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Antimicrobial Resistance in Kidney Stone Disease: A Scoping Review of Microbiological Patterns, Culture Discordance, and Stewardship Implications

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Abstract

Kidney stone disease (KSD) is a recurrent condition frequently managed with endourological procedures and drainage devices, resulting in repeated exposure to urinary tract instrumentation, microbiological testing, and antibiotics. This clinical ecology may promote antimicrobial resistance (AMR) and complicate the prevention and treatment of stone-associated infections. This scoping review mapped contemporary evidence on AMR in KSD, with particular attention to resistance phenotypes, microbiological sampling strategies, higher-risk clinical contexts, and antimicrobial stewardship (AMS) implications. A PubMed-based scoping review was conducted of English-language studies published between 2016 and 2025 that reported AMR outcomes in KSD or its management. Data charted included clinical context, sampling source, organism profile, resistance phenotype, and stewardship-relevant reporting. Thirty-one studies were included. The evidence base was dominated by non-procedural epidemiological studies and procedural series, particularly percutaneous nephrolithotomy, with fewer studies in ureteroscopy, retrograde intrarenal surgery, and drainage- or device-related pathways. Resistant Gram-negative uropathogens were prominent. Multidrug-resistant and extended-spectrum beta-lactamase-producing Enterobacterales were the most frequently reported phenotypes, whereas fluoroquinolone resistance, extensively drug-resistant phenotypes, and carbapenem-resistant Enterobacterales were less commonly reported but remained clinically important. Several studies reported discordance between bladder urine cultures and renal pelvic urine or stone cultures, supporting the concept of stones as protected microbial reservoirs and highlighting the limitations of relying on midstream urine alone for microbiological risk estimation. Higher AMR burden clustered in recurrent stone disease, prior antibiotic exposure, indwelling devices, obstruction requiring urgent decompression, and more complex procedures, especially percutaneous nephrolithotomy. Only a minority of studies explicitly reported stewardship-oriented measures. Overall, KSD should be recognised as an AMR-prone clinical ecology in which resistance-aware risk stratification, targeted sampling, locally informed prophylaxis, and minimisation of unnecessary antibiotic exposure are more consistently embedded within clinical pathways.

Keywords

Kidney Stone Disease, Antimicrobial Resistance, Kidney Stone Management, Urinary Tract Infection, Stone-Associated Infection

1. Introduction

Kidney stone disease (KSD; urolithiasis) is a common and increasingly recognised chronic, relapsing condition with substantial clinical and health-system implications. Epidemiological syntheses have estimated lifetime risk at approximately 10% - 12% in many high-income settings, with rising incidence and disease burden also reported across several low- and middle-income regions [1] [2]. Beyond the acute morbidity of renal colic, KSD is associated with recurrent emergency presentations, repeated procedural interventions, impaired health-related quality of life, and considerable healthcare expenditure at population level [3]. Stone formation is bio-logically multifactorial, arising through processes of urinary supersaturation, nucleation, crystal growth, aggregation, and retention within the urinary tract. These processes are shaped by metabolic predisposition, dietary exposures, anatomical variation, and environmental influences such as dehydration and heat stress [1]. In addition, the heterogeneity of stone composition, including calcium oxalate, calcium phosphate, uric acid, struvite, and cystine calculi, contributes to marked variation in clinical phenotype, recurrence trajectory, and therapeutic approach [1] [3].

At the same time, the management of KSD has undergone a sustained transition from open surgery towards minimally invasive and non-invasive approaches. Contemporary guidance positions percutaneous nephrolithotomy (PCNL) as a first-line intervention for large-volume, complex, and staghorn calculi, whereas ureteroscopy and retrograde intrarenal surgery (URS/RIRS) have become central to the management of a broad spectrum of ureteric and intrarenal stones, facilitated by advances in endoscopic instrumentation and laser lithotripsy [4] [5]. Shock wave lithotripsy (SWL) remains an established non-invasive option for selected stones, although its relative utilisation has evolved alongside the expansion of endourological capability [4] [5]. In selected anatomical or reconstructive contexts, laparoscopic or robotic approaches may still be considered, while medical expulsive therapy and chemolysis for uric acid stones provide non-procedural management options in appropriately selected cases [4]. Although these developments have improved stone-free rates and reduced recovery times, they have also increased the frequency of urinary tract instrumentation, irrigation, stone fragmentation, and temporary drainage device use, including ureteric stents and nephrostomy catheters [5].

