Bioluminescent: Journal of Biology and Life https://doi.org/10.37253/bio.v1i1.12200
Volume 1, Number 1, June 2026

Microbiological Characteristics and Antibiotic Resistance Patterns of Uropathogenic *Escherichia coli* in Urinary Tract Infections: A Literature Review

Mona Fathia*, Witri Winanda, Khoirul Anwar, Ramadani Fitra, Wardatul Aini, Azizul Berlyansah and Celine Law

Biology Study Program, Faculty of Health and Science, Universitas Internasional Batam, Baloi-Sei Ladi, Jl. Gajah Mada, Tiban Indah, Sekupang District, Batam City 29426, Riau Archipelago, Indonesia.
***Corresponding author**: mona.fathia@uib.ac.id

Submitted: 10 May 2026; **Final Revision**: 29 June 2026; **Accepted**: 29 June 2026

ABSTRACT

Urinary tract infection (UTI) is one of the most common bacterial infections, with uropathogenic Escherichia coli (UPEC) as the main causative agent. This literature review aims to examine the microbiological characteristics and antibiotic resistance patterns of UPEC. Based on the analyzed literature, UPEC possesses various virulence factors, such as fimH adhesin, biofilm formation, hemolysin production, and iron acquisition systems that support colonization, persistence, and infection recurrence. In addition, UPEC shows increased resistance to several antibiotics, particularly fluoroquinolones, trimethoprim-sulfamethoxazole, and β-lactams, as well as the emergence of MDR and ESBL strains. Therefore, antibiotic selection based on susceptibility testing and local resistance surveillance is necessary to support more effective UTI management.

Keywords: *microbiological characteristics, multidrug resistance, Urinary tract infection, uropathogenic Escherichia coli, virulence factors*

1. INTRODUCTION

Urinary tract infection (UTI) is an infection that occurs in the urinary system, including the urethra, bladder, ureters, and kidneys. UTIs are among the most common bacterial infections in the world and pose a significant public health problem, with high incidence rates across various age groups (Rappaport et al., 2025). Microbiologically, most UTI cases are caused by uropathogenic bacteria originating from the intestinal flora and capable of colonizing the urinary tract epithelium. Uropathogenic *Escherichia coli* (UPEC) is the main cause of UTIs, especially in uncomplicated cases, and contributes to most infections both in the community and healthcare facilities (Klein & Hultgren, 2020; Whelan et al., 2023). Besides UPEC, other bacteria such as *Klebsiella pneumoniae, Proteus mirabilis,* and *Pseudomonas aeruginosa* also play a role in certain cases, while Gram-positive bacteria such as *Staphylococcus saprophyticus* and *Enterococcus faecalis* have also been reported as causes of UTIs, although with lower prevalence (Qiao et al., 2013).

The ability of UPEC to cause infection is inseparable from its microbiological characteristics, including virulence factors such as adhesins, fimbriae, hemolysin, as well as

the ability to form biofilms. These factors allow the bacteria to adhere, invade, and survive in the urinary tract environment, which has high immunological pressure (García et al., 2025; Terlizzi et al., 2017). In addition, in recent years there has been a significant increase in antibiotic resistance, including the emergence of Extended Spectrum Beta Lactamase (ESBL) producing strains, which further complicates the management of UTIs (Bunduki et al., 2021; Whelan et al., 2023).

Although various studies have discussed the characteristics of UPEC and antibiotic resistance, reviews that comprehensively integrate microbiological aspects and resistance patterns in a single study are still limited. Therefore, this literature review aims to examine the microbiological characteristics and antibiotic resistance patterns of uropathogenic Escherichia coli based on recent scientific publications, to provide a more comprehensive understanding and support more effective UTI management.

