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A Bibliography Study on Biofilm Research Method

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Abstract: This paper explores the multifaceted impact of biofilms, bacterial communities enveloped in extracellular polymeric substance (EPS). Biofilms play a dual role, acting as environmental champions and health threats. They interact with heavy metals, either causing pollution or aiding environmental remediation. Beneficial biofilms generate electricity and repair concrete cracks, offering sustainable solutions. Conversely, they contribute to infections, posing health risks. The study emphasizes the need for in-depth research, utilizing bibliographic methods to analyze global biofilm research. By identifying keywords, core countries, and pivotal organizations, the paper informs future investigations, offering insights into biofilm research evolution and practical applications.

Keywords: Biofilm; Extracellular Polymeric Substance (EPS); Biofilm Research Mehtod; Bibliographic Analysis; VOSviewer

1. Introduction

Biofilms, complex communities of bacteria adhering to surfaces and encased in a self-produced extracellular polymeric substance (EPS), represent a ubiquitous and impactful facet of microbial life [1]. Their influence extends across various domains of human activity, affecting both the environment [2] and human health [3]. The versatile nature of biofilms is evident in their potential to interact with heavy metals [4], substances known to pollute water sources [5]. While detrimental biofilms contribute to pollution, their more favorable counterparts can be harnessed for environmental remediation [6]. This includes the immobilization of heavy metals from waterways, a critical process in mitigating water pollution [7].

Conversely, the darker side of biofilms unfolds when they contribute to various infections, posing risks to human health [8–10]. Biofilm-related infections manifest in different forms, ranging from lung infections [11–13] to urinary tract infections [14–16]. Understanding the intricate dynamics of biofilm formation and its implications is paramount for developing strategies to mitigate the negative consequences associated with biofilm-related infections [17].

Given the pivotal role of biofilms in both positive and negative aspects of human life, there exists a pressing need for in-depth research to unravel their complexities. Traditional methods for biofilm investigation involve sophisticated imaging techniques such as confocal laser scanning microscopy [18,19], structured illumination microscopy [20], and mass spectrometry [21,22]. However, in this paper, we adopt a bibliographic research method [23] to delve into the vast realm of biofilm research methods. This approach involves an extensive survey of existing literature, aiming to identify the most crucial keywords, elucidate the core countries and regions leading in biofilm research, and recognize the pivotal organizations contributing to this field.

Through the utilization of the bibliography approach, our goal is to offer a thorough insight into the various research methods employed worldwide in the study of biofilms. This document acts as a valuable reference, illuminating the complex procedures associated with investigating biofilms and the techniques utilized by researchers to unravel their intricacies. By delving deeply into the current body of literature, our intention is to emphasize the principal themes, methodologies, and patterns in biofilm research, ultimately enhancing the shared knowledge within this pivotal scientific field.

2. Materials and method

The bibliographic analysis is following previous studies [24,25] with slightly modifications. The research commenced with a systematic exploration of the Web of Science database [26,27], employing the search query "biofilm research method." A comprehensive collection of scholarly articles related to biofilm research methods was obtained, yielding a total of 1000 documents for analysis.

To provide a visual representation and gain insights into the key themes and relationships within the collected data, the state-of-the-art data visualization tool, VOSviewer, was employed [28,29]. This powerful tool allows for the dynamic visualization of keyword occurrences, geographical distribution, and organizational contributions within the realm of biofilm research methods.

In the process of visualization, certain parameters were established to ensure the focus on significant elements. A minimum keyword occurrence threshold of 10 was set to emphasize keywords that are recurrent and influential in the literature. Furthermore, the analysis extended to the geographical distribution of biofilm research, considering a minimum of 12 documents from each country to highlight regions with substantial contributions. In parallel, the investigation delved into the organizational landscape by setting a minimum document threshold of 4 for each organization. This criterion ensured that the analysis captured the noteworthy contributions of organizations actively engaged in biofilm research method studies.

3. Results

In Figure 1, we delve into the intricate landscape of keywords associated with biofilm research methods, unveiling a rich tapestry of diverse elements. Among the prominent features are species-related keywords, shedding light on specific microbial participants in biofilm formation. Notable examples include Staphylococcus aureus and Candida albicans, underscoring the varied microbial compositions under investigation.

Furthermore, the keyword landscape encompasses method-related terms, providing insights into the tools and techniques employed in biofilm research. Keywords such as microscopy, PCR (polymerase chain reaction), diagnosis, and device illuminate the methodological spectrum, reflecting the varied approaches researchers employ to unravel the complexities of biofilm dynamics.