These procedural realities are clinically important because KSD care pathways intersect repeatedly with infection risk and antimicrobial exposure. Instrumentation and manipulation of the urinary tract may disrupt mucosal barriers, mobilise adherent or stone-embedded organisms, and create conditions conducive to colonisation and infection, particularly in the presence of obstruction, residual fragments, or indwelling devices [5]. In routine practice, patients may accumulate antimicrobial exposure over time through peri-operative prophylaxis, empirical or targeted treatment of symptomatic urinary tract infection (UTI) or urosepsis, and post-procedural prescribing related to devices, recurrent symptoms, or perceived microbiological risk [5] [6]. This cumulative exposure, combined with repeated healthcare contact, creates a plausible eco-logical environment for the selection and amplification of antimicrobial resistance (AMR), with downstream consequences for both patient safety and antimicrobial stewardship (AMS) [7] [8]. In this review, the term "AMR-prone clinical ecology" is used to denote a recurrent care environment in which repeated instrumentation, device exposure, microbiological testing, and cumulative antibiotic use create sustained opportunities for the selection, persistence, and clinical expression of resistant organisms. The term "stewardship signals" is used to refer to explicit or implicit findings relevant to antimicrobial optimisation, including culture-guided prescribing, prophylaxis tailoring, duration minimisation, de-escalation, and antibiotic-sparing approaches.

The interface between KSD and infection is biologically complex and extends beyond the classical paradigm of "infection stones". Struvite and carbonate apatite calculi are traditionally associated with urease-producing organisms, particularly Proteus mirabilis, which hydrolyse urea, increase urinary pH, and promote precipitation of magnesium ammonium phosphate and related mineral phases [9] [10]. However, emerging evidence suggests that microbial involvement in KSD is not confined to these stone types or to superficial colonisation alone. Prospective and observational studies have demonstrated that microorganisms may be detected within the stone matrix itself and may persist despite apparently appropriate antimicrobial therapy, thereby providing a mechanistic basis for recurrent infection and for negative midstream urine cultures that underestimate true microbial burden [11] [12]. More recent work on the urinary microbiome and stone-microbe interactions further supports a continuum model in which microbial communities may be present across multiple stone phenotypes and may contribute to inflammation, persistence, and recurrence dynamics, although causality and biological directionality remain incompletely resolved [10] [13].

From a clinical standpoint, AMR is increasingly encountered within urological infection pathways, including those involving stones, obstruction, and indwelling devices. Multidrug-resistant (MDR) uropathogens, extended-spectrum beta-lactamase (ESBL)-producing Enterobacterales, and fluoroquinolone-resistant Gram-negative bacilli are reported with growing frequency across both community and hospital settings, and are associated with treatment failure, escalation to broader-spectrum therapy, prolonged hospitalisation, and severe outcomes in high-risk presentations [7] [8]. Within procedural stone care, observational evidence suggests that pre-operative culture positivity is a consistent predictor of post-intervention infectious complications, and that this association is clinically modified by resistance phenotype, particularly in the setting of MDR bacteriuria [8]. In parallel, repeated discordance has been reported between pre-operative bladder or midstream urine cultures and intra-operative cultures obtained from renal pelvic urine or stone fragments, with intra-operative sampling often identifying additional or different organisms that may better predict post-procedural systemic inflammatory responses. These findings support the concept of stones as protected microbial reservoirs and raise important questions about the adequacy of relying on bladder urine alone for microbiological risk estimation in selected patients [11] [12].

Current guidance for urolithiasis and urological infections emphasises urine assessment before intervention, treatment of active infection prior to elective stone surgery, and procedure-appropriate peri-operative prophylaxis, while discouraging unnecessary antimicrobial exposure in lower-risk contexts such as SWL when baseline urine is sterile [4]. Nevertheless, real-world prescribing remains heterogeneous with respect to antibiotic choice, timing, and duration, reflecting variation in case mix, local resistance epidemiology, microbiological practices, and uncertainty regarding the optimal approach for patients with higher-risk resistance phenotypes [5] [6]. Importantly, much of the historical prophylaxis literature has focused primarily on short-term infectious endpoints and has not consistently incorporated AMR outcomes, detailed resistance phenotyping, or longitudinal assessment of resistance selection across repeated episodes of care [5] [6]. As a result, a practical evidence gap remains for clinicians and stewardship programmes seeking to balance procedural safety with sustainable antimicrobial use in an era of increasing resistance.