2. MATERIALS AND METHODS

This study is a narrative literature review aimed at comprehensively examining the microbiological characteristics and patterns of antibiotic resistance in uropathogenic *Escherichia coli* (UPEC), the primary cause of urinary tract infections (UTIs). A narrative approach was used to synthesize the latest research findings and describe trends in antimicrobial resistance over the past decade. The literature search was conducted electronically using the PubMed, ScienceDirect, and Google Scholar databases. The keywords used were a combination of the following terms: “urinary tract infection” OR “UTI”, “uropathogenic *Escherichia coli*” OR “UPEC”, “microbiological characteristics”, “virulence factors”, “biofilm formation”, “antibiotic resistance” OR “antimicrobial resistance”, “extended-spectrum beta-lactamase” OR “ESBL”. The articles considered were publications from 2015 to 2025, in English or Indonesian, to ensure the relevance and recency of the data reviewed.

The literature selected for this review includes original research articles and reviews that discuss uropathogenic *Escherichia coli* (UPEC), virulence factors, and antibiotic resistance in humans. Articles that were irrelevant, not available in full text, or inconsistent with the focus of the study were excluded from the review. Following the selection process, a number of articles that met the criteria were used in the analysis.

Data from the relevant articles were analyzed and synthesized descriptively in narrative form and compared across studies to identify consistent patterns and variations in

findings. The discussion focused on the microbiological characteristics of UPEC, its biofilm forming ability, and trends in resistance to first-line and second-line antibiotics, including the production of Extended Spectrum Beta Lactamase (ESBL). This synthesis aims to identify common patterns, differences between studies, and clinical implications for the selection of UTI therapy.

3. RESULTS AND DISCUSSION

3.1 Microbiological Characteristics of Uropathogenic *Escherichia coli* (UPEC)

Uropathogenic *Escherichia coli* (UPEC) is the leading cause of urinary tract infections (UTIs), both in community acquired and nosocomial cases. Various studies indicate that *E. coli* is responsible for the majority of UTIs, particularly uncomplicated UTIs in adult women (Zagaglia et al., 2022) Genetically, UPEC belongs to the group of extraintestinal pathogenic *Escherichia coli* (ExPEC), which possesses the ability to cause infections outside the gastrointestinal tract. Most UPEC isolates originate from phylogroups B2 and D, which are known to have a higher content of virulence genes compared to other phylogroups. Tanabe et al. (2022) and Wang et al. (2023) reported the dominance of phylogroup B2 with a high prevalence of virulence genes such as fimH, traT, and other adhesion factors.

Based on a synthesis of several studies, the main microbiological characteristics of UPEC include adhesion, cellular invasion, biofilm formation, toxin production, and iron acquisition systems. Raeispour & Ranjbar (2018) reported a prevalence of the aer gene at 90%, the fimH gene at 89%, and the hlyA gene at 60% in UPEC isolates. These findings indicate that adhesion, iron acquisition, and toxin production are key determinants in the pathogenesis of UTIs. UPEC adhesion is primarily mediated by type 1 fimbriae, with the FimH adhesin binding to mannosylated residues on bladder epithelial uroplakin. This interaction facilitates bacterial colonization and internalization into urothelial cells. Additionally, P fimbriae with the PapG adhesin have an affinity for renal epithelium and are associated with the occurrence of pyelonephritis. Beyond adhesion mechanisms, several studies highlight the importance of intracellular bacterial communities (IBCs) and biofilm formation in infection persistence. Karigoudar et al., (2019) demonstrated that biofilm-forming UPEC strains exhibit higher colonization and persistence capabilities compared to non-biofilm-forming strains. (Khan et al., 2023; Shah et al., 2019) also reported that biofilm-forming strains exhibit higher levels of multidrug resistance (MDR) compared to non-

biofilm-forming strains. These findings indicate that biofilms not only enhance bacterial resilience to the environment but also contribute to antibiotic resistance and UTI recurrence.

