

Article

The Changing Landscape of Urinary Tract Infections: Epidemiology, Pathogen Distribution and Antimicrobial Resistance over Six Years

Sara Lopes ¹, Patrícia Coelho ^{1,2} , Catarina Chaves ³, Sónia Mateus ^{1,2} , João Metello ^{1,3} and Francisco Rodrigues ^{1,2,*} 

¹ Dr. Lopes Dias Higher School of Health, Polytechnic University of Castelo Branco, 6000-084 Castelo Branco, Portugal; lopes.sara004@gmail.com (S.L.); patriciacelho@ipcb.pt (P.C.); soniamateus@ipcb.pt (S.M.); joaometello@ipcb.pt (J.M.)

² Sport Physical Activity and Health Research & Innovation Center (Sprint), Polytechnic University of Castelo Branco, 6000-084 Castelo Branco, Portugal

³ Microbiology, Clinical Pathology Department, Coimbra Local Health Unit (ULS), 3004-561 Coimbra, Portugal; catarinachaves@ulscoimbra.min-saude.pt

* Correspondence: franciscobrodrigues@ipcb.pt

Abstract

Background: Urinary tract infections (UTIs) are among the most common bacterial infections worldwide and remain a major cause of antimicrobial prescribing in both community and hospital settings. Continuous epidemiological surveillance is essential to monitor changes in uropathogen distribution and antimicrobial resistance, particularly in aging populations. **Methods:** A retrospective observational study was conducted using urine culture data from a Portuguese tertiary healthcare network between January 2020 and December 2025. Demographic, microbiological, and antimicrobial susceptibility data were extracted from the laboratory information system. After applying predefined exclusion criteria, 44,596 positive urine cultures corresponding to distinct infectious episodes were included. Pathogen distribution, temporal trends, polymicrobial infections and antimicrobial susceptibility patterns were analyzed according to age, sex, and healthcare setting. **Results:** During the study period, 165,269 urine samples were processed, yielding 44,596 positive urine cultures. Women accounted for most infections, while individuals aged ≥ 65 years represented the largest patient group. Of all positive cultures, 41,555 (93.2%) were monomicrobial and 3041 (6.8%) were polymicrobial. *Escherichia coli* was the predominant uropathogen (49.6%), followed by *Klebsiella pneumoniae* (17.4%), *Proteus mirabilis* (7.0%), *Enterococcus faecalis* (5.3%), and *Pseudomonas aeruginosa* (5.1%). The overall microbiological profile remained relatively stable throughout the six-year period. Antimicrobial susceptibility testing demonstrated preserved activity of fosfomycin against the principal Enterobacterales, whereas resistance to fluoroquinolones and trimethoprim–sulfamethoxazole remained substantial. Polymicrobial infections occurred predominantly among older and hospitalized patients. **Conclusions:** This large-scale six-year surveillance study provides a comprehensive overview of the epidemiology of urinary tract infections within a Portuguese tertiary healthcare network. The findings confirm the continued predominance of *Escherichia coli*, highlight the growing burden of UTIs among older adults, and emphasize the importance of continuous local microbiological surveillance to support empirical antimicrobial therapy, antimicrobial stewardship, and future public health strategies.



Academic Editor: Vasco Ariston De Carvalho Azevedo

Received: 3 July 2026

Revised: 11 August 2026

Accepted: 16 September 2026

Published: 1 October 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and

conditions of the [Creative Commons](https://creativecommons.org/licenses/by/4.0/)

[Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

Keywords: urinary tract infections; urine culture; antimicrobial resistance; uropathogens; *Escherichia coli*; epidemiological surveillance; polymicrobial infection; Portugal

1. Introduction

Urinary tract infections (UTIs) are among the most common bacterial infections worldwide and represent a major cause of healthcare utilization, antimicrobial prescribing, and hospital admissions [1–3]. It is estimated that hundreds of millions of individuals are affected annually, generating a substantial burden on healthcare systems and significantly impacting patient quality of life [4,5]. Although UTIs affect individuals of all ages, their incidence is particularly high among women, older adults, and patients with underlying comorbidities [6–8]. Their epidemiology may also vary substantially over time and across healthcare settings, supporting the need for continuous, large-scale microbiological surveillance.

The epidemiology of UTIs is influenced by a complex interaction of host, microbial and healthcare-related factors. Female anatomy, hormonal changes, urinary tract abnormalities, diabetes mellitus, urinary catheterization, and exposure to healthcare environments are recognized risk factors that contribute to both infection occurrence and recurrence. As populations age and healthcare systems become increasingly complex, the clinical and microbiological profile of UTIs continues to evolve [6,9,10]. Consequently, the microbiological profile of UTIs may differ substantially according to patient age, sex, and healthcare setting, with potentially important implications for empirical antimicrobial selection.

Escherichia coli remains the predominant uropathogen worldwide and is responsible for a substantial proportion of urinary tract infections. However, several other microorganisms, including *Klebsiella pneumoniae*, *Proteus mirabilis*, *Enterococcus faecalis* and *Pseudomonas aeruginosa*, play an increasingly important role, particularly among hospitalized patients and individuals with complicated urinary tract infections. The relative prevalence of these pathogens may vary considerably according to demographic characteristics, healthcare setting, and local epidemiological conditions [2,11,12].

Simultaneously, antimicrobial resistance has emerged as one of the most significant challenges in the management of urinary tract infections. The widespread use of antibiotics in both community and hospital settings has contributed to the selection of resistant microorganisms, compromising the effectiveness of empirical treatment and increasing the risk of adverse clinical outcomes [11,13–15].

Continuous local surveillance is therefore essential to support evidence-based therapeutic decisions and antimicrobial stewardship initiatives [16,17]. Importantly, resistance surveillance should not be interpreted solely as an overall institutional measure, as antimicrobial susceptibility profiles may differ according to the bacterial species, patient population and healthcare context.

Although several studies have characterized urinary tract infections in specific Portuguese populations or over shorter observation periods, a comprehensive longitudinal assessment integrating urine culture activity, positivity rates, demographic characteristics, healthcare setting, pathogen distribution, polymicrobial infections, and antimicrobial susceptibility patterns remains limited. Such an integrated approach is particularly relevant in the context of population aging, increasing healthcare utilization, and the ongoing evolution of antimicrobial resistance.