Against this background, there is a clear need for a structured synthesis of how contemporary KSD management pathways intersect with antimicrobial resistance, microbiological risk stratification, and stewardship practice. The overarching aim of this scoping review was to map the AMR-relevant evidence base in KSD across medical and procedural care pathways. The specific objectives were to: 1) classify the clinical and procedural contexts in which resistant infections or resistance-related findings have been reported; 2) characterise the organisms, resistance phenotypes, and sampling strategies described in the literature; 3) identify higher-risk patient groups and clinical scenarios in which AMR burden appears to be concentrated; and 4) assess the extent and nature of explicit or implicit antimicrobial stewardship signals within the included studies. In doing so, the review sought to position AMR as a clinically integrated dimension of stone disease management rather than as a secondary microbiological consideration.

2. Methodology

2.1. Study Design, Protocol, and Reporting

A scoping review was undertaken to systematically map and characterise the published literature on AMR in KSD across both procedural and non-procedural clinical contexts, and to identify AMS-relevant signals within this evidence base. A protocol was developed a priori to define the review objectives, research questions, eligibility criteria, clinical context categories, and data-charting framework. Formal prospective registration was not pursued because the review was exploratory in scope and not designed as a systematic review of intervention effectiveness; moreover, scoping reviews are not routinely eligible for registration in all review registries. Nevertheless, the protocol, screening framework, and review log were retained to support methodological transparency and reproducibility, and are available from the authors upon reasonable request. Reporting was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR). The study selection process is summarised in Figure 1.

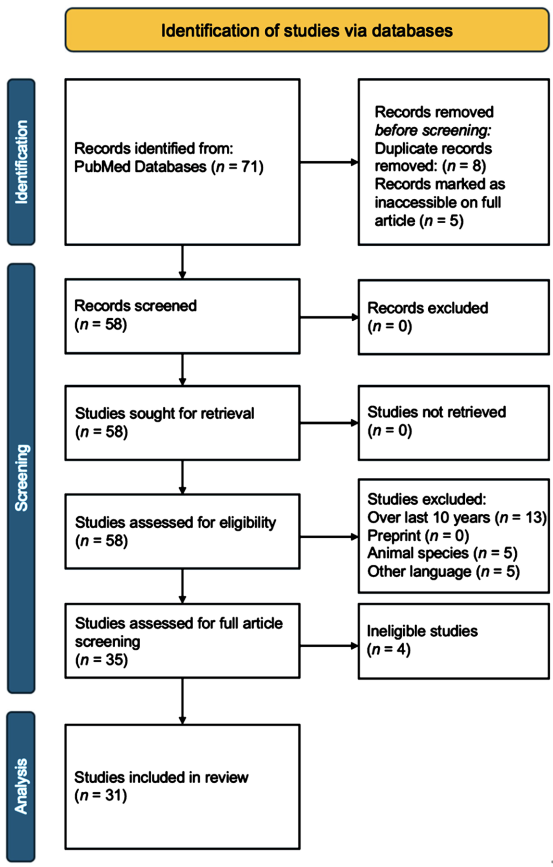

Figure 1. PRISMA-ScR flow diagram of study selection for the scoping review. PubMed records identified (n = 71), duplicate records removed (n = 8), and inaccessible records removed before screening (n = 5) resulted in records screened (n = 58). Following eligibility assessment, studies assessed for full-article screening (n = 35), ineligible studies excluded (n = 4), and studies included in the review (n = 31) are shown.

2.2. Information Source and Search Strategy

A structured literature search was conducted in PubMed to identify peer-reviewed studies reporting AMR in the context of KSD and its medical or procedural management. PubMed was selected as the primary database because of its strong coverage of biomedical, clinical, and microbiological literature relevant to urolithiasis, urinary tract infection, and antimicrobial resistance. The final PubMed search was conducted on 12 January 2026. The search was restricted to studies published between 1 January 2016 and 31 December 2025 and to articles published in English.

The search strategy combined Medical Subject Headings (MeSH) and free-text terms relating to three core concepts: kidney stone disease, stone-related procedures or therapies, and bacterial antimicrobial resistance. The final PubMed search string was as follows:

("Urolithiasis" [Mesh] OR "Kidney Calculi" [Mesh] OR nephrolithiasis [tiab] OR "kidney stone*" [tiab] OR "renal stone*" [tiab]) AND ("Nephrostomy, Percutaneous" [Mesh] OR "Lithotripsy" [Mesh] OR "Ureteroscopy" [Mesh] OR "Drug Therapy" [Mesh] OR "Anti-Bacterial Agents" [Mesh] OR PCNL [tiab] OR SWL [tiab] OR RIRS [tiab] OR ureteroscop* [tiab] OR "medical expulsive therapy" [tiab] OR tamsulosin [tiab]) AND ("Drug Resistance, Bacterial" [Mesh] OR "antimicrobial resistance" [tiab] OR "antibiotic resistance" [tiab] OR MDR [tiab] OR "multidrug-resistant" [tiab]).

