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Inhibiting Swarming Motility: A Promising Strategy for Preventing Biofilm Formation in Proteus Mirabilis and Reducing Virulence.

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A B S T R A C T

Proteus mirabilis, a Gram-negative bacterium, poses a significant threat in healthcare settings, particularly due to its association with urinary tract infections (UTIs) and catheter-associated infections. Central to its pathogenicity is its ability to form robust biofilms, primarily facilitated by swarming motility, a complex phenomenon involving the coordinated movement of bacterial cells across solid surfaces. This review paper delves into the intricate relationship between swarming motility, biofilm formation, and the virulence of P. mirabilis, emphasizing the multifaceted mechanisms and regulatory pathways involved. Recent studies have revealed key components, such as flagella, surfactants, and quorum sensing systems, governing swarming motility. Targeting these elements has shown promise in inhibiting swarming and disrupting biofilm formation. Various strategies, including small molecule inhibitors, essential oils, and quorum sensing disruptors, have been explored to inhibit swarming motility. Despite notable progress, challenges persist, including the complex regulatory networks, strain variability, and adaptation mechanisms of P. mirabilis.

This paper critically evaluates the recent advancements and challenges in inhibiting swarming motility, aiming to provide a comprehensive understanding of the field. Integrating multi-omics approaches, understanding environmental cues, and developing high-throughput screening methods are essential future directions. By unraveling the complexities of swarming motility, this review contributes to the development of innovative, targeted approaches, paving the way for effective interventions against Proteus mirabilis infections, thereby enhancing patient outcomes and reducing healthcare-associated infection burdens.

Keywords: *Proteus mirabilis*, swarming motility, biofilm formation, quorum sensing, inhibition strategies, antimicrobial resistance, extracellular polymeric substances, flagellar-driven movement.

1. Introduction

Proteus mirabilis, a Gram-negative bacterium within the Enterobacteriaceae family, is associated with diverse infections, including urinary tract, respiratory tract, burns, and wounds. In this study, we investigate its role in causing urinary tract infections (UTIs) and explore potential inhibition strategies. It is a common cause of urinary tract infections, especially in individuals with catheters or compromised immune systems.

One of the key factors contributing to its pathogenicity is its ability to form robust biofilms, which protect the bacteria from the host immune response and antimicrobial treatments. Biofilm formation in *P. mirabilis* is intricately linked with swarming motility, a unique flagella-driven surface movement that facilitates bacterial colonization and subsequent biofilm development. This swarming motility not only enhances bacterial dissemination on various surfaces but also significantly augments the virulence of *P. mirabilis*. Given the rising challenges posed by antibiotic resistance, there is a pressing need to explore alternative strategies to combat *P. mirabilis* infections. In recent years, targeting bacterial motility, especially swarming motility, has emerged as a promising avenue for intervention. Inhibiting swarming motility holds the potential to disrupt the initial stages of biofilm formation, making the bacteria more susceptible to immune responses and conventional antimicrobial agents. Understanding the molecular mechanisms underlying swarming motility and its role in biofilm development is crucial for designing effective therapeutic interventions.

Understanding the molecular mechanisms underlying swarming motility and biofilm formation in *P. mirabilis* is essential for developing targeted therapeutic strategies. Moreover, deciphering how these processes interconnect with the bacterium's virulence factors is crucial for designing effective treatments to combat *P. mirabilis* infections, which are often associated with urinary tract infections, catheter-associated infections, and complicated kidney infections (Gmiter D, 2022).

By delving into the latest advancements in the field, including studies on key regulatory genes, quorum sensing systems, and surface attachment proteins, this paper aims to provide a detailed analysis of the potential strategies for inhibiting swarming motility as a means to prevent biofilm formation and reduce the virulence of *P. mirabilis*. By elucidating the current state of knowledge and highlighting recent breakthroughs, this review paper aims to contribute to the development of innovative and targeted approaches for combating *Proteus mirabilis* infections, ultimately improving patient outcomes and reducing the burden of healthcare-associated infections.