Zooming in further, the intricate cellular processes within biofilm development are elucidated through a set of keywords. These include growth, detachment, adhesion, expression, as well as specific processes like nitrification and denitrification. These keywords offer a glimpse into the dynamic cellular activities that shape the biofilm life cycle, highlighting key stages and processes that researchers focus on in their investigations.

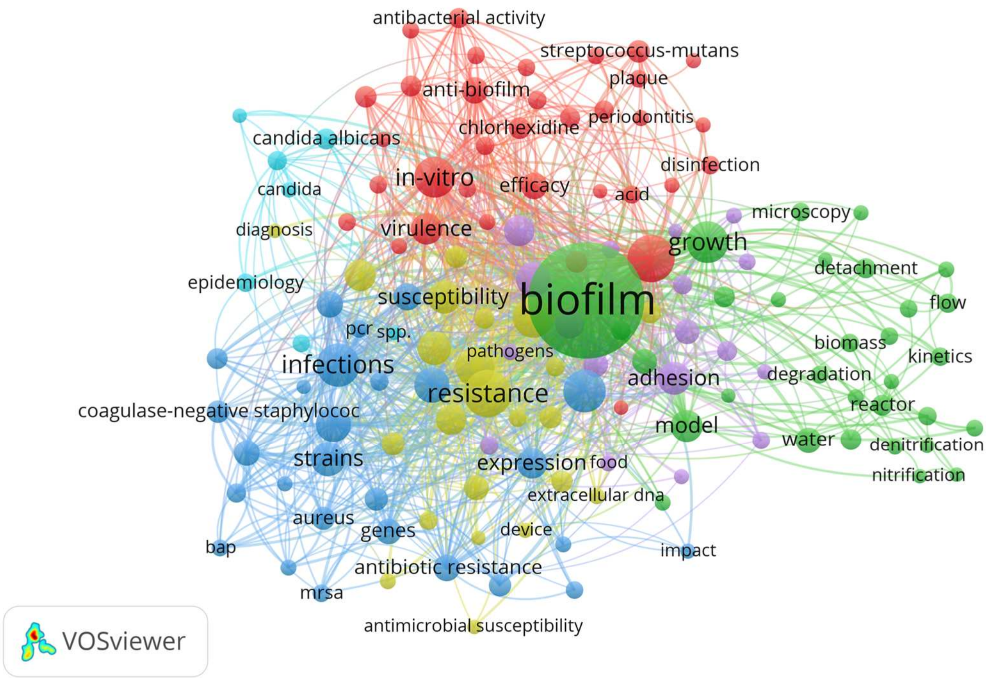

Figure 1. The keyword analysis in biofilm research method field based on VOSviewer.

In Figure 2, a comprehensive panorama of the primary countries and regions engaged in biofilm research methods is depicted, showcasing the global landscape of this pivotal scientific field. Notably, China and the United States emerge as central players, occupying key positions at the forefront of biofilm research endeavors. However, the significance of this field is by no means confined to these two giants; rather, a multitude of nations contribute significantly to the advancement of biofilm research methods.

Among these noteworthy contributors, countries such as Pakistan, Poland, Germany, Canada, the United Kingdom, Portugal, Belgium, Turkey, Italy, Spain, Switzerland, France, the Netherlands, Sweden, Denmark, Japan, Malaysia, Australia, Iran, Thailand, Saudi Arabia, and more, play crucial roles in shaping the trajectory of research in this field. The extensive international participation underscores the global relevance and impact of biofilm research, emphasizing the collaborative nature of scientific exploration.

International cooperation stands out as an integral aspect of biofilm research, fostering synergy among researchers from diverse cultural and academic backgrounds. Collaborative efforts enhance research efficiency, promote knowledge exchange, and contribute to the collective understanding of biofilm dynamics. As the biofilm research community continues to expand and diversify, the role of international collaboration becomes increasingly indispensable, offering a pathway to address complex challenges and advance scientific frontiers collectively. The rich and varied contributions from countries and regions worldwide underscore the truly global nature of biofilm research and the necessity of collaborative endeavors to propel this field into new realms of discovery and innovation.