The search was designed to capture studies addressing both direct microbiological resistance outcomes and clinically relevant AMR-related findings arising within stone-associated pathways of care.

2.3. Eligibility Criteria and Study Selection

Studies were considered eligible if they were peer-reviewed primary or review publications reporting AMR-relevant microbiological findings in the context of KSD, stone-associated urinary tract infection (UTI), or the clinical management of patients with urinary stones. Eligible AMR-related outcomes included antimicrobial susceptibility testing results, defined resistance phenotypes such as extended-spectrum beta-lactamase (ESBL)-producing Enterobacterales, fluoroquinolone resistance, multidrug resistance (MDR), carbapenem resistance, or other clinically relevant resistance patterns; resistance-associated risk factors in stone populations; and stewardship-relevant management findings linked to resistance risk.

Studies were excluded if they did not report extractable AMR-related microbiological or susceptibility data, were not relevant to KSD or stone-associated infection pathways, involved non-human populations, were published outside the predefined date range, were not available in English, or lacked accessible full text such that key data could not be reliably extracted. Preprints and non-peer-reviewed materials were also excluded.

Titles and abstracts were screened against the predefined eligibility criteria, and potentially relevant records were subsequently assessed at full-text level. Screening and full-text review were undertaken independently by two reviewers. Discrepancies were resolved through discussion and consensus. Where full-text articles were not accessible through institutional subscriptions, attempts were made to obtain them through interlibrary request and, where feasible, by contacting the corresponding authors. Records that remained unobtainable after these efforts were excluded and documented as full-text unavailable.

2.4. Data Charting, Procedure Categorisation, and Critical Appraisal

Data were charted using a standardised extraction form developed a priori and piloted before full extraction. The extraction framework captured bibliographic details (author, year, journal), study design, population characteristics, clinical context, procedure or exposure category, microbiological sampling source, organism profile, reported resistance phenotype(s) and/or susceptibility findings, and stewardship-relevant management observations. Sampling sources included, where applicable, midstream urine, bladder urine, renal pelvic urine, stone culture, blood culture, irrigation fluid, and device-associated samples. When more than one sampling source was reported within a single study, findings were charted separately to preserve within-study microbiological discordance.

Each included study was assigned to a primary clinical context category according to predefined operational definitions. These categories were: percutaneous nephrolithotomy (PCNL); ureteroscopy (URS), including ureteroscopy-based interventions such as flexible ureteroscopy and ureteroscopic lithotripsy; retrograde intrarenal surgery (RIRS); decompression, defined as urgent drainage procedures such as ureteric stent placement and/or percutaneous nephrostomy when these constituted the primary clinical context; device-centred pathways, defined as studies in which indwelling urinary devices represented the principal exposure or microbiological context; and non-procedural contexts, including stone populations studied outside a specific intervention pathway, such as observational epidemiological studies, microbiological investigations, genomic studies, and narrative reviews. Where a single dominant exposure or procedural context could not be determined, studies were classified as mixed or unclear and were summarised descriptively.

In keeping with scoping review methodology, formal risk-of-bias assessment was not used as a basis for study exclusion. However, methodological limitations and internal validity concerns were documented during data charting in order to support cautious interpretation of the evidence base. Where appropriate, design-specific critical appraisal tools were applied to contextualise study quality: the Newcastle-Ottawa Scale (NOS) for observational studies, RoB 2 for randomised trials, and the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for case reports. Appraisal findings were summarised descriptively and were used to inform interpretation rather than to determine eligibility. Data charting was performed independently by two reviewers using the predefined extraction form. Any discrepancies in extraction or classification were resolved through discussion and consensus.

2.5. Synthesis Approach and Stewardship Coding

The evidence was synthesised using structured narrative methods supported by tabulation. The distribution of included studies across clinical context categories was summarised descriptively, and key microbiological and AMR-related findings were mapped according to procedural or non-procedural context, sampling source, organism profile, and reported resistance phenotype. Quantitative meta-analysis was not undertaken because of substantial heterogeneity in study design, populations, microbiological methods, sampling frameworks, and outcome definitions.