From a metabolic perspective, the iron acquisition system is a critical factor in the survival of UPEC in the iron-deprived urinary environment. The production of siderophores such as aerobactin enables the bacteria to acquire iron to support growth and colonization. (Raeispour & Ranjbar, 2018) demonstrated a high prevalence of the aer gene in UPEC isolates, indicating the importance of the siderophore system in enhancing bacterial virulence. Epidemiologically, certain UPEC clones, such as ST131, have high clinical relevance as they combine virulence factors with antibiotic resistance (Kim et al., 2024). These clones are often associated with the production of extended spectrum β-lactamases (ESBLs) and multidrug resistance (MDR), thereby increasing the risk of treatment failure. Thus, the microbiological characteristics of UPEC reflect a complex integration of virulence factors, genetic adaptation, and antibiotic resistance that supports the bacterium's success in causing urinary tract infections.

3.2 Virulence Factors and Pathogenesis *Uropathogenic Escherichia coli* (UPEC)

The pathogenesis of uropathogenic *Escherichia coli* (UPEC) is influenced by various virulence factors that support adhesion, colonization, invasion, biofilm formation, toxin production, and nutrient acquisition. These factors enable UPEC to persist in the urinary tract and evade the host's immune response. Adhesion is a critical initial step in infection. Type 1 fimbriae with the FimH adhesin play a role in UPEC attachment to the bladder epithelium. (Raeispour & Ranjbar, 2018) reported that the fimH gene was found in 89% of UPEC isolates, indicating its dominant role in urinary tract colonization. Additionally, P fimbriae, MRHA, MSHA, and other adhesins such as papGII, afa, and sfa also support attachment to uroepithelial tissue and are associated with upper urinary tract infections.

After attachment, UPEC can invade epithelial cells and form intracellular bacterial communities (IBCs) as well as quiescent intracellular reservoirs (QIRs). These structures help the bacteria survive immune responses and antibiotic exposure, thereby contributing to UTI recurrence. Furthermore, biofilm formation is a key factor in the persistence of infection. (Karigoudar et al., 2019) and (Shah et al., 2019) demonstrate that biofilm-forming strains exhibit higher levels of antibiotic resistance compared to non biofilm forming strains.

UPEC also produces toxins such as α-hemolysin (hlyA), which can damage tissue and trigger an inflammatory response. Munkhdelger et al. (2017) and Raeispour & Ranjbar

(2018), reported the hlyA gene in 60% of UPEC isolates, while the aer gene was found in 90% of isolates, indicating the importance of aerobactin in iron acquisition. Thus, UPEC virulence results from a combination of adhesion, invasion, biofilm formation, toxins, and iron acquisition systems that support the occurrence of persistent and recurrent infections.

3.3 Antibiotic Resistance Patterns of Uropathogenic *Escherichia coli* (UPEC)

The rise in antibiotic resistance among UPEC has become a major challenge in the modern management of urinary tract infections. According to various studies, high levels of resistance are primarily observed against antibiotics frequently used for empirical therapy, such as trimethoprim-sulfamethoxazole (TMP-SMX), fluoroquinolones, and certain β-lactams. (Polgárová et al., 2011; Qiao et al., 2013) reported high resistance to fluoroquinolones and cephalosporins in ESBL producing *E. coli* isolates, with an ESBL prevalence reaching 52.9%. However, fosfomycin and nitrofurantoin still demonstrate good efficacy against most UPEC isolates. Similar findings were also reported by (Sohail et al., 2015; Terlizzi et al., 2017), which showed high resistance to cephalexin and cephradine (95%), pipemidic acid (92%), and nalidixic acid (91%). Conversely, the highest sensitivity was found for imipenem, meropenem, and cefoperazone (97%) as well as fosfomycin (90%).

Ahmed et al., (2019) reported high resistance to ampicillin (88.3%), piperacillin (72.7%), and amoxicillin/clavulanic acid (66.2%). In addition, approximately 80% of the isolates were classified as multidrug-resistant (MDR). Kot (2019) and Shah et al. (2019) also found MDR in 51% of UPEC isolates and ESBL in 46% of isolates, with higher resistance rates in biofilm forming strains compared to non biofilm forming strains. The relationship between biofilms and antibiotic resistance was also demonstrated by Karigoudar et al. (2019), the study showed that biofilm forming UPEC strains exhibited high resistance to amoxiclav and cephalexin (98.6%), ciprofloxacin, gentamicin, and norfloxacin (94.2%), as well as nalidixic acid (92.7%). Nevertheless, nitrofurantoin and imipenem still showed relatively good efficacy against most isolates.

