PSM Journals

PSM
Microbiology

Mini-Review **2025 | Volume 10 | Issue 1 | 137-141**

Open Access

Article Information

Received: October 10, 2025

Accepted: October 17, 2025

Published: October 22, 2025

Keywords

Urinary microbiome;
Urological disorders;
Dysbiosis;
Recurrent urinary tract infections;
Bladder microbiota;
Microbiome-based diagnostics;
Overactive bladder;
Interstitial cystitis;
Precision urology;
Next-generation sequencing.

Authors' Contribution

SAK conceptualised the study; SAK and GFK contributed to writing the manuscript. All authors read and approved the final version of the manuscript.

How to cite

Khorsheed, S.A., Karim, G.F., 2025. The Urinary Microbiome: Silent Revolutions in Understanding Urological Disorders. PSM Microbiol., 10(1): 137-141.

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The Urinary Microbiome: Silent Revolutions in Understanding Urological Disorders

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Abstract:

For decades, urinary tract was traditionally it considered a sterile environment in healthy individuals. Still, recent advancements in next-generation sequencing and culture-independent microbiological techniques have revolutionized this long-standing belief. Emerging evidence supports the existence of a distinct and dynamic Microbial community of the urinary tract that could play a crucial function in both health and pathology of the urinary tract. The following review aims to provide a comprehensive overview of current knowledge regarding the urinary microbiome as well as its implications for urological disorders. We summarize key findings on the constitution and diversity of the urinary normal flora in healthy populations, highlighting differences based on age, sex, and hormonal status. We then explore the associations between urinary dysbiosis and a range of urological conditions, including recurrent urinary tract infections, extracellular cystitis/bladder pain syndrome, overactive bladder, urinary incontinence, and nephric malignancies. Furthermore, we discuss the impact of urological interventions, such as catheterization, antibiotics, and surgical procedures, on microbial balance within the urinary tract. The review also highlights potential diagnostic and therapeutic applications, including microbiome-based biomarkers, probiotics, and targeted microbiome modulation strategies. Despite promising insights, challenges remain in standardizing sampling methods, defining healthy microbiomes, and establishing causative relationships. By synthesizing the latest research, this article underscores the transformative potential of urinary microbiome science in reshaping our understanding of urological diseases. Identifying the urinary microbiome as a key biological player begins new avenues for precision medicine, individualized urological care, and novel therapeutic interventions.

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INTRODUCTION

For decades, urinary tract has been perceived as a aseptic environment among healthy individuals, a concept rooted in conventional urine culture methods. However, introduction of high-throughput sequencing technologies as well as advanced microbial detection techniques has overturned this long-standing dogma (Alsamarai *et al.*, 2016). New studies have revealed the presence of a diverse and dynamic community of microorganisms residing within the urinary system, jointly referred to as the urinary microbiome (Alsamarai *et al.*, 2016; Iqbal *et al.*, 2021). This microbial ecosystem, although less dense than that of the gut or skin, appears and play a critical role in maintaining the urinary tract health as well as modulating host immune responses (Alsamarai and Khorshed, 2018). Modifications in the composition or function of the urinary normal flora commonly termed urinary microbial imbalance have been increasingly connected with various urological situations, including recurrent the urinary tract infections (rUTIs) (Iqbal *et al.*, 2022; Khorshed, 2022; Karim, 2011). Between cells cystitis/bladder pain syndrome (IC/BPS), overactive bladder (OAB), urinary incontinence, and even urologic malignancies (Bhide *et al.*, 2020).

Understanding the urinary microbiome offers a novel perspective on the pathogenesis, diagnosis, and treatment of these conditions (Alsamarai and Korshid, 2022). It also opens the door to innovative therapeutic approaches, such as microbiota-targeted therapies, probiotics, and personalized interventions based on microbiome profiling (Alsamarai *et al.*, 2022). This case review, we aim to provide a comprehensive synthesis recent research of the urinary microbiome (Khorsheed, 2025). We will examine its composition in health, explore its alterations in disease, and discuss its clinical implications, including diagnostic and therapeutic potentials. As the field rapidly evolves, integrating microbiome science into urology may pave the way for a new era of precision urological medicine (Alsamarai *et al.*, 2016).