Stewardship-related content was coded using an a priori analytical framework. Studies were classified as demonstrating explicit AMS framing when they directly used stewardship language or made clearly stewardship-oriented recommendations, such as antibiotic-sparing strategies, minimisation of unnecessary treatment duration, avoidance of routine broad-spectrum prescribing, or explicit calls for stewardship-guided practice. Studies were classified as demonstrating implicit AMS framing when they contained stewardship-aligned recommendations without explicitly using AMS terminology, for example, culture-guided therapy, risk-stratified antimicrobial selection, avoidance of agents with high local resistance rates, or recommendations to tailor prophylaxis according to patient or procedural risk. Where relevant, the dominant stewardship message type, including duration minimisation, culture-guided selection, or prophylaxis individualisation, was also recorded to support structured interpretation of stewardship signals across the included literature. AMS coding was performed independently by two reviewers using the a priori framework. Any disagreements in coding were resolved through discussion and consensus.

3. Results

3.1. Review Summary and Characteristics of Included Studies

A total of 31 studies met the eligibility criteria and were included in the review. The included studies were published between 2016 and 2025, with one study published in 2016 and one in 2017, two studies in 2018 and 2019, five studies in 2020, four in 2021, five in each of 2022, 2023, and 2024, and one study in 2025. Study-level characteristics, clinical or procedural context, and extracted microbiological findings are presented in supplementary data (**Table S1**). Patient subgroup and clinical scenario data extracted from selected studies are presented in Supplementary data (**Table S2**), and stewardship-related extraction fields are presented in Supplementary data (**Table S3**).

3.2. Landscape of Kidney Stone Management Contexts Represented in the Evidence Base

Across the 31 included studies, clinical and procedural contexts were grouped into five categories for descriptive synthesis: non-procedural/epidemiological contexts, PCNL, drainage/device-related pathways, URS/RIRS/FURS-related pathways, and TUL. Non-procedural or epidemiological contexts accounted for 15 studies, PCNL for 9 studies, drainage/device-related contexts for 4 studies, URS/RIRS/FURS-related contexts for 2 studies, and TUL for 1 study. These distributions are shown in **Figure 2**, while study-level context classifications and extracted microbiological observations are presented in Supplementary data (**Table S1**).

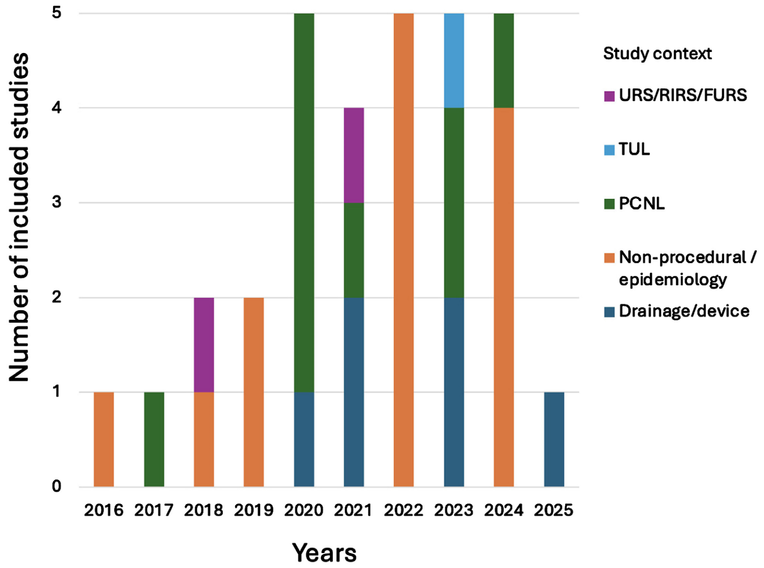

Figure 2. Publication-year distribution of the 31 included studies according to primary kidney stone disease management context. Each stacked bar represents the number of studies published in a given year (2016-2025), stratified by the predefined clinical or procedural context used for descriptive synthesis: non-procedural/epidemiology, percutaneous nephrolithotomy (PCNL), drainage/device-related pathways, ureteroscopy/retrograde intrarenal surgery/flexible ureteroscopy (URS/RIRS/FURS), and transureteral lithotripsy (TUL). The figure illustrates the predominance of non-procedural/epidemiological and PCNL-focused studies within the evidence base, with comparatively limited representation of other endourological contexts.