Wang et al. (2023) reported that certain phylogroups, particularly group B2, have higher rates of multidrug resistance (MDR) compared to other phylogroups. Additionally, Tanabe et al. (2022) reported resistance to ampicillin at 46.4% and to trimethoprim sulfamethoxazole at 34.8%, with an ESBL prevalence of 9.8%. Raeispour & Ranjbar (2018) reported high resistance to cefepime (100%), cephalothin (74%), cefpodoxime (67%), and cotrimoxazole (54%). However, all isolates remained susceptible to imipenem, doxycycline, and vancomycin. These findings indicate that resistance to β-lactams and fluoroquinolones

continues to rise, while carbapenems still maintain high efficacy. In addition to conventional resistance patterns, the emergence of strains producing extended-spectrum β-lactamases (ESBL) is a major concern in clinical practice. Epidemiological clones such as ST131 are reported to possess a combination of high virulence and broad resistance to various antibiotics, including fluoroquinolones and third-generation cephalosporins. This situation narrows therapeutic options and increases the risk of treatment failure. The antibiotic resistance patterns of UPEC, based on various studies analyzed in this review, are shown in **Table 1**. Overall, the UPEC resistance pattern shows a trend toward increasing multidrug resistance with significant geographical variation. Therefore, the selection of UTI therapy should take into account local surveillance data and antibiotic susceptibility test results to prevent further escalation of resistance.

3.4 Clinical Implications and Therapeutic Challenges

The rise in antibiotic resistance among UPEC has significant implications for the success of UTI treatment. High resistance to first line antibiotics such as TMP-SMX, fluoroquinolones, and some β-lactams makes empirical therapy increasingly difficult and increases the risk of treatment failure. Various studies have shown that nitrofurantoin, fosfomycin, and carbapenems still maintain relatively good efficacy against most UPEC isolates (Qiao et al., 2013) and (Sohail et al., 2015) reported high sensitivity to fosfomycin and imipenem, whereas (Raeispour & Ranjbar, 2018) demonstrated full sensitivity to imipenem. However, excessive use of broad-spectrum antibiotics has the potential to accelerate the selection of new resistant strains.

In addition to antibiotic resistance, UPEC's ability to form biofilms, IBCs, and QIRs also contributes to recurrent UTIs and the persistence of infection. (Karigoudar et al., 2019) dan (Shah et al., 2019) demonstrated that biofilm-forming strains have higher MDR rates compared to non-biofilm-forming strains. This suggests that treatment success is influenced not only by antibiotic susceptibility but also by the bacteria's ability to survive within protective intracellular niches or biofilms. In clinical practice, this situation underscores the importance of rational antibiotic use based on culture and susceptibility testing. In addition, local resistance surveillance should be conducted periodically to support the selection of more effective empirical therapies.

Table 1. Microbiological Characteristics, Virulence, and Resistance Patterns of UPEC Based on the Literature