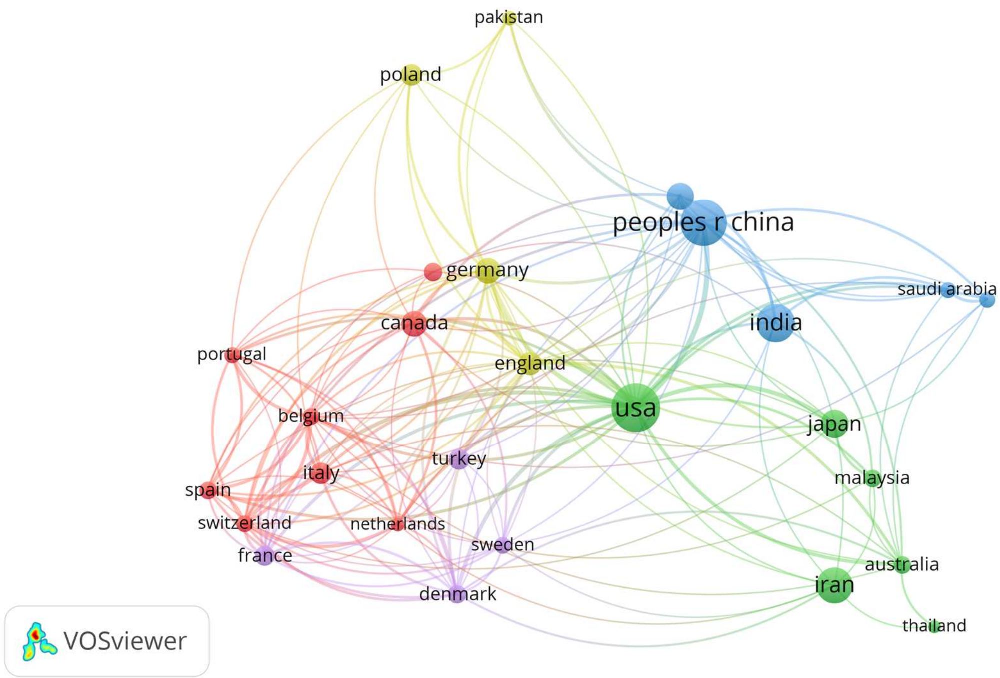

Figure 2. The main countries/regions working in biofilm research method field. The line indicates the research collaboration.

In Figure 3, a detailed depiction is provided, showcasing the critical organizations that form the backbone of advancements in the field of biofilm research methods. At the very heart of this network of institutions lies Montana State University, assuming a central role in shaping the trajectory of biofilm research. Serving as a hub for innovation and collaboration, Montana State University stands out as a key contributor to the evolving landscape of biofilm studies.

The significance of the contributions extends beyond Montana State University, encompassing a diverse array of institutions globally. The Chinese Academy of Sciences, with its strong research foundation, stands as a prominent player in advancing biofilm research methodologies. Similarly, the University of Porto, Rigshospitalet, Shanghai Jiao Tong University, King Saud University, Technical University of Denmark, University of Michigan, University of Hong Kong, University of Belgrade, Tabriz University of Medical Sciences, Islamic Azad University, and University of Tehran Medical Sciences each bring their unique strengths and expertise to the collective pursuit of understanding and unraveling the complexities of biofilm research.

What stands out in this collaborative network is the fusion of perspectives and methodologies from different corners of the world. The global collaboration not only broadens the scope of research in biofilm studies but also enhances the efficiency of scientific investigations. Through this cross-cultural collaboration, the exchange of ideas, methodologies, and findings becomes a catalyst for breakthroughs in the field. The diverse cultural and academic backgrounds represented by these institutions contribute to a rich tapestry of biofilm research, fostering an environment where innovative solutions and novel approaches can flourish.

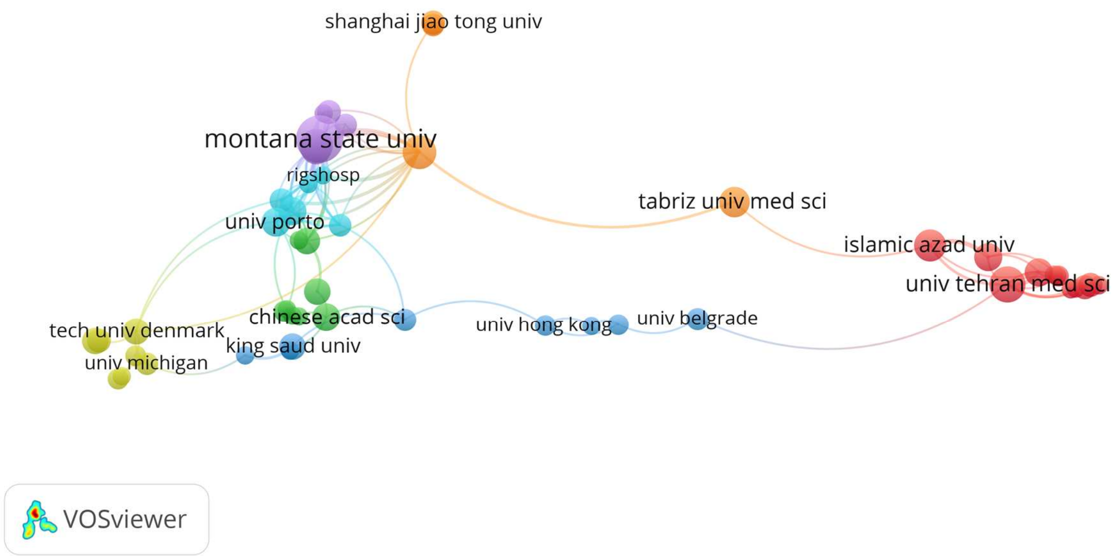

Figure 3. The main organizations working in biofilm research method field. The line indicates the research collaboration.