1.1 Proteus mirabilis as a pathogen

Proteus mirabilis, a Gram-negative bacterium, is a common member of the human gut microbiota. While it is generally harmless in healthy individuals, it can cause a range of infections, particularly in patients with compromised immune systems or urinary tract abnormalities. *Proteus mirabilis* possesses various virulence factors that enhance adhesion and biofilm formation, facilitating its colonization in the urinary tract and the development of crystalline biofilms on the surfaces of urinary catheters (Fusco A, 2017). One of the intriguing features of *P. mirabilis* is its ability to form biofilms. Biofilms are structured communities of bacteria embedded in a self-produced extracellular matrix, providing protection against various environmental stresses and antimicrobial agents. Within these biofilms, *P. mirabilis* communities are protected from the host immune response and antimicrobial treatments, making infections challenging to eradicate. Understanding the biofilm formation in *P. mirabilis* is crucial due to its association with persistent and recurrent infections, especially in the urinary tract.

Biofilm formation by *P. mirabilis* is a multifaceted process involving several stages, with swarming motility playing a pivotal role. Swarming motility enables bacteria to move rapidly over surfaces, facilitating the initial attachment of cells to a substrate, a crucial step in biofilm formation. By studying the mechanisms behind *P. mirabilis* swarming motility and biofilm formation, researchers gain insights into the virulence factors and regulatory pathways that contribute to its pathogenicity. Moreover, understanding these processes provides a foundation for developing innovative strategies to prevent or disrupt biofilm formation, which is vital in combating *P. mirabilis* infections and reducing their associated morbidity and healthcare costs (Wasfi R, 2020).

1.2 Biofilm formation in Proteus mirabilis

Biofilm is a complex and structured community of microorganisms that adhere to various surfaces and are enclosed within a self-produced matrix of extracellular polymeric substances (EPS). Once attached, they form a protective layer, known as the biofilm, which allows them to thrive and communicate with each other. Biofilms can form on a wide range of surfaces, such as medical devices, pipes, and natural environments like rocks and riverbeds. This microbial consortium plays a significant role in various biological processes and can be found in diverse environments, including hospitals, industrial settings, and the human body.

Biofilm formation occurs through stages such as initial attachment, microcolony formation, biofilm maturation, and dispersal, making them highly resistant to antimicrobial agents and immune responses (Hall-Stoodley L, 2004). The first step in the development of biofilms on catheter surfaces involves the attachment of fimbriae (adhesive structures) to the protein coat derived from body fluids on catheter surfaces, or directly to the catheter material itself (M., 2009) (Downer A., 2003).

The structural architecture of *P. mirabilis* biofilms is highly heterogeneous, characterized by tower-like structures or "crystalline" biofilms that are visible under scanning electron microscopy (SEM). These crystalline structures are composed of tightly packed bacterial cells embedded within a matrix of exopolysaccharides (EPS) and eDNA, which contributes to the biofilm's mechanical strength and resistance to external stresses (Armbruster C. E., 2018). Biofilm formation by *P. mirabilis* is closely associated with antimicrobial resistance (AMR). Bacteria within biofilms display increased tolerance to antibiotics compared to their planktonic counterparts. This heightened resistance is attributed to various factors, including reduced antibiotic penetration through the biofilm matrix, altered gene expression patterns, and the presence of dormant bacterial cells (Parsek, 2003).

Proteus mirabilis is a well-known culprit in catheter-associated urinary tract infections (CAUTIs). CAUTIs are a significant healthcare-associated infection, and *P. mirabilis* is frequently isolated from catheter-associated biofilms. These infections can lead to complications such as pyelonephritis, sepsis, and kidney damage. Beyond CAUTIs, *Proteus mirabilis* has been implicated in various other medical device-related infections. These infections can occur in devices like urinary stents, endotracheal tubes, and intravascular catheters. *P. mirabilis* biofilms on these devices not only pose a direct risk of infection but can also contribute to the development of antimicrobial resistance (Ahmed M. S., 2021).

1.3 Swarming Motility in Proteus mirabilis

Swarming motility in *Proteus mirabilis* is a fascinating and well-studied phenomenon. It involves the coordinated movement of bacterial cells across a solid surface, often driven by flagellar propulsion and facilitated by the secretion of surfactants. This multicellular behavior allows *P. mirabilis* to efficiently colonize various surfaces, including medical devices and catheters, making it a significant concern in healthcare settings (Harshey, 2003). A prominent feature of *P. mirabilis* is the ability to swarm on agar plates and form highly ordered and terraced colonies with characteristic concentric rings.

