emphasizing its significance in bacterial infectious diseases and the advantages it provides to bacteria. The historical trajectory of biofilm research and its influence on chronic infectious diseases, including its association with cancer growth, is discussed.

The subsequent section delves into the effects of electricity on bacteria and biofilms. Electric current is examined as a physical agent with inhibitory and bactericidal effects, providing an alternative approach to combat bacteria with increased resistance due to biofilm formation. The mechanisms of electricity-induced bacterial death, including thermal and electrolysis effects, alterations in transmembrane potential, and the role of reactive oxygen species (ROS), are elucidated.

Furthermore, factors influencing the bactericidal efficacy of electricity are outlined, emphasizing the intensity and duration of electric current exposure as critical determinants. The review concludes with a specific focus on Klebsiella pneumoniae bacteria, presenting findings from previous research that demonstrate the bactericidal effect of a 10 mA electric current, resulting in bacterial death after a 30-minute exposure period. This comprehensive review contributes to our understanding of the potential applications of low voltage electricity in eradicating bacteria within biofilms and highlights avenues for future research in this field.

Keywords: Biofilm; Electricity; Bactericidal Efficacy; Klebsiella Pneumoniae.

1. Biofilm

1.1. Definition of Biofilm

The term "Biofilm" refers to an aggregation of bacteria that congregates and establishes a colony on a solid surface, as outlined by Kokare et al. (2009). Biofilms are comprised of bacterial cell formations that amass on a surface, accompanied by extracellular polymeric substances containing elements such as polysaccharides, proteins, nucleic acids, and fats. Bacteria engaged in biofilm formation coalesce to create a structure and bind together, with extracellular polymeric substances playing a crucial role in stabilizing the bacterial formation (Flemming & Wingender, 2010).

The formation of a biofilm structure by bacteria poses a formidable challenge. Notably, biofilm formation constitutes a critical factor in numerous bacterial infectious diseases, including osteomyelitis, dental caries, and chronic lung infections. This increased resistance is attributed to the fact that bacteria within biofilms can withstand antimicrobials at concentrations 10-1000 times higher than those required to eliminate bacteria in non-biofilm states. Additionally, biofilm-associated bacteria exhibit resistance to phagocytosis, rendering them exceptionally challenging to eradicate (Jefferson, 2004).

Biofilms offer several advantages to bacteria, such as sustenance, a nutrient-rich habitat, and mutual support for survival. The biofilm matrix serves various functions, including protection, nutrient provision, reinforcement of the structural integrity of bacterial formations, and the metabolism of substances within the biofilm. These attributes collectively contribute to the remarkable success of biofilms as the most prevalent form of life on Earth (Flemming & Wingender, 2010).

1.2. Why Bacteria Make Biofilm

The formation of biofilms by bacteria is driven by the inherent instinct for survival and the perpetuation of their species, akin to other living organisms. While biofilm formation leads to a deceleration in bacterial reproduction, it offers a nutrient-abundant environment conducive to bacterial sustenance.

During biofilm formation, bacteria derive several advantages, as outlined by Jefferson (2004):

- Enhanced Defense: Biofilms exhibit increased resilience against physical forces, alterations in pH, oxygen radicals, antibiotics, and phagocytic cells.
- Optimal Habitat: Biofilm-forming bacteria, possessing heightened resistance, can strategically select growth locations abundant in nutrients, ample water, sufficient oxygen, and optimal temperatures.
- Communal Growth: Bacteria participating in biofilm formation cooperate to foster more optimal growth compared to their free-living counterparts.

1.3. Biofilm Formation

Biofilm formation in bacteria involves a series of processes, commencing with the selection of a surface for attachment and subsequent adaptation of the bacteria to both the surface and its associated substances and microorganisms. Following environmental adaptation, the bacterial colony undergoes the development of a protective biofilm structure, serving to shield itself and the collective colony. Additionally, biofilms exhibit mechanisms for polysaccharide degradation, facilitating nutrient consumption by cells and releasing free bacterial cells to mitigate populations during conditions of scarcity (Watnick & Kolter, 2000).