Therefore, this study aimed to provide a comprehensive six-year epidemiological and microbiological characterization of positive urine cultures in a Portuguese tertiary healthcare institution. Specifically, we assessed annual distribution of positive urine cul-

tures, demographic characteristics, healthcare setting, pathogen distribution, polymicrobial infections, and antimicrobial susceptibility profiles of the principal uropathogens. By integrating these dimensions within a large longitudinal dataset, this study sought to provide a contemporary overview of the changing landscape of UTIs and generate evidence relevant to empirical antimicrobial therapy, microbiological surveillance, and antimicrobial stewardship.

2. Materials and Methods

2.1. Study Design and Setting

A retrospective observational study was conducted at the Department of Microbiology of a central healthcare institution serving a large population in central Portugal. The study included all urine samples submitted for microbiological analysis between 1 January 2020 and 31 December 2025. The study was conducted and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations.

2.2. Sample Selection

Between January 2020 and December 2025, a total of 165,269 urine samples were processed by the Microbiology Department of a Portuguese tertiary healthcare network. After applying the predefined inclusion and exclusion criteria, 44,596 positive urine cultures corresponding to distinct infectious episodes were included in the study. Of these, 41,555 (93.2%) were monomicrobial cultures and 3,041 (6.8%) were polymicrobial cultures. To ensure data quality and epidemiological consistency, duplicate records, samples without microbiological results, nephrostomy specimens, and contaminated cultures (defined as the presence of three or more microorganisms) were excluded from the analysis. To avoid overrepresentation of recurrent or repeated microbiological findings, repeated isolation of the same microorganism from the same patient within 30 days was considered part of the same infectious episode, and only the first isolate was retained for the primary analysis. Polymicrobial cultures were defined as urine cultures yielding exactly two bacterial species, whereas cultures yielding three or more microorganisms were considered contaminated and excluded from the analysis.

2.3. Data Collection

Data were extracted from the institutional laboratory information system (Clinidata[®] XXI, Maxdata) and anonymized before analysis.

The following variables were collected:

- Age;
- Sex;
- Date of sample collection;
- Healthcare setting (Emergency Department, Hospitalization, Outpatient Clinic, Day Hospital, and Other Services);
- Urine collection method;
- Isolated microorganism;
- Antimicrobial susceptibility profile.

Positive urine cultures were defined according to the microbiological criteria routinely adopted by the institution during the study period. Urine collection methods were categorized according to the laboratory record as midstream clean-catch urine, catheter urine, pediatric urine collection, and other documented methods.

2.4. Microbiological Procedures

Urine samples were processed according to the standard operating procedures of the Microbiology Department in a Portuguese tertiary healthcare network, which provides laboratory services for the three hospital units and affiliated primary healthcare facilities within the healthcare network.

Screening of non-pediatric midstream urine samples was performed using the Sysmex UF-5000TM flow cytometry system (Sysmex Corporation, Kobe, Japan) [18]. Samples meeting predefined institutional thresholds for leukocyte and bacterial counts proceeded to urine culture. Pediatric urine samples were routinely cultured regardless of screening results. For non-pediatric samples, urine cultures were performed when the UF-5000 results met the predefined screening thresholds of ≥ 12 leukocytes/ μL and ≥ 283 bacteria/ μL .

Urine cultures were performed on blood agar and cystine–lactose–electrolyte-deficient (CLED) agar and incubated at 37 °C for 18–24 h. Bacterial identification was carried out using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS) on the MicroflexTM platform (Bruker Daltonics, Bremen, Germany) [19]. Species identification was performed using the manufacturer's routinely updated reference database.

Antimicrobial susceptibility testing was performed using the DxM 1096 MicroScan WalkAway system (Beckman Coulter, Brea, CA, USA). When required, susceptibility testing was complemented by the disk diffusion method. Susceptibility results were interpreted according to the European Committee on Antimicrobial Susceptibility Testing (EUCAST) recommendations applicable at the time of testing [20]. The laboratory information system was routinely updated whenever new EUCAST breakpoint versions were implemented, ensuring that susceptibility interpretations reflected the recommendations in force during each study year.

For analyses of pathogen distribution, only monomicrobial positive urine cultures were considered. Polymicrobial cultures were analysed separately because they represent a distinct microbiological entity requiring specific epidemiological interpretation.

For antimicrobial susceptibility analyses, isolates classified as susceptible (S) or resistant (R) according to the applicable EUCAST criteria were included in the calculation of susceptibility and resistance proportions. Isolates classified as susceptible, increased exposure (I) were excluded from these calculations because this category does not represent antimicrobial resistance under current EUCAST definitions.

2.5. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics, version 31.0 (IBM Corp., Armonk, NY, USA). Categorical variables were summarized using absolute frequencies and percentages, while continuous variables were described using means and standard deviations, where appropriate.

Descriptive analyses were used to characterize the distribution of positive urine cultures according to age, sex, healthcare setting, microorganism, polymicrobial status, and antimicrobial susceptibility profile.

Annual distributions of positive urine cultures and principal urinary pathogens were evaluated descriptively to characterize temporal patterns during the study period. No formal inferential trend analysis or multivariable modelling was performed, given the primarily descriptive surveillance objective of the study and the limitations of the available clinical dataset.

2.6. Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of CHUC (267/26 CE).

As the study was retrospective and based exclusively on anonymized laboratory records, the requirement for informed consent was waived by the Ethics Committee.

3. Results

3.1. Study Population

Between January 2020 and December 2025, a total of 165,269 urine samples were processed by the Microbiology Department in a Portuguese tertiary healthcare network. After applying the predefined inclusion and exclusion criteria, 44,596 positive urine cultures corresponding to distinct infectious episodes were included in the study. Of these, 41,555 (93.2%) were monomicrobial cultures and 3041 (6.8%) were polymicrobial cultures. Thus, the overall urine culture positivity rate among eligible samples was 29.8%.

Among patients with positive urine cultures, women accounted for 29,797 cases (66.8%), whereas men accounted for 14,799 (33.2%). The mean age of patients was 63.1 years. Patients aged ≥ 65 years represented the largest age group, accounting for 61.2% of positive cultures, followed by adults aged 15–64 years (approximately 28%) and pediatric patients aged 0–14 years (approximately 11%).

Regarding the healthcare setting, the Emergency Department accounted for 37.7% of positive urine cultures, followed by hospitalization (29.5%) and outpatient clinics (11.1%). The remaining positive cultures originated from other healthcare settings within a Portuguese tertiary healthcare network.