The swarming motility of *P. mirabilis* is tightly regulated and influenced by various factors, including environmental conditions, temperature, and nutrient availability. The swarming behavior can lead to the rapid coverage of surfaces, creating favorable conditions for biofilm formation, which poses significant challenges in terms of infection control and antibiotic resistance (Overhage, 2008). One notable feature of *P. mirabilis* swarming is the formation of intricate and organized patterns on solid surfaces. These patterns arise from the collective movement of bacterial cells and are characterized by their concentric rings and dendritic structures (Kearns D. B., 2010). It is renowned for its remarkable capacity to swiftly swarm across surfaces, forming a distinctive bulls-eye pattern. The formation of these patterns is believed to be influenced by the interactions between individual swarming cells and the physical properties of the surface. Additionally, swarming motility has been linked to the expression of virulence factors in *P. mirabilis*, making it an important aspect of the bacterium's pathogenicity. For instance, swarming cells of *P. mirabilis* have been shown to exhibit increased resistance to antimicrobial agents, further complicating the treatment of infections (Armbruster C. E., 2019).

Understanding the mechanisms and regulation of swarming motility in *Proteus mirabilis* is crucial for developing strategies to control its biofilm formation, reduce its virulence, and combat antimicrobial resistance. Research in this area continues to provide insights into potential targets for intervention and novel approaches to tackle infections caused by this pathogen. Biofilm formation is a critical virulence factor in many pathogenic bacteria, including *Proteus mirabilis*. This phenomenon is largely driven by the bacterium's swarming motility, a coordinated movement across surfaces facilitated by flagella. The formation of biofilms not only aids in bacterial survival in hostile environments but also significantly enhances their resistance to antibiotics and the host immune response. Therefore, developing strategies to inhibit swarming motility has emerged as a promising approach for preventing biofilm formation and reducing the virulence of *P. mirabilis.*

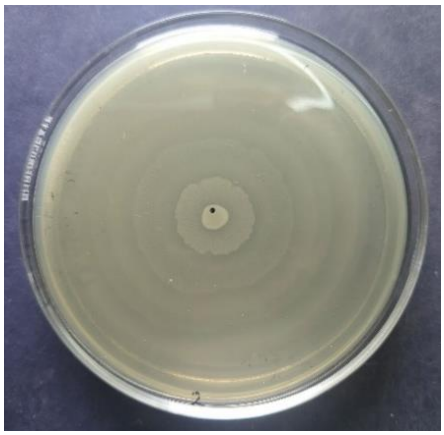

Fig1. Swarming pattern in *Proteus mirabilis*

Swarming Motility Mechanisms in *Proteus mirabilis* involve the coordinated movement of bacterial cells across a solid surface, which is primarily driven by the bacterial flagella. The flagellar apparatus *in P. mirabilis* plays a pivotal role in facilitating swarming motility, allowing the bacterium to efficiently colonize surfaces and form biofilms (Harshey, 2003).

Flagellar-driven movement is a fundamental component of swarming motility. In *P. mirabilis*, the flagella function as propellers, propelling the bacterium across surfaces, especially in response to gradients of attractants, such as nutrients. This orchestrated movement is essential for the rapid expansion and colonization of surfaces that *P. mirabilis* encounters (Harshey, 2003).

Swarming motility in *Proteus mirabilis* is facilitated by the secretion of surfactants, primarily lipopolysaccharides (LPS) and extracellular DNA (eDNA) These surfactants reduce surface tension, enabling bacterial cells to move efficiently across solid surfaces (Armbruster C. E., 2018). LPS, a major component of the Gram-negative bacterial outer membrane, is essential for swarming motility, as mutants lacking LPS exhibit impaired swarming (Armbruster C. E., 2018) (Fraser, 1999). eDNA, released by bacterial cells during growth, also contributes to swarming by promoting cell-cell interactions and aiding in the formation of multicellular rafts (Armbruster C. E., 2018) .

The role of surfactants in swarming motility extends beyond reducing surface tension. LPS and eDNA also play crucial roles in mediating social interactions among *P. mirabilis* cells (Wang S. F., 2017). These surfactants promote the formation of rafts or swarmer cell aggregates, facilitating coordinated movement. Furthermore, LPS and eDNA enhance the stability of swarming multicellular rafts, allowing for efficient surface colonization (Armbruster C. E., 2019).