References	Major Virulence Factors	Pathogenesis Mechanisms	Antibiotic Resistance Patterns
Toval et al. (2014)	Stx, fimH, adhesin Saa, Gb3Cer/Gb4Cer interaction	Adhesion to urothelial cells, Stx toxicity to bladder cells, and ascending colonization in a murine UTI model	Not the main focus of the research
Qiao et al. (2013)	ESBL-producing *E. coli*, biofilm on *Staphylococcus epidermidis*	ESBL production increases β-lactam resistance; biofilms facilitate bacterial adhesion and protect bacteria against antibiotics and phagocytosis	High resistance to fluoroquinolones and cephalosporins; ESBL-producing *E. coli* reached 52.9%; fosfomycin and nitrofurantoin remain effective against most isolates
Sohail et al., (2015)	ESBL-producing *E. coli*	ESBL production increases β-lactam resistance; *E. coli* dominates as the primary uropathogen in patients with UTIs	*E. coli* exhibits high resistance to cephalexin (95%), cephradine (95%), pipemidic acid (92%), amikacin (91%), and nalidixic acid (91%); the highest sensitivity is observed for imipenem, meropenem, and cefoperazone (97%) as well as fosfomycin (90%)
Ahmed et al. (2019)	Pili, capsul, lipopolisakarida (LPS), cell surface structures	Adhesion, colonization, invasion of host cells, and evasion of the immune system via surface virulence factors	High resistance to ampicillin (88.3%), piperacillin (72.7%), amoxicillin/clavulanic acid (66.2%), and trimethoprim/sulfamethoxazole (50%); MDR was found in approximately 80% of isolates
Wang et al. (2023)	High virulence genotype in phylogroup B2	Variation in virulence among phylogroups	High MDR in certain phylogroups
Karigoudar et al. (2019)	Biofilm formation, intracellular bacterial communities (IBCs)	Biofilms enhance UPEC adhesion and colonization on the urothelium, inhibit the diffusion of antimicrobials, and increase the persistence and recurrence of UTIs	Biofilm-producing UPEC exhibited high resistance to amoxiclav and cephalexin (98.6%), norfloxacin, ciprofloxacin, and gentamicin (94.2%), nalidixic acid (92.7%), and ampicillin (91.3%); nitrofurantoin and imipenem remained relatively effective
Shah et al. (2019)	Hemolysin, biofilm, MRHA (P fimbriae), MSHA (type 1 fimbriae)	Adhesion to the uroepithelium via fimbriae, biofilm formation for sustained infection, and hemolysin-mediated tissue damage and colonization by UPEC	High resistance to ampicillin, cotrimoxazole, and norfloxacin; MDR was found in 51% of isolates and ESBL in 46% of UPEC isolates. Resistance was higher in biofilm-forming strains than in non-biofilm-forming strains
Tanabe et al. (2022)	fimH (98.2%), traT, ecpA	Dominasi phylogroup B2, high virulence	Ampicillin 46.4%, TMP-SMX 34.8%, ESBL 9.8%
Raeispour & Ranjbar (2018)	fimH, hlyA, aerobactin (aer)	fimH mediates UPEC adhesion to uroepithelial cells and the formation of intracellular biofilms; hlyA causes tissue damage; aerobactin aids in iron acquisition for bacterial growth	High resistance to cefepime (100%), cephalothin (74%), cefpodoxime (67%), nalidixic acid (63%), and cotrimoxazole (54%); imipenem, doxycycline, and vancomycin still show 100% susceptibility

Alternative approaches such as FimH adhesion inhibition, anti-biofilm therapy, and immune response modulation are also being developed as additional strategies in the management of UTIs caused by UPEC. Overall, the therapeutic challenges of UPEC associated UTIs are not only related to increasing multidrug resistance but also to the complexity of virulence factors that allow the bacteria to persist and cause recurrent infections. Therefore, the integration of resistance surveillance, rational antibiotic use, and the development of alternative therapies are crucial steps in controlling UPEC-associated UTIs.

4. CONCLUSION

Uropathogenic *Escherichia coli* (UPEC) is a leading cause of urinary tract infections and exhibits complex virulence characteristics, including adhesion, cellular invasion, biofilm formation, toxin production, and iron acquisition. Virulence factors such as fimH, hlyA, aerobactin, and the ability to form biofilms play a crucial role in colonization, persistence, and recurrence of infection. In addition, UPEC shows increased resistance to various antibiotics, particularly fluoroquinolones, trimethoprim-sulfamethoxazole, and β-lactams, with the discovery of MDR and ESBL strains. Therefore, antibiotic use based on susceptibility testing, local resistance surveillance, and the development of alternative therapeutic strategies are necessary to improve the success of UTI management.