Regarding the urine collection method, midstream clean-catch urine was the predominant method (59.3%), followed by catheterized urine (36.6%). Collection bags and suprapubic aspiration accounted for 3.3% and 0.8% of positive samples, respectively.

The demographic, healthcare setting, and urine collection characteristics of the study population are summarized in Table 1.

Table 1. Demographic and clinical characteristics of patients with positive urine cultures.

Variable	n	%
Positive urine cultures	44,596	100.0
Sex		
Female	29,797	66.8
Male	14,799	33.2
Age group		
Pediatric (0–14 yr)	5044	11.2
Adult (15–64 yr)	12,284	27.6
Geriatric (≥ 65 yr)	27,268	61.2
Healthcare setting		
Emergency Department	16,812	37.7
Hospitalization	13,156	29.5
Other	3434	7.7
Outpatient Clinic	4950	11.1
Pediatric emergency department	2363	5.3
Pediatric Inpatient Ward	1828	4.1
Surgery	2053	4.6
Urine collection method		
Catheter	16,322	36.6
Collection bag	1472	3.3
Midstream clean-catch	26,445	59.3
Suprapubic aspiration	357	0.8

3.2. Distribution of Urinary Pathogens

The distribution of urinary pathogens was evaluated using the 41,555 monomicrobial positive urine cultures included in the study. *Escherichia coli* was the predominant uropathogen, accounting for 20,614 isolates (49.6%). *Klebsiella pneumoniae* was the second most frequently isolated microorganism (7236 isolates; 17.4%), followed by *Proteus mirabilis* (2911; 7.0%), *Enterococcus faecalis* (2205; 5.3%), and *Pseudomonas aeruginosa* (2122; 5.1%). Collectively, these five microorganisms accounted for 84.5% of all monomicrobial positive urine cultures, whereas the remaining microorganisms represented 15.5% of isolates (Table 2).

Table 2. Distribution of the principal microorganisms identified in monomicrobial positive urine cultures (n = 41,555).

Microorganism	n	%
<i>Escherichia coli</i>	20,614	49.6%
<i>Klebsiella pneumoniae</i>	7236	17.4%
<i>Proteus mirabilis</i>	2911	7.0%
<i>Enterococcus faecalis</i>	2205	5.3%
<i>Pseudomonas aeruginosa</i>	2122	5.1%
Others	6467	15.5%
Total	41,555	100.0%

Although *Escherichia coli* predominated across all demographic groups, differences in pathogen distribution were observed according to age and healthcare setting. *Enterococcus faecalis* and *Pseudomonas aeruginosa* were proportionally more frequent among older adults and hospitalized patients, whereas *Escherichia coli* predominated among women and outpatient cultures.

The distribution of the five most frequently isolated urinary pathogens is presented in Table 2.

3.3. Temporal Trends in Positive Urine Cultures

During the six-year study period, the annual contribution of positive urine cultures to the overall study population showed only moderate variation. Of the 44,596 positive urine cultures included in the study, 16.0% were identified in 2020, 18.0% in 2021, 17.4% in 2022, 17.4% in 2023, 14.7% in 2024, and 16.4% in 2025 (Table 3). These values represent the annual distribution of positive urine cultures included in the study and should not be interpreted as annual urine culture positivity rates, as the total number of urine samples processed each year was not available for analysis.

Table 3. Annual distribution of positive urine cultures between 2020 and 2025.

Year	Positive Cultures	% Total
2020	7135	16.0%
2021	8027	18.0%
2022	7760	17.4%
2023	7760	17.4%
2024	6554	14.7%
2025	7314	16.4%
Total	44,596	100%

Overall, the annual distribution remained relatively stable throughout the study period, with no marked increases or decreases in the number of positive urine cultures. Likewise, the microbiological profile remained consistent over time, with *Escherichia coli*

persistently representing the predominant uropathogen, followed by *Klebsiella pneumoniae*, *Proteus mirabilis*, *Enterococcus faecalis*, and *Pseudomonas aeruginosa*. Although minor year-to-year variations were observed, no substantial changes in the overall distribution of the principal urinary pathogens were identified.

3.4. Antimicrobial Resistance Patterns

Antimicrobial resistance profiles varied substantially according to bacterial species and antimicrobial class. Resistance percentages were calculated after exclusion of isolates classified as susceptible, increased exposure (I), according to the applicable EUCAST criteria.

Escherichia coli showed relatively low resistance to fosfomycin (4.1%) and piperacillin/tazobactam (5.2%), while higher resistance proportions were observed for trimethoprim/sulfamethoxazole (30.3%) and ciprofloxacin (26.4%). Resistance to cefotaxime was 14.2%, whereas resistance to amoxicillin/clavulanate reached 28.7%. ESBL-positive isolates accounted for 14.0% of *E. coli* isolates.

Klebsiella pneumoniae demonstrated higher resistance proportions across several antimicrobial classes. Resistance was particularly high for amoxicillin/clavulanate (58.1%), cefotaxime (54.8%), ciprofloxacin (58.2%), and trimethoprim/sulfamethoxazole (59.3%). Resistance to gentamicin and meropenem was 34.1% and 10.2%, respectively, while fosfomycin resistance was 15.7%. ESBL-positive isolates represented 11.8% of *K. pneumoniae* isolates, and carbapenemase-positive isolates accounted for 0.5%.

Proteus mirabilis showed comparatively lower resistance to third-generation cephalosporins, with cefotaxime resistance of 3.9%, while higher resistance was observed for ciprofloxacin (34.0%) and trimethoprim/sulfamethoxazole (31.6%). Resistance to fosfomycin was 14.3% and to amoxicillin/clavulanate 12.1%.

Pseudomonas aeruginosa showed measurable resistance to gentamicin (15.7%) and meropenem (12.6%), while colistin resistance was 2.8%. Results for other antimicrobial agents were not available for verification and were therefore not included in the corresponding analyses.

Enterococcus faecalis showed resistance to trimethoprim/sulfamethoxazole in 75.8% of isolates and to ciprofloxacin in 25.9%, whereas no resistance was observed against amoxicillin/clavulanate or fosfomycin. Resistance to ampicillin was low (1.1%).

Overall, the resistance profiles demonstrated marked species-specific differences, emphasizing the importance of pathogen-specific antimicrobial susceptibility data when informing empirical treatment and antimicrobial stewardship strategies. The presence of ESBL- and carbapenemase-positive isolates, particularly among Enterobacterales, further supports the need for continuous local surveillance of antimicrobial resistance (Table 4).