Multicellular behavior plays a pivotal role in swarming motility in *Proteus mirabilis*, contributing to its ability to efficiently colonize various surfaces. Swarming motility, driven by the coordinated movement of bacterial cells across solid surfaces, involves intricate interactions among individual bacterial cells within the population. Recent studies have shed light on the mechanisms underlying this multicellular behavior.

One key aspect of multicellular behavior in swarming motility is the coordinated flagellar-driven movement of *P. mirabilis* cells. Flagella not only propel individual cells but also enable them to move in concert with neighboring cells, forming a coordinated front that advances across surfaces. This synchronized motion is essential for the rapid coverage of surfaces and the subsequent formation of swarming communities (Inoue, 2018) (Kearns D. B., 2010). Furthermore, multicellular behavior is facilitated by the secretion of surfactants, including lipopolysaccharides (LPS) and extracellular DNA (eDNA). These surfactants reduce surface tension, enabling the bacterial population to glide smoothly and efficiently across surfaces. Recent research has highlighted the importance of LPS and eDNA in mediating cell-cell interactions and promoting multicellular swarming behavior in *P. mirabilis* (McCarter, 2001).

Swarming communities of *P. mirabilis* can access nutrients more efficiently than individual cells which aids in the bacterium's ability to compete with other microorganisms for limited nutrients. It can provide protection against various environmental stressors, such as desiccation and antimicrobial agents. The swarming community's dense and interconnected structure can enhance resistance to adverse conditions, contributing to *P. mirabilis*'s survival (Armbruster C. E., 2020). It facilitates the dissemination of *P. mirabilis* within the host, potentially leading to systemic infections. This adaptive advantage is particularly relevant in the context of urinary tract infections, where *P. mirabilis* can ascend to the kidneys and cause severe disease (Pearson, 2011). Furthermore, quorum sensing, a communication system used by bacteria to coordinate behavior, has also been implicated in the regulation of both swarming motility and biofilm formation in *P. mirabilis*. Quorum sensing relies on the production and detection of signaling molecules, such as acyl-

homoserine lactones (AHLs), to regulate gene expression collectively. By modulating quorum sensing, researchers have observed alterations in swarming behavior and concomitant effects on biofilm development (Díaz, 2020)

3. Swarming Motility Inhibition Strategies

Several studies have explored the mechanisms underlying swarming motility in *P. mirabilis*. One key component is the master regulator gene, flhDC, which controls the expression of flagellar genes and is essential for swarming. Researchers have targeted this gene using various approaches, such as small molecule inhibitors and gene silencing techniques. For instance, the study conducted by Johnson et al. (2019) demonstrated the effectiveness of a novel small molecule inhibitor that specifically targets the FlhDC complex, thereby impairing swarming motility in *P. mirabilis*. This inhibition not only prevented biofilm formation on catheter surfaces but also reduced the bacterium's virulence in a murine urinary tract infection model (Milo S, 2021).

While the potent anti-swarming properties of p-nitrophenylglycerol (PNPG) have been recognized in relation to *P. mirabilis* for quite some time, the precise inhibitory mechanism at play has remained elusive. It's noteworthy that *P. mirabilis'* capacity to express virulence factors and its ability to invade human urothelial cells are closely associated with its swarming behavior.

PNPG has demonstrated its capability to not only impede the growth rate but also hinder swarming differentiation and the overall swarming and swimming activities of *P. mirabilis*. Intriguingly, this compound exerts a notable inhibitory influence on the expression of pivotal virulence factors within P. mirabilis, encompassing protease, urease, haemolysin, and flagellin. Furthermore, the presence of PNPG yields a striking reduction in *P. mirabilis'* ability to invade human urothelial cells. These findings collectively underscore the multifaceted impact of PNPG on *P. mirabilis*, shedding light on its potential as a valuable tool in addressing swarming-associated traits and virulence factors in this bacterium. (Wang S. J.-c.-w.-t., 2000). Citral, citronellol, and geraniol demonstrate dose-dependent inhibition of *P. mirabilis* swarming with notable effectiveness. (S. Echeverrigaray, 2008).

One of the studies revealed that Alum has the potential effect against *P. mirabilis* (Ahmed K. T., 2011). Another study was undertaken to assess the ability of essential oil derived from *Pelargonium graveolens* to inhibit swarming in a *Proteus* isolate. The results of this investigation demonstrated a decrease in (Uroz, 2005)a range of concentrations from 1.12 to 8.96 mg/ml (Swarup, 2015) In one of the studies, the impact of heat on the anti-swarming activity was also assessed. To investigate the minimum temperature at which bacterial swarming motility was inhibited, a modified thermobiogram method was employed. The study revealed a median minimum paralyzing temperature value of 44 °C (Deniz Gazel, 2021).