Non-procedural and epidemiological studies were represented throughout the review period and constituted the entirety of the 2022 publication set. By contrast, PCNL-focused studies were concentrated in the middle of the review window and were most prominent in 2020. Drainage- and device-related studies appeared intermittently across 2020, 2021, 2023, and 2025. URS/RIRS/FURS-related contexts were represented in 2018 and 2021, while the sole TUL-context study was published in 2023. These patterns indicate that the published AMR literature in KSD has been weighted towards observational and PCNL-associated contexts, with more limited representation of other endourological pathways.

3.3. Microbiological Spectrum and Resistance Phenotypes Reported

Resistance phenotypes were categorised at study level and are summarised in Figure 3. Across the included studies, MDR was reported in 10 studies and ESBL-associated resistance in 9 studies. Fluoroquinolone-resistant phenotypes were reported in 3 studies, XDR in 1 study, and CRE-associated resistance in 1 study. In addition, 7 studies were classified within an "other resistance/stewardship signal" category, reflecting resistance findings that did not fall within the predefined MDR, ESBL, fluoroquinolone-resistant, XDR, or CRE groupings, or studies in which resistance-related findings were reported primarily through stewardship-relevant clinical signals. These phenotype distributions are further detailed in Figure 3, and organism-level and susceptibility-related findings are presented in Supplementary data (Table S1 and Table S2).

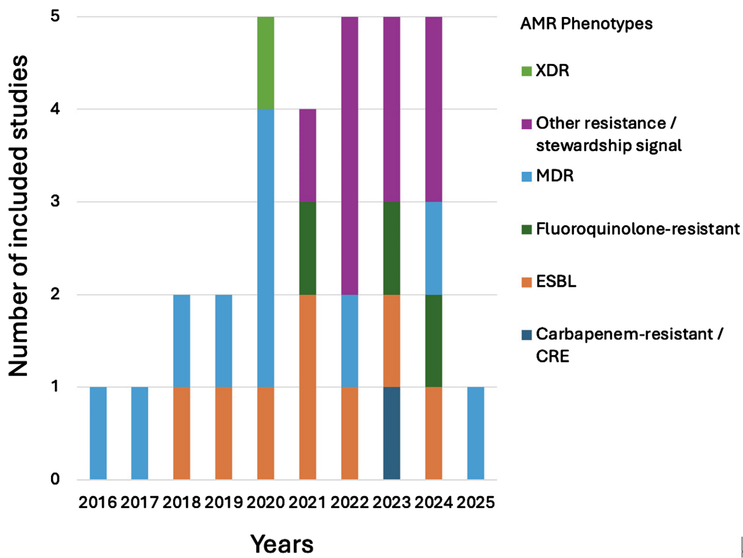

Figure 3. Publication-year distribution of reported antimicrobial resistance phenotypes across the included kidney stone disease studies. Each stacked bar represents the number of studies published in a given year (2016-2025) reporting multidrug resistance (MDR), extended-spectrum beta-lactamase (ESBL)-associated resistance, fluoroquinolone-resistant phenotypes, extensively drug-resistant (XDR) phenotypes, carbapenem-resistant Enterobacterales (CRE)-associated resistance, or other resistance/stewardship-related signals. The figure demonstrates that MDR and ESBL-associated resistance dominated the AMR literature in kidney stone disease, while more advanced or less frequently reported phenotypes, including XDR and CRE, appeared only sporadically within the review window.

Across the evidence base, resistant Gram-negative organisms were prominent, particularly *Escherichia coli*, *Klebsiella pneumoniae*, *Proteus mirabilis*, and other Enterobacterales. Several studies also reported clinically important Gram-positive and mixed microbiological findings, including *Enterococcus faecalis*, as well as fungal isolates in selected contexts. MDR and ESBL-producing organisms were the most frequently recurring resistance patterns, while fluoroquinolone resistance, XDR, and carbapenem resistance were reported less commonly but remained clinically important where identified.

Temporally, MDR was reported in studies published in 2016, 2018, 2019, 2020, 2022, 2024, and 2025, while ESBL-associated resistance was reported from 2018 onwards and appeared repeatedly in studies published between 2020 and 2024. Fluoroquinolone-resistant phenotypes were reported in 2021, 2023, and 2024, XDR in 2020, and CRE-associated resistance in 2023. Overall, the phenotype profile suggests that the AMR literature in KSD has been dominated by MDR- and ESBL-related concerns, with smaller but clinically significant signals relating to more advanced resistance phenotypes. Although some individual studies reported study-specific proportions, including 33% MDR isolates in one microbiological cohort, 44% MDR isolates in a mixed stone-procedure cohort, and approximately 19.6% ESBL Enterobacterales in a febrile upper-tract stone cohort, heterogeneity in patient populations, sampling sources, microbiological methods, and resistance definitions was too substantial to support a single meaningful cross-study range estimate for resistance phenotype burden.