It is established that bacterial biofilms constitute organized communities with shared objectives, collaborating for mutual benefit. Mature biofilms exhibit mobility and growth, actively seeking nutrients and advantageous locations. This underscores the complexity of activities undertaken by mature biofilms to ensure their sustained survival, extending beyond the basic adherence of bacterial cells toward nutrient-rich areas characteristic of newly formed biofilms (Lewandowski & Bevenal, 2015).

1.4. The Role of Biofilms in Infectious Disease

The investigation and scrutiny of biofilms have a historical trajectory dating back to 1683, yet it wasn't until the 1970s that these structures garnered substantial interest from medical microbiologists. The pivotal discovery of an association between persistent infections and biofilms in cystic fibrosis patients during this period marked a turning point. Biofilms exert a notable influence on various chronic infectious diseases due to their heightened resistance to antibiotics and evasion of the body's immune cells. Moreover, biofilms have been implicated in contributing to the growth of cancer. This knowledge bears significance in informing the development of strategies for the care and treatment of infectious diseases (Vestby et al., 2020).

2. The Influence of Electricity on Bacteria

2.1. Effects of Electricity on Bacteria and Biofilms

Electricity, as a physical agent, exerts inhibitory and bactericidal effects, offering an alternative means to combat bacteria that have developed increased resistance through biofilm formation. Exposure to electric current induces alterations in the shape and composition of biofilms, resulting in the demise of bacterial cells within the biofilm (Brinkman et al., 2016). The lethal impact of electric current on bacteria can be attributed to several mechanisms. Electric current introduces thermal and electrolysis effects, causing bacterial death (Hasanah, 2020). Furthermore, electric fields elevate the transmembrane voltage of bacteria, leading to significant membrane damage and a bidirectional leakage of ions and proteins, ultimately culminating in bacterial death (Bestari, 2015). Bacterial cell membranes are susceptible to damage by electricity with a current of less than 100 μA for 30 minutes (Krishnamurthi et al., 2020). The rise in bacterial intracellular reactive oxygen species (ROS) also contributes to bacterial cell death during exposure to electric current (Brinkman et al., 2016). However, it is noteworthy that low voltage electricity applied to biofilms, without the concurrent use of antibiotics, does not significantly impact bacterial viability (Del Pozo et al., 2009).

Another facet of electricity's influence on biofilms involves the reduction of bacterial biofilm mass when subjected to electric current. This reduction occurs as the electric current facilitates the detachment of bacteria and extracellular matrix from the biofilm structure. The application of electric current enhances electrostatic forces between the surface and bacterial cells, thereby promoting the release of bacteria from the surface (Del Pozo et al., 2009). Additionally, the applied electric current induces a potential difference in the fluid surrounding the biofilm, leading to the movement of ions and providing an additional force that aids in loosening the biofilm (Van Der Borden et al., 2004).

2.2. Determinants Affecting the Bactericidal Efficacy of Electricity

Factors influencing the bactericidal efficacy of electricity, as outlined by Del Pozo et al. (2009), include:

1. Intensity of electric current: The potency of the electric current directly correlates with the augmentation of electrical components, such as the generated field, thereby enhancing the effectiveness of electricity in bactericidal actions.
2. Duration of electrical exposure: Prolonged exposure of bacteria to electricity leads to heightened damage processes, such as an increase in transmembrane potential, resulting in a greater number of bacterial fatalities.

2.3. Determinants Affecting the Bactericidal Efficacy of Electricity

In previous research, findings indicated that the electrical current applied to the group of Klebsiella pneumoniae bacteria could result in the bactericidal effect. In one experiment, Klebsiella pneumoniae exposed to a 10 mA electric current exhibited bacterial death, starting from a 30-minute exposure period (Wijoyo et al., 2023).