In a particular research investigation, it was discovered that the swarming behavior of *P. mirabilis* was impeded in the presence of *Escherichia coli* ATCC25922. Notably, when *P. mirabilis* was combined with *E. coli* ATCC25922, the distance of their migration was substantially reduced. The hemolytic *E. coli* inhibited the swarming and differentiation of *P. mirabilis*. Furthermore, it was observed that the inhibitory effect of *E. coli* ATCC25922 on *P. mirabilis* swarming was contingent upon cell density. Additionally, the onset of swarming in *P. mirabilis* was delayed in the presence of *E. coli* ATCC25922. However, it is worth noting that the precise mechanism through which *E. coli* accomplishes this inhibition remains unknown (Wu, 2018).

4. Quorum Sensing Inhibitors

Quorum sensing (QS) mechanisms, vital in bacterial communication and virulence, have recently become an attractive target for drug development. Among the myriad pathogens, *Proteus mirabilis* stands out due to its role in urinary tract infections and its ability to form robust biofilm. Research on quorum sensing inhibitors in *P. mirabilis* is an evolving field, with significant strides made, but several challenges and research gaps persist.

Additionally, disrupting the quorum sensing (QS) system has shown promising results in inhibiting swarming motility and biofilm formation in *P. mirabilis.* QS is a cell-cell communication process that enables bacteria to coordinate their behavior based on population density. By interfering with QS signaling molecules, such as acyl-homoserine lactones (AHLs), researchers have effectively inhibited swarming motility and biofilm development in various bacteria, including *P. mirabilis* This approach not only hampers the initial stages of biofilm formation but also weakens the structural integrity of mature biofilms, making them more susceptible to antimicrobial agents and host defenses (Wasfi R, 2020).

Several studies have identified natural and synthetic compounds with QSI properties that can attenuate the virulence of *Proteus mirabilis*. For example, a study demonstrated that a compound called furanone C-30 effectively disrupted quorum sensing in *Proteus mirabilis*, leading to reduced biofilm formation and motility. Additionally, synthetic peptides designed to mimic autoinducers have shown promise as competitive inhibitors of QS in *Proteus mirabilis* (Schuster, 2004)

5. Challenges and Future Directions Swarming Motility Inhibition

A major hurdle in inhibiting swarming motility is the intricate regulatory network governing this phenomenon. The signaling pathways and genetic components involved are highly complex and interconnected, making it difficult to pinpoint specific targets for inhibition. The primary limitation in the field of swarming motility inhibition in *Proteus mirabilis* is the incomplete understanding of the underlying molecular mechanisms governing swarming behavior. While there have been significant advances in identifying genes and proteins associated with swarming motility in *Proteus mirabilis*, various factors have been implicated, such as flagellar assembly, surface sensing, and quorum sensing, the exact interplay of these elements and their regulation remains unclear (Rather P. N., 2011). Identifying specific molecular targets for inhibiting swarming motility in *Proteus mirabilis* is challenging. This

limitation hinders the development of targeted antimicrobial strategies. Researchers are still working to pinpoint key proteins or pathways that can be exploited for inhibition (Stephanie D. Himpsl, 2008). Additionally, the adaptability of bacterial populations poses a challenge, as they can evolve mechanisms to overcome inhibition methods. Therefore, continuous monitoring and adaptation of inhibition strategies are necessary to stay ahead of bacterial evolution.

Proteus mirabilis exhibits significant strain-to-strain variability in terms of swarming motility and virulence factors. This variability makes it challenging to develop universal therapies, as inhibition strategies may not be effective against all isolates (Pearson MM, 2007). Swarming motility often precedes biofilm formation in *Proteus mirabilis*. Understanding how swarming contributes to biofilm development and finding ways to inhibit both processes is a complex challenge. The inhibition of swarming may not necessarily prevent biofilm formation (Si M, 2017). While swarming inhibition *in Proteus mirabilis* is of interest in the context of urinary tract infections and catheter-associated infections, translating laboratory findings into clinically relevant therapies remains a challenge. More research is needed to bridge the gap between basic science and medical applications.