Discussion

A discovery of the normal flora of urinary has profoundly reshaped our perception of urological disease and health (Wolfe and Brubaker, 2015). Traditionally, the urinary tract was considered sterile, and the presence of bacteria was equated with infection (Wu *et al.*, 2017; Raheem, and Ahmed, 2022). . However, recent evidence demonstrates that a complex, low-biomass bacterial community exists still in asymptomatic individuals. This paradigm shift raises critical questions about the true nature of “infection” and the role of microbial balance in urological pathophysiology (Brubaker and Wolfe, 2015). One of the most compelling findings is the link between urinary dysbiosis and recurrent urinary tract infections (rUTIs) (Komesu *et al.*, 2020). Conventional antibiotic treatments often fail to prevent recurrence, possibly due to their non-specific effects on the microbial community, which may disrupt protective commensal organisms (Iqbal *et al.*, 2024; Radha *et al.,* 2024; Sfanos *et al.*, 2018). Identifying beneficial microbial signatures may offer new targets for probiotic therapy or bacteriotherapy, reducing reliance on antibiotics and helping combat antimicrobial resistance (Aragon *et al.*, 2018; Whiteside *et al.*, 2015).

Beyond infections, the urinary microbiome is increasingly implicated in non-infectious urological circumstances, such as interstitial cystitis/bladder pain syndrome (IC/BPS) and overactive bladder (OAB). Studies suggest that these disorders may be associated with specific microbial profiles or immune interactions influenced by microbial metabolites (Meriwether *et al.*, 2019). However, data remain inconsistent, and further research is needed to clarify causality versus correlation. Emerging evidence also links urinary microbiota with urologic cancers, particularly bladder cancer. Some microbial metabolites may influence carcinogenesis through chronic inflammation or by affecting host cell signaling pathways (Andolfi *et al.*, 2020; Bučević Popović *et al.*, 2018). While still in early stages, microbiome-based biomarkers hold promise for non-invasive early

detection and prognosis assessment. Despite these advances, several challenges hinder the clinical translation of urinary microbiome research. First, standardized sampling methods (e.g., midstream urine vs. catheterized samples) are lacking, which affects data reproducibility (Fok *et al.*, 2018; Wolfe *et al.*, 2012). Second, distinguishing contamination from true microbial colonization remains a technical hurdle, especially seeing that the low biomass of urinary specimens (Karstens *et al.*, 2018; Moreland *et al.*, 2025). Third, a definition to "healthy" urinary microbiome is still evolving, with significant inter-individual variability influenced by age, sex, hormonal status, and lifestyle factors (Lewis *et al.*, 2013). Moreover, most studies to date are cross-sectional and lack longitudinal data. Causal relationships between dysbiosis and disease remain speculative in many cases. Large-scale, well-controlled studies with integrated many-omics approaches (e.g., metagenomics, metabolomics, host transcriptomics) are essential of deepen our understanding (Shrestha *et al.*, 2018).

In conclusion, while the urinary microbiome presents exciting opportunities for innovation in urology, cautious interpretation and robust methodological designs are needed (Brubaker and Wolfe, 2016; Fricke and Rasko, 2014). Future integration of microbiome science into precision urology could revolutionize diagnostics, prevention, and treatment paradigms across a range of urological conditions (Andolfi *et al.*, 2020).

CONCLUSION

The recognition of the urinary microbiome as a resident bacterial community within a urinary tract has opened the new frontier in urological research. No longer can the urinary system be viewed as a sterile domain; instead, it represents a dynamic ecosystem that may influence both disease and health. Current evidence demonstrates that alterations in urinary microbiota structure referred to as urinary dysbiosis are associated with a wide spectrum of urological disorders, ranging from recurrent infections to functional bladder conditions and potentially malignancies. These associations highlight a diagnostic and therapeutic potential of targeting a microbiome, offering promising avenues for non-invasive biomarkers and microbiota a directed treatments. However, the field remains in its early stages. Significant challenges persist, including variability in sampling methods, lack of consensus on what defines a "healthy" urinary microbiome, and limited longitudinal data. Overcoming these obstacles will require standardized protocols, multidisciplinary collaboration, and integration of advanced omics technologies. In the years to come, a deeper understanding of the urinary microbiome may transform clinical practice in urology, ushering in an era of personalized, microbiome-informed care. Continued research is essential to fully unlock the clinical value of this once-overlooked microbial frontier.

CONFLICT OF INTEREST

There is no conflict of interest.

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