4. Discussion

4.1. Unveiling Biofilm Complexity: Exploring the Intricacies with Traditional Research Methods

Traditional biofilm research methods encompass techniques such as confocal laser scanning microscopy [30], structured illumination microscopy [31], mass spectrometry [32], and more. These methodologies have been instrumental in unraveling the intricate nature of biofilms. A well-formed biofilm holds tremendous potential for various applications, including the removal of heavy metals from water [30], the generation of electricity through microbial fuel cells [33–35], and even the repair of cracks in concrete structures [36–38]. Conversely, the presence of harmful biofilms can lead to issues such as lung infections [39] and urinary tract infections [40], underscoring the dual nature of these microbial communities.

The utilization of traditional biofilm research methods enables a deeper understanding of the processes involved in biofilm formation and function. By employing advanced microscopy and analytical techniques [41,42], researchers gain insights into the structural composition, microbial interactions, and metabolic activities within biofilms. This knowledge, in turn, facilitates the harnessing of beneficial biofilms for practical applications [43] while also providing strategies to prevent harmful bacterial or biofilm growth [44–46].

For instance, the ability to visualize biofilm structures through confocal laser scanning microscopy allows researchers to observe the spatial organization of microbial communities [47,48]. Structured illumination microscopy provides detailed insights into the three-dimensional architecture of biofilms [49,50]. Mass spectrometry aids in the identification of biofilm components and their potential roles in various biological and environmental processes [51,52].

As we delve deeper into understanding biofilm dynamics, the integration of interdisciplinary approaches and emerging technologies promises to open new avenues for research and applications [53]. The continuous refinement of biofilm research methods not only expands our knowledge but also presents opportunities to harness the positive aspects of biofilms for sustainable solutions in diverse fields [54]. Through these endeavors, scientists and researchers aim to strike a balance

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between leveraging the benefits of biofilms and mitigating the potential risks associated with their detrimental counterparts [55].

4.2. Navigating the Future: Biofilm Research Method in the Era of Big Data and Machine Learning

The future trajectory of biofilm research methods is poised to intertwine seamlessly with cutting-edge technologies such as big data and machine learning. These transformative technologies have already found widespread applications in diverse fields, ranging from autonomous driving [56,57] and facial recognition [58,59] to global species distribution prediction [60], educational psychology database establishing [61,62] and forecasting [63]. Much like these domains, biofilm research methods stand to benefit significantly from the synergistic integration with big data and machine learning [64,65].

Consider the potential synergy between biofilm research methods and these advanced technologies. By leveraging big data and machine learning, researchers can embark on a journey of enhanced understanding and prediction within the realm of biofilm dynamics. Imagine establishing a comprehensive database encompassing variables such as media composition, species diversity, temperature, humidity, heavy metal distribution, and heavy metal concentration. This expansive dataset becomes the foundation for the application of machine learning models.

As an illustrative example, let's focus on the biofilm's interaction with heavy metals. With the data-rich environment provided by big data, a machine learning model can be trained to predict the efficacy of biofilm-mediated heavy metal removal. The model can analyze intricate relationships between various parameters, allowing for accurate predictions of how biofilms respond to different environmental conditions and metal concentrations. This predictive capability extends further, offering insights into strategies for enhancing heavy metal removal efficiency.

The integration of biofilm research methods with big data and machine learning heralds a new era of precision and efficiency in understanding and manipulating these microbial communities. Researchers can harness the power of data-driven insights to not only comprehend biofilm behaviors but also to optimize their applications. The interconnectedness of biofilm research with advanced technologies not only propels scientific exploration but also paves the way for sustainable solutions in areas such as environmental remediation, healthcare, and industrial processes.

In this evolving landscape, the collaboration between biofilm research, big data, and machine learning is not merely a technological advancement; it is a paradigm shift. It signifies a departure from traditional approaches towards a more dynamic and adaptive understanding of biofilm interactions. As researchers delve into this interdisciplinary frontier, the potential for groundbreaking discoveries and innovations becomes boundless, unlocking novel avenues for addressing complex challenges in diverse scientific domains.

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