IJRP.ORG
International Journal of Research Publications
ISSN: 2708-3578 (Online)

3. Conclusion

In conclusion, this review provides a comprehensive examination of the intricate relationship between low voltage electricity and bacterial biofilms. The exploration encompasses the definition and challenges of biofilm formation, emphasizing its critical role in infectious diseases. The adaptive advantages, enhanced defense mechanisms, and communal nature of biofilms are discussed. Historical scrutiny underscores the significance of biofilms in medical microbiology, influencing disease care and treatment strategies.

Transitioning to the impact of electricity on bacteria, the review delves into the nuanced effects on biofilm structure and bacterial cell death. The specific influence on Klebsiella pneumoniae bacteria is highlighted. Insights from determinants affecting the bactericidal efficacy of electricity offer valuable considerations for optimizing parameters in antibacterial interventions. In summary, this review contributes valuable insights to the dynamic interplay between low voltage electricity and bacterial biofilms, with potential implications for innovative healthcare strategies.

Acknowledgements

The authors would like to express their gratitude to all parties involved in the making of this review.

References

Bestari, J.A., 2015. Optimasi medan listrik berpulsa untuk menghambat pertumbuhan biofilm Listeria monocytogenes (Doctoral dissertation, Universitas Islam Negeri Maulana Malik Ibrahim).

Brinkman, C.L., Schmidt-Malan, S.M., Karau, M.J., Greenwood-Quaintance, K., Hassett, D.J., Mandrekar, J.N. and Patel, R., 2016. Exposure of bacterial biofilms to electrical current leads to cell death mediated in part by reactive oxygen species. PloS one, 11(12), p.e0168595.

Del Pozo, J.L., Rouse, M.S., Mandrekar, J.N., Steckelberg, J.M. and Patel, R., 2009. The electricidal effect: reduction of Staphylococcus and Pseudomonas biofilms by prolonged exposure to low-intensity electrical current. Antimicrobial agents and chemotherapy, 53(1), pp.41-45.

Flemming, H.C. and Wingender, J., 2010. The biofilm matrix.Nature reviews microbiology, 8(9), pp.623-633.

Hasanah, W., 2020.Efek stimulasi arus listrik terhadap pertumbuhan bakteri Pseudumonas aeruginosa pada luka Mencit (Mus Muscullus) diabetes mellitus (Doctoral dissertation, Universitas Islam Negeri Maulana Malik Ibrahim).

Jefferson, K.K., 2004. What drives bacteria to produce a biofilm?. FEMS microbiology letters, 236(2), pp.163-173.

Kokare, C.R., Chakraborty, S., Khopade, A.N. and Mahadik, K.R., 2009. Biofilm: importance and applications.

Krishnamurthi, V.R., Rogers, A., Peifer, J., Niyonshuti, I.I., Chen, J. and Wang, Y., 2020. Microampere electric current causes bacterial membrane damage and two-way leakage in a short period of time. Applied and environmental microbiology, 86(16), pp.e01015-20.

Lewandowski, Z. and Beyenal, H., 2013. Fundamentals of biofilm research. CRC press.

Van Der Borden, A.J., Van Der Werf, H., Van Der Mei, H.C. and Busscher, H.J., 2004. Electric current-induced detachment of Staphylococcus epidermidis biofilms from surgical stainless steel. Applied and environmental microbiology, 70(11), pp.6871-6874.

Vstby, L.K., Grønseth, T., Simm, R. and Nesse, L.L., 2020. Bacterial biofilm and its role in the pathogenesis of disease. Antibiotics, 9(2), p.59.

Watnick, P. and Kolter, R., 2000. Biofilm, city of microbes.Journal of bacteriology, 182(10), pp.2675-2679.

Wijoyo, D.L.S., Koendhori, E.B., Susilo, I. and Wardhani, P., 2023. Effect of low voltage electric currents on the decrease of Klebsiella pneumoniae ESBL and non-ESBL colonies. Journal of Clinical Microbiology and Infectious Diseases, 3(1), pp.6-11.