3.4. Patient Subgroups and Clinical Scenarios Associated with Higher AMR Burden

Patient subgroup characteristics and clinical scenarios were variably reported across the included literature. Extracted examples are presented in Supplementary data (**Table S2**) and include sex distribution, age structure, clinical setting, urolithiasis with UTI or other complicated infection presentations, prior nephrolithiasis history, prior antibiotic exposure, obstructive presentations requiring urgent decompression, and the presence and duration of indwelling urinary devices. Because Supplementary data (**Table S2**) contains selected extracted examples rather than complete subgroup extraction for all 31 studies, these findings should be interpreted as illustrative rather than exhaustive.

Within the studies for which subgroup-level information was available, higher AMR burden or more resistant phenotypes were reported in several recurring scenarios. These included older age and male sex in some observational cohorts, prior kidney stone history, recurrent UTI, prior antibiotic exposure, indwelling ureteric stents or percutaneous nephrostomy catheters, obstruction requiring urgent decompression, and large or complex stone burden in PCNL contexts. In selected studies, recurrent or device-associated infection pathways were linked to ESBL-producing organisms, carbapenem-resistant organisms, XDR phenotypes, or reduced susceptibility to commonly used empirical agents. These subgroup and scenario-level resistance signals are summarised in Supplementary data (**Table S2**).

3.5. Microbiological Sampling Strategies and Culture Discordance Reporting

Microbiological sampling strategies varied across the included studies and are presented in Supplementary data (**Table S1**). Sampling sources included pre-operative midstream urine and bladder urine cultures and, in procedural contexts, intra-operative or device-associated sources such as renal pelvic urine, stone cultures, irrigation-fluid isolates, and nephrostomy- or stent-related specimens. Where more than one sampling source was reported within a single study, findings from each source were extracted separately in order to preserve within-study microbiological discordance.

Several studies, particularly in PCNL-related contexts, reported discordance between conventional urine cultures and renal pelvic urine or stone cultures. In these studies, intra-operative or stone-associated cultures identified additional or different organisms and, in some cases, were described as better predictors of post-procedural infection or sepsis than pre-operative urine cultures alone. These findings support the view that reliance on bladder or midstream urine alone may underestimate microbiological burden in selected high-risk KSD pathways. Sampling contexts and extracted microbiological observations are presented in Supplementary data (Table S1) and summarised in Supplementary data (Table S1 and Table S2).

3.6. Stewardship Signals and Extent of Explicit Antimicrobial Stewardship Reporting

Stewardship-related content varied across the included studies. Explicit AMS framing was identified in 5 of 31 studies, while the remaining 26 studies were classified as containing implicit or non-explicit stewardship-relevant reporting. The studies with explicit AMS framing addressed antibiotic-sparing aminoglycoside strategies, duration minimisation after urgent decompression, prophylaxis individualisation in RIRS, short-course culture-directed prophylaxis in PCNL, and non-antibiotic adjunctive approaches within UTI-prone populations that included nephrolithiasis. These stewardship-related findings are presented in Supplementary data (Table S3).

Although most studies did not use explicit AMS terminology, many nevertheless contained stewardship-relevant observations, including culture-guided antimicrobial selection, resistance-aware empirical prescribing, avoidance of unnecessary prolonged antibiotic exposure, and consideration of local susceptibility patterns. Accordingly, stewardship signals were not confined to the explicitly framed studies alone, but were distributed more broadly across the literature. These broader stewardship-related findings are presented in Supplementary data (Table S3) and summarised alongside resistance-related findings in Supplementary data (Tables S1-S3).

4. Discussion

4.1. Key Findings and Comparison with Existing Guidance

This scoping review synthesised evidence published between 2016 and 2025 on AMR in KSD across procedural and non-procedural care pathways. Taken together, the findings presented in Supplementary data (Tables S1-S3) support a clear overarching interpretation: KSD care frequently operates within an AMR-prone clinical ecology in which recurrent urinary tract instrumentation, repeated healthcare exposure, intermittent or prolonged device use, and cumulative antibiotic exposure interact with the capacity of stones to harbour microorganisms and biofilm-associated communities. Within this framework, resistance phenotypes do not appear as isolated microbiological observations, but as recurring features of a broader and clinically important infection ecology.