Table 4. Antimicrobial resistance profiles (%) of the principal uropathogens isolated from monomicrobial urine cultures. Resistance percentages were calculated after exclusion of isolates classified as susceptible, increased exposure (I), according to EUCAST recommendations.

Antimicrobial	<i>E. faecalis</i>	<i>E. coli</i>	<i>K. pneumoniae</i>	<i>P. mirabilis</i>	<i>P. aeruginosa</i>
β-lactams					
Ampicillin	1.1	52.7	—	—	—
Amoxicillin/clavulanate	0.0	28.7	58.1	12.1	—
Cefotaxime	—	14.2	54.8	3.9	—
Piperacillin/tazobactam	—	5.2	35.0	1.3	—
Carbapenems					
Imipenem	—	0.2	6.6	0.6	—
Meropenem	—	0.2	10.2	0.2	12.6
Fluoroquinolones					
Ciprofloxacin	25.9	26.4	58.2	34.0	—
Aminoglycosides					

Table 4. Cont.

Antimicrobial	<i>E. faecalis</i>	<i>E. coli</i>	<i>K. pneumoniae</i>	<i>P. mirabilis</i>	<i>P. aeruginosa</i>
Gentamicin	—	14.1	34.1	17.7	15.7
Urinary agents					
Fosfomycin	0.0	4.1	15.7	14.3	—
Trimethoprim/sulfamethoxazole	75.8	30.3	59.3	31.6	62.6
Other agents					
Colistin	—	—	—	—	2.8
Tigecycline	0.8	0.1	1.8	—	—
Resistance mechanisms					
ESBL-positive	—	14.0	11.8	0.2	—
Carbapenemase-positive	—	<0.1	0.5	—	—

— Data unavailable for verification and therefore excluded from the analysis.

3.5. Polymicrobial Infections

Among the 44,596 positive urine cultures included in the study, 3041 were polymicrobial, corresponding to 6.8% of all positive cultures. According to the predefined study criteria, polymicrobial cultures were defined as cultures yielding exactly two bacterial species, whereas cultures yielding three or more microorganisms were excluded as probable contaminants.

Polymicrobial cultures were observed across the different age groups and healthcare settings, with a higher proportion occurring among older patients and those hospitalized. This finding is consistent with the greater clinical and microbiological complexity commonly observed in these populations.

Overall, monomicrobial cultures predominated, accounting for 41,555 cultures (93.2%), whereas polymicrobial cultures represented 3041 cultures (6.8%). Polymicrobial cultures were analysed separately from monomicrobial cultures because the presence of two bacterial species may reflect a distinct microbiological context and may complicate the interpretation of pathogen-specific antimicrobial susceptibility patterns.

4. Discussion

This study provides one of the largest longitudinal epidemiological analyses of urinary tract infections conducted in Portugal, comprising 44,596 positive urine cultures collected over a six-year period within a tertiary healthcare network. To our knowledge, this is the first large-scale longitudinal study describing the epidemiology of urinary tract infections and antimicrobial resistance within the Portuguese tertiary healthcare network. By integrating demographic characteristics, healthcare setting, pathogen distribution, polymicrobial infections, and antimicrobial susceptibility profiles, this study offers a comprehensive overview of the current epidemiology of UTIs and provides clinically relevant data to support microbiological surveillance, empirical antimicrobial therapy, and antimicrobial stewardship programmes. Furthermore, the inclusion of patients from primary care, emergency departments, and hospitalized settings allows a broader characterization of UTIs across different levels of healthcare [21–24].

The predominance of women observed in this study is consistent with the extensive international literature and reflects the well-established anatomical and physiological factors that facilitate bacterial colonization and ascending urinary tract infection [25,26]. Hormonal influences, sexual activity, pregnancy, and the shorter female urethra remain important determinants of the higher incidence of UTIs among women. Although pregnant women constitute a particularly vulnerable population due to physiological and immunological changes that increase susceptibility to infection, pregnancy-specific analyses were beyond

the scope of the present study, despite approximately 1.4% of urine cultures originating from obstetric departments or obstetric emergency services [27].

Despite the higher overall frequency of UTIs among women, male patients demonstrated greater microbiological diversity, particularly among older individuals and hospitalized patients. This observation is consistent with previous studies showing that UTIs in men are more frequently associated with structural urinary tract abnormalities, urinary catheterization, benign prostatic hyperplasia, recurrent infections, and other complicated clinical conditions that favour colonization by a broader range of microorganisms [28–30].

One of the most relevant findings of the present study was the substantial contribution of older adults to the overall burden of UTIs. More than half of all positive urine cultures were identified in patients aged 65 years or older, emphasizing the growing impact of population ageing on urinary tract infection epidemiology. Age-related functional changes in the urinary tract, higher prevalence of chronic diseases, increased exposure to healthcare environments, institutionalization, urinary catheterization, and repeated antimicrobial exposure are likely to contribute to this phenomenon [31–33]. As life expectancy continues to increase, healthcare systems should anticipate a progressive rise in complicated UTIs and infections caused by multidrug-resistant microorganisms.

These findings are particularly relevant in Portugal, one of the European countries with the oldest populations, where demographic ageing is expected to further increase the burden of urinary tract infections in the coming decades.

Escherichia coli remained the predominant uropathogen throughout the entire study period, confirming its central role in both community-acquired and healthcare-associated urinary tract infections. This finding is fully consistent with previous Portuguese studies and with international surveillance reports, where *E. coli* typically accounts for approximately half of all urinary isolates [21–24,34–36]. Nevertheless, the substantial contribution of *Klebsiella pneumoniae*, *Proteus mirabilis*, *Enterococcus faecalis*, and *Pseudomonas aeruginosa* highlights the increasing microbiological complexity of UTIs, particularly among elderly patients and those receiving hospital care [35–39]. The greater representation of these opportunistic pathogens reinforces the importance of considering patient characteristics and healthcare setting when selecting empirical antimicrobial therapy.

The antimicrobial susceptibility results further illustrate the evolving challenges associated with the empirical management of urinary tract infections. *Escherichia coli* maintained excellent susceptibility to fosfomycin and low resistance to carbapenems, supporting the continued use of these agents when clinically indicated. Conversely, resistance to fluoroquinolones and trimethoprim–sulfamethoxazole remained substantial, reflecting the sustained selective pressure associated with the widespread use of these antimicrobials in both community and hospital settings [40–46]. These findings reinforce current antimicrobial stewardship recommendations advocating the prudent use of broad-spectrum antibiotics and the continuous updating of local empirical treatment guidelines.