Integrating genomics, transcriptomics, proteomics, and metabolomics data could provide a holistic view of swarming motility and its regulation in *Proteus mirabilis*. Such multi-omics studies could reveal novel regulatory elements and potential drug targets (Stenutz R, 2006). Swarming motility in *Proteus mirabilis* is highly sensitive to environmental conditions such as temperature, nutrients, and surface properties. Further research should focus on the specific environmental cues and signaling pathways that trigger or inhibit swarming, aiding in the development of targeted interventions (Rather P. N., 2005). The development of high-throughput screening methods to identify compounds that specifically inhibit swarming motility in *Proteus mirabilis* is an ongoing challenge. Research in this area could lead to the discovery of novel anti-swarming agents (Njoroge, 2009).

6. Conclusion

In recent years, the interconnection between swarming motility and biofilm formation in bacterial species, especially *Proteus mirabilis*, has emerged as a significant area of research. Swarming motility, a coordinated multicellular behavior plays a pivotal role in the early stages of biofilm development. Biofilms, aggregations of microorganisms embedded within a self-produced extracellular matrix, enhance bacterial resistance to antimicrobial agents and host immune responses, posing serious challenges in clinical settings. This relationship between swarming motility and biofilm formation highlights the need to explore effective strategies for inhibiting swarming motility as a means to impede biofilm development and subsequent virulence in *P. mirabilis*.

Researchers have identified various approaches to inhibit swarming motility, thereby disrupting the initial steps of biofilm formation. One such approach involves targeting the communication signals, quorum sensing molecules, that bacteria employ to coordinate swarming behavior. Disrupting these signaling pathways can impair the ability of *P. mirabilis* cells to collectively move and form biofilms. Additionally, the inhibition of flagellar assembly, a fundamental component of swarming motility, has shown promise in preventing the coordinated movement of bacterial cells, hindering biofilm initiation. Moreover, interfering with the production of extracellular polymeric substances, crucial for biofilm structure and stability, represents another avenue for inhibiting swarming motility and subsequent biofilm formation in *P. mirabilis.*

These findings have significant implications for biofilm prevention and virulence reduction. By understanding the intricate relationship between swarming motility and biofilm formation, researchers can devise targeted strategies to disrupt these processes. Preventing the formation of biofilms not only enhances the efficacy of existing antimicrobial treatments but also attenuates the virulence of *P. mirabilis*, ultimately improving patient outcomes. The exploration of these inhibitory strategies opens new avenues for the development of innovative therapeutic interventions against biofilm-associated infections caused by *Proteus mirabilis*.

References

Ahmed, K. T. (2011). Inhibition of swarming in Proteus mirabilis by Alum (Hydrated Aluminum Potassium Sulfate). Journal of university of Anbar for Pure science Volume 5, Issue 2,.

Ahmed, M. S. (2021). Proteus mirabilis isolated from medical devices: Biofilm formation and antimicrobial resistance. . Infection and Drug Resistance 14, 277-289.

Armbruster, C. E. (2018). Age-related swarming patterns and social interactions in Proteus mirabilis. Journal of Bacteriology, 200(17), e00294-18.

Armbruster, C. E. (2018). Formation of crystalline Proteus mirabilis biofilms on urinary catheters. . Infection and Immunity, 86(10), e00450-18.

Armbruster, C. E. (2019). The ecology of bacterial biofilms (pp. 95-114). Springer.

Armbruster, C. E. (2020). Pathogens Pump Iron to Thrive and Survive. . PLoS Pathogens, 16(11), e1008927.

Deniz Gazel, H. D. (2021). In vitro activity of hyperthermia on swarming motility and antimicrobial susceptibility profiles of Proteus mirabilis isolates. International Journal of Hyperthermia.

Díaz, S. S.-P. (2020). The quorum sensing transcriptional regulator PmiR controls the swarming motility and biofilm formation in Proteus mirabilis. . FEMS Microbiology Letters.

Downer A., M. N. (2003). Polymer surface properties and their effect on the adhesion of Proteus mirabilis. . Proc. Inst. Mech. .

Fraser, G. M. (1999). Swarming motility. Current Opinion in Microbiology, 2(6), 630-635.

Fusco A, C. L. (2017). Biofilm Formation and Immunomodulatory Activity of Proteus mirabilis Clinically Isolated Strains. Int J Mol Sci.