REFERENCES

Ahmed, S. S., Shariq, A., Alsalloom, A. A., Babikir, I. H., & Alhomoud, B. N. (2019). *Uropathogens and their antimicrobial resistance patterns: Relationship with urinary tract infections*.

Bunduki, G. K., Heinz, E., Phiri, V. S., Noah, P., Feasey, N., & Musaya, J. (2021). Virulence factors and antimicrobial resistance of uropathogenic Escherichia coli (UPEC) isolated from urinary tract infections: a systematic review and meta-analysis. *BMC Infectious Diseases*, *21*(1). https://doi.org/10.1186/s12879-021-06435-7

García-García, J. D., Contreras-Alvarado, L. M., Cruz-Córdova, A., Hernández-Castro, R., Flores-Encarnacion, M., Rivera-Gutiérrez, S., Arellano-Galindo, J., A. Ochoa, S., & Xicohtencatl-Cortes, J. (2025). Pathogenesis and Immunomodulation of Urinary Tract Infections Caused by Uropathogenic Escherichia coli. In *Microorganisms* (Vol. 13, Number 4). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/microorganisms13040745

Karigoudar, R. M., Karigoudar, M. H., Wavare, S. M., & Mangalgi, S. S. (2019). Detection of biofilm among uropathogenic Escherichia coli and its correlation with antibiotic resistance

pattern. *Journal of Laboratory Physicians*, *11*(01), 017–022. https://doi.org/10.4103/jlp.jlp_98_18

Khan, M. A., Rahman, A. U., Khan, B., Al-Mijalli, S. H., Alswat, A. S., Amin, A., Eid, R. A., Zaki, M. S. A., Butt, S., Ahmad, J., Fayad, E., & Ullah, A. (2023). Antibiotic Resistance Profiling and Phylogenicity of Uropathogenic Bacteria Isolated from Patients with Urinary Tract Infections. *Antibiotics*, *12*(10). https://doi.org/10.3390/antibiotics12101508

Kim, J. H., Lee, J. H., Sim, Y. J., Kim, G. C., & Jeong, H. J. (2024). Uropathogenic distribution and antibiotic resistance patterns according to multidrug-resistant bacteria colonization status in patients with stroke. *Medicine (United States)*, *103*(4). https://doi.org/10.1097/MD.0000000000036980

Klein, R. D., & Hultgren, S. J. (2020). Urinary tract infections: microbial pathogenesis, host–pathogen interactions and new treatment strategies. In *Nature Reviews Microbiology* (Vol. 18, Number 4, pp. 211–226). Nature Research. https://doi.org/10.1038/s41579-020-0324-0

Kot, B. (2019). Antibiotic Resistance among Uropathogenic Escherichia coli. In *Polish Journal of Microbiology* (Vol. 68, Number 4, pp. 403–415). Polish Society of Microbiologists. https://doi.org/10.33073/PJM-2019-048

Munkhdelger, Y., Gunregjav, N., Dorjpurev, A., Juniichiro, N., & Sarantuya, J. (2017). Detection of virulence genes, phylogenetic group and antibiotic resistance of uropathogenic Escherichia coli in Mongolia. *Journal of Infection in Developing Countries*, *11*(1), 51–57. https://doi.org/10.3855/jidc.7903

Polgárová, K., Lüthje, P., Cerami, A., & Brauner, A. (2011). The erythropoietin analogue ARA290 modulates the innate immune response and reduces Escherichia coliinvasion into urothelial cells. *FEMS Immunology and Medical Microbiology*, *62*(2), 190–196. https://doi.org/10.1111/j.1574-695X.2011.00801.x