A notable finding was the less favourable susceptibility profile observed for *Klebsiella pneumoniae*, which demonstrated considerably higher resistance to several antimicrobial classes compared with *E. coli*. These differences highlight that resistance surveillance should not be interpreted exclusively at the institutional level but should also consider species-specific susceptibility patterns. Local antibiograms remain fundamental tools for guiding empirical therapy and minimizing inappropriate antimicrobial exposure.

The detection of extended-spectrum β -lactamase (ESBL)-producing Enterobacterales deserves particular attention. ESBL production substantially limits the effectiveness of third-generation cephalosporins and is frequently associated with multidrug resistance, resulting in fewer therapeutic options and increased clinical complexity. Although the prevalence observed in the present study is comparable to that reported in previous Portuguese

investigations, continuous surveillance remains essential to monitor the dissemination of these resistant organisms and support infection prevention strategies [40–46].

These findings support the recommendation that empirical treatment protocols should rely on updated local surveillance data rather than extrapolation from national or international averages.

Another important aspect of the present study was the identification of more than three thousand polymicrobial urinary tract infections. Although monomicrobial infections remained predominant, polymicrobial cultures represented a substantial proportion of positive urine cultures and were more frequently associated with elderly patients and healthcare-associated settings. These infections frequently reflect complex clinical scenarios, including urinary catheterization, structural urinary tract abnormalities, recurrent infections, or prolonged healthcare exposure. Future studies integrating microbiological findings with detailed clinical information will be important to better understand their prognostic significance and optimize their clinical management [46–48].

From a public health perspective, continuous microbiological surveillance remains essential to monitor changes in pathogen distribution and antimicrobial resistance over time [49,50]. Large laboratory-based surveillance studies provide robust evidence to support empirical prescribing policies, antimicrobial stewardship programmes, and infection prevention initiatives. In the context of increasing antimicrobial resistance and progressive population ageing, longitudinal epidemiological analyses such as the present study constitute valuable tools for improving healthcare quality and informing public health decision-making [51–53].

The principal strengths of this study include its exceptionally large sample size, the six-year observation period, standardized microbiological procedures, and the inclusion of patients from multiple healthcare settings within a tertiary healthcare network. Together, these characteristics provide a robust and representative overview of the contemporary epidemiology of urinary tract infections in central Portugal.

This study also presents several limitations. Its retrospective observational design precluded the inclusion of detailed clinical information, including urinary catheterization, previous antimicrobial exposure, comorbidities, clinical severity, and patient outcomes, which could further improve the interpretation of microbiological findings. In addition, antimicrobial susceptibility results were interpreted according to the EUCAST recommendations applicable at the time of testing, reflecting routine clinical practice. Because individual MIC values were not available, retrospective reinterpretation using a single EUCAST version across the entire study period was not feasible. Because the analysis was primarily descriptive, formal multivariable modelling and inferential trend analyses were not performed. Residual confounding inherent to observational laboratory-based studies cannot therefore be excluded.

Overall, the large longitudinal database established in this study provides an important platform for future investigations. Further analyses focusing on pathogen-specific epidemiology, multidrug-resistant organisms, healthcare-associated urinary tract infections, polymicrobial infections, temporal prediction models, and machine learning approaches may further improve our understanding of urinary tract infections and contribute to more personalized strategies for empirical antimicrobial therapy. The present study should be interpreted as a laboratory-based epidemiological surveillance study rather than a patient-level clinical outcome study.

5. Conclusions

Urinary tract infections remain a major clinical and public health challenge, particularly in ageing populations with increasing exposure to healthcare services. In this six-year

analysis of 44,596 positive urine cultures from a large Portuguese healthcare network, *Escherichia coli* remained the predominant uropathogen, while *Klebsiella pneumoniae*, *Proteus mirabilis*, *Enterococcus faecalis*, and *Pseudomonas aeruginosa* also contributed substantially to the overall burden of infection, particularly among older adults and hospitalized patients. The identification of 3041 polymicrobial cultures further emphasizes the complexity of urinary tract infections in routine clinical practice.

The antimicrobial susceptibility findings reinforce the importance of continuous local surveillance and species-specific interpretation of resistance patterns. Although several first-line antimicrobials maintained favorable activity against the principal uropathogens, the persistence of resistance to commonly prescribed agents and the presence of ESBL-producing isolates highlight the need for evidence-based empirical therapy and sustained antimicrobial stewardship programmes. Regular updating of local antibiograms remains essential to optimize antimicrobial prescribing and support clinical decision-making.

Overall, this study provides one of the largest longitudinal descriptions of urinary tract infection epidemiology performed in Portugal and offers a comprehensive overview of pathogen distribution and antimicrobial resistance within a tertiary healthcare network. These findings provide valuable evidence for clinicians, microbiology laboratories, and public health authorities, while establishing a robust foundation for future studies integrating microbiological surveillance with clinical characteristics, antimicrobial exposure, urinary catheterization, recurrence, and patient outcomes.

Author Contributions: Conceptualization, P.C. and F.R.; methodology, P.C., S.M. and J.M.; validation, C.C.; formal analysis and data curation, P.C.; investigation, S.L. and J.M.; writing—original draft preparation, S.L., S.M. and J.M.; writing—review and editing, F.R. and C.C.; visualization, P.C.; supervision, F.R.; project administration, F.R. All authors have read and agreed to the published version of the manuscript.

Funding: SPRINT: Sport Physical Activity and Health Research & Innovation Center; Centro de Investigação & Inovação em Desporto Atividade Física e Saúde; Portugal; FCT: Fundação para a Ciência e a Tecnologia; Portuguese Foundation for Science and Technology; UID/06185/2025 (<https://doi.org/10.54499/UID/06185/2025>); UID/PRR/06185/2025 (<https://doi.org/10.54499/UID/PRR/06185/2025>); UID/PRR2/06185/2025.

Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of CHUC (267/26 CE) for studies involving humans on 26 May 2026.

Informed Consent Statement: Patient consent was waived due to the retrospective observational design of the study and the use of anonymized laboratory data collected during routine clinical care, with no direct patient contact and no impact on patient management.