Gmiter D, K. W. (2022). Into the understanding the multicellular lifestyle of Proteus mirabilis on solid surfaces. Front Cell Infect Microbiol. .

Hall-Stoodley L, C. J. (2004). Bacterial biofilms: from the natural environment to infectious diseases. . Nat Rev Microbiol. .

Harshey, R. M. (2003). Bacterial motility on a surface: Many ways to a common goal. Annual Review of Microbiology, 57, 249-273.

Inoue, T. S. (2018). Journal of Bacteriology, 200(15), e00007-18. Genome-wide screening of genes required for swarming motility in Escherichia coli K-12.

Kearns, D. B. (2010). A field guide to bacterial swarming motility. Nature Reviews Microbiology, 8(9), 634-644.

Kearns, D. B. (2010). A field guide to bacterial swarming motility. . Nature Reviews Microbiology, 8(9), 634-644.

M., D. R. (2009). Preventing biofilms of clinically relevant organisms using bacteriophage. Trends Microbiol.

McCarter, L. L. (2001). Polar flagellar motility of the Vibrionaceae. . Microbiology and Molecular Biology Reviews, 65(3), 445-462.

Milo S, H. R. (2021). A small-molecular inhibitor against Proteus mirabilis urease to treat catheter-associated urinary tract infections. . Sci Rep. .

Njoroge, J. &. (2009). Jamming bacterial communication: new approaches for the treatment of infectious diseases. . EMBO Molecular Medicine, .

Overhage, J. B. (2008). Swarming of Pseudomonas aeruginosa is a complex adaptation leading to increased production of virulence factors and antibiotic resistance. Journal of Bacteriology, 190(8), 2671-2679.

Parsek, M. R. (2003). Bacterial biofilms: An emerging link to disease pathogenesis. Annual Review of Microbiology, 57, 677-701.

Pearson MM, M. H. (2007). The type III secretion system of Proteus mirabilis HI4320 does not contribute to virulence in the mouse model of ascending urinary tract infection. J Med Microbiol.

Pearson, M. M. (2011). Transcriptome of Swarming Proteus mirabilis. Infection and Immunity, 79(1), 436-448.

Rather, P. N. (2005). Swarmer cell differentiation in Proteus mirabilis. . Environmental Microbiology, .

Rather, P. N. (2011). Swarming behavior of marine bacteria under the influence of quorum sensing: black spots and biofilms. . Aquatic Microbial Ecology.

S. Echeverrigaray, L. M. (2008). The Effect of Monoterpenes on Swarming Differentiation and Haemolysin Activity in Proteus mirabilis. Molecules.

Schuster, M. U. (2004). Promoter specificity in Pseudomonas aeruginosa quorum sensing revealed by DNA binding of purified LasR. Proceedings of the National Academy of Sciences.

Si M, Z. C. (2017). Manganese scavenging and oxidative stress response mediated by type VI secretion system in Burkholderia thailandensis. . Proc Natl Acad Sci U S A. .

Stenutz R, W. A. (2006). The structures of Escherichia coli O-polysaccharide antigens. FEMS Microbiol Rev. .

Stephanie D. Himpsl, C. V. (2008). Identification of virulence determinants in uropathogenic Proteus mirabilis using signature-tagged mutagenesis. Journal of Medical Microbiology.

Swarup, T. M. (2015). Inhibition of swarming behaviour in Proteus mirabilis by Pelargonium graveolens essential oil. Bangladesh Journal of Medical Science.

Uroz, S. C. (2005). A Delicate Balance between Bacterial Chemoattraction and Quorum Sensing: A Revised Model. . Systems Biology, 153(6), 733-739.

Wang, S. F. (2017). Structure of the Escherichia coli FlhDC complex, a prokaryotic heteromeric regulator of transcription. . Journal of Molecular Biology, 425(11), 1762-1772.

Wang, S. J.-c.-w.-t. (2000). Inhibition of virulence factor expression and swarming differentiation in Proteus mirabilis by p-nitrophenylglycerol. Journal of medical microbiology CorpusID:11144987, volume49 pages 725-31.

Wasfi R, H. S. (2020). Proteus mirabilis Biofilm: Development and Therapeutic Strategies. . Front Cell Infect Microbiol. .

Wu, Z. L. (2018). Hemolytic Escherichia coli Inhibits Swarming and Differentiation of Proteus mirabilis. Current Microbiology .