Qiao, L. D., Chen, S., Yang, Y., Zhang, K., Zheng, B., Guo, H. F., Yang, B., Niu, Y. J., Wang, Y., Shi, B. K., Yang, W. M., Zhao, X. K., Gao, X. F., Chen, M., & Tian, Y. (2013). Characteristics of urinary tract infection pathogens and their in vitro susceptibility to antimicrobial agents in China: Data from a multicenter study. *BMJ Open*, *3*(12). https://doi.org/10.1136/bmjopen-2013-004152

Raeispour, M., & Ranjbar, R. (2018). Antibiotic resistance, virulence factors and genotyping of Uropathogenic Escherichia coli strains. *Antimicrobial Resistance and Infection Control*, *7*(1). https://doi.org/10.1186/s13756-018-0411-4

Rappaport, Y. H., Rahav, N., Chertin, B., & Shenfeld, O. Z. (2025). Risk of Urinary Tract Infection with Perineal Urethrostomy Versus Urethroplasty. *European Urology Open Science*, *82*, 8–12. https://doi.org/10.1016/j.euros.2025.09.011

Shah, C., Baral, R., Bartaula, B., & Shrestha, L. B. (2019). Virulence factors of uropathogenic Escherichia coli (UPEC) and correlation with antimicrobial resistance. *BMC Microbiology*, *19*(1). https://doi.org/10.1186/s12866-019-1587-3

Sohail, M., Khurshid, M., Murtaza Saleem, H. G., Javed, H., & Khan, A. A. (2015). Characteristics and antibiotic resistance of urinary tract pathogens isolated from Punjab, Pakistan. *Jundishapur Journal of Microbiology*, *8*(7). https://doi.org/10.5812/jjm.19272v2

Tanabe, R. H. S., Dias, R. C. B., Orsi, H., de Lira, D. R. P., Vieira, M. A., Dos Santos, L. F., Ferreira, A. M., Rall, V. L. M., Mondelli, A. L., Gomes, T. A. T., Camargo, C. H., &

Hernandes, R. T. (2022). Characterization of Uropathogenic Escherichia coli Reveals Hybrid Isolates of Uropathogenic and Diarrheagenic (UPEC/DEC) E. coli. *Microorganisms*, *10*(3). https://doi.org/10.3390/microorganisms10030645

Terlizzi, M. E., Gribaudo, G., & Maffei, M. E. (2017). UroPathogenic Escherichia coli (UPEC) infections: Virulence factors, bladder responses, antibiotic, and non-antibiotic antimicrobial strategies. In *Frontiers in Microbiology* (Vol. 8, Number AUG). Frontiers Media S.A. https://doi.org/10.3389/fmicb.2017.01566

Toval, F., Schiller, R., Meisen, I., Putze, J., Kouzel, I. U., Zhang, W., Karch, H., Bielaszewska, M., Mormann, M., Müthing, J., & Dobrindt, U. (2014). Characterization of urinary tract infection-associated Shiga toxin-producing Escherichia coli. *Infection and Immunity*, *82*(11), 4631–4642. https://doi.org/10.1128/IAI.01701-14

Wang, M. C., Fan, Y. H., Zhang, Y. Z., Bregente, C. J. B., Lin, W. H., Chen, C. A., Lin, T. P., & Kao, C. Y. (2023). Characterization of uropathogenic Escherichia coli phylogroups associated with antimicrobial resistance, virulence factor distribution, and virulence-related phenotypes. *Infection, Genetics and Evolution*, *114*. https://doi.org/10.1016/j.meegid.2023.105493

Whelan, S., Lucey, B., & Finn, K. (2023). Uropathogenic Escherichia coli (UPEC)-Associated Urinary Tract Infections: The Molecular Basis for Challenges to Effective Treatment. In *Microorganisms* (Vol. 11, Number 9). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/microorganisms11092169

Zagaglia, C., Ammendolia, M. G., Maurizi, L., Nicoletti, M., & Longhi, C. (2022). Urinary Tract Infections Caused by Uropathogenic Escherichia coli Strains—New Strategies for an Old Pathogen. *Microorganisms*, *10*(7). https://doi.org/10.3390/microorganisms1007142