Data Availability Statement: The datasets generated and analysed during the current study are not publicly available because they contain institutional clinical data but are available from the corresponding author upon reasonable request and subject.

Acknowledgments: The authors thank the clinical, laboratory, and administrative teams involved in urine sample processing, microbiological diagnosis, and data management during the study period.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Siddiqui, N.Y.; Bradley, M.S. Updates in clinical management of recurrent urinary tract infections. *Obstet. Gynecol.* **2025**, *146*, 631–644. [[CrossRef](#)] [[PubMed](#)]
2. Aggarwal, N.; Leslie, S.W. Recurrent urinary tract infections. In *StatPearls*; StatPearls Publishing: Treasure Island, FL, USA, 2025.

3. Ibrahim, A.I.A.; Abdelgyoum, H.A.; Elfaki, N.S.; Elbadawi, M.H.; Kashif, E. Bacterial etiology of urinary tract infections and their sensitivity patterns towards commonly used antibiotics in Port Sudan City, Sudan: A retrospective study. *BMC Infect. Dis.* **2025**, *25*, 1017. [[CrossRef](#)] [[PubMed](#)]
4. Liu, X.; Kamperman, M. Smart bacteria-responsive coatings for combating catheter-associated urinary tract infections. *Mater. Today Bio* **2025**, *34*, 102191. [[CrossRef](#)] [[PubMed](#)]
5. Leung, V.K.Y.; Hubbard, K.; Orr, E.; Marshall, C. Surveillance of catheter-associated urinary tract infections at an Australian tertiary hospital, 2024–2025. *Infect. Dis. Health* **2026**, *31*, 100444. [[CrossRef](#)] [[PubMed](#)]
6. Gottlieb, M.; Amponsah, T.; Bernard, K.; Moyer, E. Epidemiology of urinary tract infections in adults among United States emergency departments from 2016 to 2023. *Am. J. Emerg. Med.* **2025**, *93*, 7–12. [[CrossRef](#)] [[PubMed](#)]
7. Hu, Y.; Ma, W.; Tang, K.; Qi, Q.; Xu, W.; Hu, R.; Liu, S.; Zhang, K.; Chen, J.; Liang, C. Global burden of urinary tract infections in older women from 1990 to 2021 with projections to 2040: A trend analysis of the Global Burden of Disease Study 2021. *Front. Cell. Infect. Microbiol.* **2025**, *15*, 1577777. [[CrossRef](#)] [[PubMed](#)]
8. Souiden, L.; Tu, L.M.; Bordeleau, M.; Laberge, G.; Richard, P.O.; Ismail, S. Prevalence and predictive factors of complicated urinary tract infections post bladder and prostate transurethral resections. *World J. Urol.* **2025**, *43*, 398. [[CrossRef](#)] [[PubMed](#)]
9. Khateb, A.M.; Alamri, L.S.; Alseyoufi, W.A.; Almusaiferi, Y.H.; Safdar, O.Y. Epidemiology of fungal urinary tract infections: A retrospective case series. *New Microbes New Infect.* **2025**, *68*, 101657. [[CrossRef](#)] [[PubMed](#)]
10. Rodrigues, F.J.; Barroso, A.P.D. Etiology and bacterial susceptibility to urinary tract infections. *Rev. Port. Saude Publica* **2011**, *29*, 123–131.
11. Ackerman, A.L.; Bradley, M.; D’Anci, K.E.; Hickling, D.; Kim, S.K.; Kirkby, E. Updates to Recurrent Uncomplicated Urinary Tract Infections in Women: AUA/CUA/SUFU Guideline (2025). *J. Urol.* **2026**, *215*, 3–12. [[CrossRef](#)] [[PubMed](#)]
12. Rodrigues, F.; Coelho, P.; Mateus, S.; Caseiro, A.; Eideh, H.; Gonçalves, T.; Branco, M.C. Decoding urinary tract infection trends: A 5-year snapshot from Central Portugal. *Clin. Pract.* **2025**, *15*, 14. [[CrossRef](#)] [[PubMed](#)]
13. Mohan, V.; Mitsakakis, K. Diagnostic tests for urinary tract infections and antimicrobial resistance—a reality check between diagnostic innovation and implementation: A critical narrative review. *Front. Cell. Infect. Microbiol.* **2026**, *16*, 1784139. [[CrossRef](#)] [[PubMed](#)]
14. Park, P.G.; Lim, S.H.; Song, J.Y.; Ahn, Y.H.; Kim, S.H.; Kang, H.G. Trends in antibiotic resistance of urinary tract infections in young children, 2010–2023. *Pediatr. Neonatol.* **2026**, *67*, 32–37. [[CrossRef](#)] [[PubMed](#)]
15. Adnan, M.; Coelho, P.M.S.C.; Castelo-Branco, M.D.S.; Rodrigues, F.J. Prevalence, determinants, and temporal dynamics of multidrug-resistant Gram-negative bacilli in urinary tract infection patients from Central Portugal (2018–2022). *Bacteria* **2026**, *5*, 8. [[CrossRef](#)]
16. Rizvi, M.; Khan, M.; Al-Jardani, A.; Al-Abri, S.S.; Ghoshal, U.; Al Jabri, Z.; Ahanjan, M.; Al Mamari, A.; Al Shizawi, N.; Sami, H.; et al. Mapping antimicrobial susceptibility of community-acquired uropathogenic *Escherichia coli* across low, middle and high-income countries highlights significant differences: Insights for empiric treatment. *IJID Reg.* **2025**, *16*, 100706. [[CrossRef](#)] [[PubMed](#)]
17. Rodrigues, F.J.; Coelho, P.M.S.C.; Mateus, S.M.F.; Castelo-Branco, M. Rising threats and evolving trends: Five years of urinary tract infection prevalence in a Portuguese hospital. *Clin. Pract.* **2025**, *15*, 100. [[CrossRef](#)] [[PubMed](#)]
18. Fujioka, A.; Nagashima, K.; Hoshi, M.; Sakurai, M.; Higashimoto, Y.; Ito, H. Comparison of bacterial detection performance between UF-5000 and USCANNER(E) based on urine culture. *Diagn. Microbiol. Infect. Dis.* **2026**, *116*, 117455. [[CrossRef](#)] [[PubMed](#)]
19. Castaño, M.J.; Torres, I.; Villarruel, K.M.; Navarro, D. Flow cytometry parameters for predicting the successful identification of gram-negative bacilli in urine by MALDI-TOF MS. *Diagn. Microbiol. Infect. Dis.* **2026**, *115*, 117303. [[CrossRef](#)] [[PubMed](#)]
20. Giske, C.G.; Turnidge, J.; Cantón, R.; Kahlmeter, G.; EUCAST Steering Committee. Update from the European Committee on Antimicrobial Susceptibility Testing (EUCAST). *J. Clin. Microbiol.* **2022**, *60*, e0027621. [[CrossRef](#)] [[PubMed](#)]
21. Zhou, Y.; Zhou, Z.; Zheng, L.; Gong, Z.; Li, Y.; Jin, Y.; Huang, Y.; Chi, M. Urinary Tract Infections Caused by Uropathogenic *Escherichia coli*: Mechanisms of Infection and Treatment Options. *Int. J. Mol. Sci.* **2023**, *24*, 10537. [[CrossRef](#)] [[PubMed](#)]
22. Murray, B.O.; Flores, C.; Williams, C.; Flusberg, D.A.; Marr, E.E.; Kwiatkowska, K.M.; Charest, J.L.; Isenberg, B.C.; Rohn, J.L. Recurrent Urinary Tract Infection: A Mystery in Search of Better Model Systems. *Front. Cell. Infect. Microbiol.* **2021**, *11*, 691210. [[CrossRef](#)] [[PubMed](#)]
23. Lee, D.S.; Lee, S.J.; Choe, H.S. Community-Acquired Urinary Tract Infection by *Escherichia coli* in the Era of Antibiotic Resistance. *BioMed Res. Int.* **2018**, *2018*, 7656752. [[CrossRef](#)] [[PubMed](#)]
24. Branco, M.C.; Coelho, P.M.S.C.; Rodrigues, F.J. Urinary tract infections in a single hospital in Central Portugal, a 5-year analysis. *Microbiol. Res.* **2024**, *15*, 850–863. [[CrossRef](#)]
25. Gupta, K.; Stamm, W.E. Pathogenesis and management of recurrent urinary tract infections in women. *World J. Urol.* **1999**, *17*, 415–420. [[CrossRef](#)] [[PubMed](#)]
26. Kodner, C.M.; Thomas Gupton, E.K. Recurrent urinary tract infections in women: Diagnosis and management. *Am. Fam. Physician* **2010**, *82*, 638–643. [[PubMed](#)]

27. Rodrigues, F.; Coelho, P.; Mateus, S.; Eideh, H.; Gonçalves, T.; Caseiro, A.; Branco, M.C. Rising trends of urinary infections among pregnant women: Insights from a Portuguese hospital (2018–2022). *Bacteria* **2025**, *4*, 10. [[CrossRef](#)]
28. Madersbacher, S.; Pycha, A.; Schatzl, G.; Mian, C.; Klingler, C.H.; Marberger, M. The aging lower urinary tract: A comparative urodynamic study of men and women. *Urology* **1998**, *51*, 206–212. [[CrossRef](#)] [[PubMed](#)]
29. Saint, S.; Chenoweth, C.E. Biofilms and catheter-associated urinary tract infections. *Infect. Dis. Clin. N. Am.* **2003**, *17*, 411–432. [[CrossRef](#)] [[PubMed](#)]
30. Kuo, H.C. Pathophysiology of lower urinary tract symptoms in aged men without bladder outlet obstruction. *Urol. Int.* **2000**, *64*, 86–92. [[CrossRef](#)] [[PubMed](#)]
31. Karim, F.; Rantell, A. Understanding the basic assessment and treatment of lower urinary tract symptoms in older women. *Nurs. Older People* **2021**, *33*, 33–41. [[CrossRef](#)] [[PubMed](#)]
32. Bardsley, A. Diagnosis, prevention and treatment of urinary tract infections in older people. *Nurs. Older People* **2017**, *29*, 32–38. [[CrossRef](#)] [[PubMed](#)]
33. Oelke, M.; Becher, K.; Castro-Diaz, D.; Chartier-Kastler, E.; Kirby, M.; Wagg, A.; Wehling, M. Appropriateness of oral drugs for long-term treatment of lower urinary tract symptoms in older persons: Results of a systematic literature review and international consensus validation process (LUTS-FORTA 2014). *Age Ageing* **2015**, *44*, 745–755. [[CrossRef](#)] [[PubMed](#)]
34. Behzad, D.; Hakimeh, A.; Hossein, R.; Khaledi, A. A middle east systematic review and meta-analysis of bacterial urinary tract infection among renal transplant recipients; Causative microorganisms. *Microb. Pathog.* **2020**, *148*, 104458. [[CrossRef](#)] [[PubMed](#)]
35. Abraham, S.N.; Miao, Y. The nature of immune responses to urinary tract infections. *Nat. Rev. Immunol.* **2015**, *15*, 655–663. [[CrossRef](#)] [[PubMed](#)]
36. Korkmazer, R.; Kayaaslan, B.; Kaya-Kalem, A.; Oktay, Z.; Eser, F.; Hasanoglu, I.; Güner, R. Causative Microorganisms in Community-Acquired Urinary Tract Infections and Risk Factors for the Development of Infection with Extended-Spectrum β -Lactamase-Producing Species. *Infect. Dis. Clin. Microbiol.* **2024**, *6*, 112–122. [[CrossRef](#)] [[PubMed](#)]
37. Szczerbic, D.; Bednarska-Szczepaniak, K.; Torzewska, A. Antibacterial properties and urease suppression ability of *Lactobacillus* inhibit the development of infectious urinary stones caused by *Proteus mirabilis*. *Sci. Rep.* **2024**, *14*, 943. [[CrossRef](#)] [[PubMed](#)]
38. Radu, V.D.; Costache, R.C.; Onofrei, P.; Miron, A.; Bandac, C.-A.; Arseni, D.; Mironescu, M.; Miftode, R.-S.; Boiculese, L.V.; Miftode, I.-L. Urinary Tract Infections with Carbapenem-Resistant *Klebsiella pneumoniae* in a Urology Clinic-A Case-Control Study. *Antibiotics* **2024**, *13*, 583. [[CrossRef](#)] [[PubMed](#)]
39. Meschiari, M.; Asquier-Khati, A.; Tiseo, G.; Luque-Paz, D.; Murri, R.; Boutoille, D.; Falcone, M.; Mussini, C.; Tattevin, P. Treatment of infections caused by multidrug-resistant Gram-negative bacilli: A practical approach by the Italian (SIMIT) and French (SPILF) Societies of Infectious Diseases. *Int. J. Antimicrob. Agents* **2024**, *64*, 107186. [[CrossRef](#)] [[PubMed](#)]
40. Doesschate, T.T.; Hendriks, K.; van Werkhoven, C.H.; van der Hout, E.C.; Platteel, T.N.; Groenewegen, I.A.; Muller, A.E.; Hoepelman, A.I.; Bonten, M.J.; Geerlings, S.E. Nitrofurantoin 100 mg versus 50 mg prophylaxis for urinary tract infections, a cohort study. *Clin. Microbiol. Infect.* **2022**, *28*, 248–254. [[CrossRef](#)] [[PubMed](#)]
41. Llor, C.; Monfà, R.; Garcia-Sangenís, A.; Leiva, A.; Marín-Cañada, J.; Sánchez-Calavera, M.A.; Moragas, A.; Aguilar-Sánchez, M.; Troncoso-Mariño, A.; Rodríguez-Barrientos, R.; et al. Clinical and bacteriological effectiveness of three different short-course antibiotic regimens and single-dose fosfomycin for uncomplicated lower urinary tract infections in women (SCOUT): A pragmatic, multicentre, open-label, randomised clinical trial. *Lancet* **2026**, *407*, 1603–1613. [[CrossRef](#)] [[PubMed](#)]
42. Shariati, A.; Arshadi, M.; Khosrojerdi, M.A.; Abedinzadeh, M.; Ganjalishahi, M.; Maleki, A.; Heidary, M.; Khoshnood, S. The resistance mechanisms of bacteria against ciprofloxacin and new approaches for enhancing the efficacy of this antibiotic. *Front. Public Health* **2022**, *10*, 1025633. [[CrossRef](#)] [[PubMed](#)]
43. Drekonja, D.M.; Trautner, B.; Amundson, C.; Kuskowski, M.; Johnson, J.R. Effect of 7 vs 14 Days of Antibiotic Therapy on Resolution of Symptoms Among Afebrile Men With Urinary Tract Infection: A Randomized Clinical Trial. *JAMA* **2021**, *326*, 324–331. [[CrossRef](#)] [[PubMed](#)]
44. Veillette, J.J.; May, S.S.; Alzaidi, S.; Olson, J.; Butler, A.M.; Waters, C.D.; Jackson, K.; Hutton, M.A.; Webb, B.J. Real-World Effectiveness of Intravenous and Oral Antibiotic Stepdown Strategies for Gram-Negative Complicated Urinary Tract Infection With Bacteremia. *Open Forum Infect. Dis.* **2024**, *11*, ofae193. [[CrossRef](#)] [[PubMed](#)]
45. Coyne, A.J.K.; Bouchard, J.; Durham, S.H.; Kang, A.Y.; Johannemann, K.M.; Moore, W.J.; Nguyen, K.; Sanders, J.; Sheveland, C.; Stimes, G.; et al. Oral β -Lactams for Complicated Urinary Tract Infections: A Systematic Review and Point-Counterpoint Comparison With Trimethoprim/Sulfamethoxazole and Fluoroquinolones. *Pharmacotherapy* **2026**, *46*, e70118. [[CrossRef](#)] [[PubMed](#)]
46. Huntsman, A.R.; Squires, C.J.; Dray Vongspanich, J.; Duby, J.J. Comparative Risk of Acute Anemia and Urinary Tract Infection With Sulfamethoxazole-Trimethoprim Versus Dapsone After Kidney Transplant. *Ann. Pharmacother.* **2026**, *60*, 693–699. [[CrossRef](#)]
47. Zou, Z.; Pinkner, J.S.; Obernuefemann, C.L.P.; Kleinschmidt, K.R.; Sanick, D.A.; Hickerson, S.M.; Dodson, K.W.; Henderson, J.P.; Hultgren, S.J.; Caparon, M.G. Metabolic cross-talk promotes persistence of *Enterococcus* in a model of polymicrobial catheter-associated urinary tract infection. *Sci. Adv.* **2026**, *12*, eade0675. [[CrossRef](#)] [[PubMed](#)]

48. Medina, A.A.; Ojeda, C.M.; Subiela, J.D.; Curtis, D.L.; Gutiérrez, A.D.; Tojeiro, S.C.; Sánchez, I.D.L.P.; Cidre, M.Á.J.; Dos Santos, V.G.; Revilla, F.J.B. A systematic review and meta-analysis evaluating the incidence, microbiological profile and risk factors associated with urinary tract infection after radical cystectomy. *Urol. Oncol.* **2026**, *44*, 12–26. [[CrossRef](#)] [[PubMed](#)]
49. McEwen, S.A.; Collignon, P.J. Antimicrobial Resistance: A One Health Perspective. *Microbiol. Spectr.* **2018**, *6*. [[CrossRef](#)] [[PubMed](#)]
50. Collignon, P.J.; McEwen, S.A. One Health-Its Importance in Helping to Better Control Antimicrobial Resistance. *Trop. Med. Infect. Dis.* **2019**, *4*, 22. [[CrossRef](#)] [[PubMed](#)]
51. Panackal, A.A.; M'ikanatha, N.M.; Tsui, F.-C.; McMahon, J.; Wagner, M.M.; Dixon, B.W.; Zubieta, J.; Phelan, M.; Mirza, S.; Morgan, J.; et al. Automatic electronic laboratory-based reporting of notifiable infectious diseases at a large health system. *Emerg. Infect. Dis.* **2002**, *8*, 685–691. [[CrossRef](#)] [[PubMed](#)]
52. Wurtz, R.; Cameron, B.J. Electronic laboratory reporting for the infectious diseases physician and clinical microbiologist. *Clin. Infect. Dis.* **2005**, *40*, 1638–1643. [[CrossRef](#)] [[PubMed](#)]
53. Moja, L.; Zanichelli, V.; Mertz, D.; Gandra, S.; Cappello, B.; Cooke, G.S.; Chuki, P.; Harbarth, S.; Pulcini, C.; Mendelson, M.; et al. WHO's essential medicines and AWaRe: Recommendations on first- and second-choice antibiotics for empiric treatment of clinical infections. *Clin. Microbiol. Infect.* **2024**, *30*, S1–S51. [[CrossRef](#)] [[PubMed](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.