Across the included studies, resistant Gram-negative uropathogens were prominent, with repeated reporting of MDR and ESBL-producing Enterobacterales, alongside less frequent but clinically consequential signals relating to carbapenem resistance and XDR phenotypes. These findings, as presented in Supplementary data (**Table S1** and **Table S2**), suggest that AMR in stone-associated populations is not merely descriptive, but likely to influence empirical adequacy, therapeutic escalation, and the likelihood that post-procedural infection becomes difficult to manage. At the same time, stewardship framing was limited, with only a minority of studies explicitly presenting their findings through an AMS lens, as presented in Supplementary data (**Table S3**). This is important because where antibiotic indication, timing, duration, and de-escalation are poorly reported, it becomes difficult to distinguish clinically necessary therapy from avoidable exposure that may amplify selection pressure.

When interpreted alongside contemporary guidance, the overall direction of the evidence is broadly concordant with the core principles of current European Association of Urology recommendations, including urine assessment before intervention, treatment of active UTI before elective stone surgery, and procedure-appropriate peri-operative prophylaxis, alongside avoidance of unnecessary antibiotic use in lower-risk contexts such as SWL when baseline urine is sterile [4]. However, the present review also highlights two clinically important implementation tensions. First, guideline-concordant prophylaxis may still be inadequate where local resistance prevalence is high or where patient-level risk factors, such as prior colonisation, recent antibiotic exposure, or recurrent instrumentation, are not sufficiently incorporated into decision-making. Second, reliance on midstream or bladder urine culture alone may underestimate upper-tract or stone-associated microbial reservoirs, thereby creating a mismatch between apparent pre-operative reassurance and actual post-procedural risk. These tensions position resistance in stone pathways as both a patient safety issue, when inadequate antimicrobial coverage contributes to infectious deterioration, and a stewardship issue, when broad or prolonged antibiotic exposure is used without clear additional benefit. Interpretation is further complicated by the historical evolution of severe infection definitions, with increasing standardisation under Sepsis-3 criteria over time [14].

4.2. Where AMR Risk Concentrates: Procedures, Devices, and Obstruction

The distribution of evidence presented in Supplementary data (**Table S1**) indicates that resistance burden and infection risk are not evenly distributed across KSD pathways. PCNL was a major focus of the included literature and appears consistently associated with comparatively higher infectious risk than many other common stone procedures. This is biologically plausible, given that renal puncture and tract dilation, larger irrigation volumes, longer procedural duration, and episodes of raised intrarenal pressure may facilitate bacterial mobilisation, translocation, and systemic inflammatory responses [15]. Within multiple cohorts, positive preoperative urine culture has emerged as a reproducible predictor of post-PCNL infectious complications, including systemic inflammatory response syndrome and sepsis [16] [17]. Importantly, susceptibility profile also appears to matter: MDR bacteriuria before PCNL has been associated with greater odds of post-operative infectious complications, suggesting that culture positivity alone is insufficient without corresponding attention to resistance phenotype [8]. Procedural complexity, including larger or staghorn stone burden, multiple access tracts, longer operative duration, and higher intrapelvic pressures, has also been linked to post-procedural infection, although confounding by underlying case complexity remains difficult to exclude fully [15] [16].

By contrast, URS and RIRS generally appear to carry lower absolute rates of severe infectious complications than PCNL, but their stewardship relevance may still be substantial because these procedures are performed at high volume. Infectious morbidity after these procedures may be influenced by obstruction, pre-existing stents, prolonged operative time, and high-pressure irrigation, while indwelling stents may provide surfaces for biofilm persistence and may complicate interpretation of urine culture findings [5]. Even when the per-case probability of severe infection is relatively low, high procedural frequency combined with repeated peri-operative or post-procedural prescribing may produce meaningful antibiotic selection pressure at population level.

Device-associated pathways represent a further concentration point for risk. Ureteric stents, nephrostomy tubes, and related urinary devices may promote colonisation, recurrent infection, and repeated antibiotic exposure, thereby reinforcing selective pressure over time [5]. The evidence presented in this review warrants cautious interpretation because device exposure is often correlated with more complex disease, greater obstruction burden, and higher baseline morbidity. Nonetheless, the repeated convergence of indwelling devices, recurrent antibiotic use, and resistant microbiology across multiple study contexts is sufficiently consistent to justify explicit pathway-level stewardship attention.

Obstruction warrants particular emphasis because it alters both the clinical urgency and the stewardship time horizon. In obstructed infected systems, urgent decompression and antimicrobial therapy are essential for patient safety [4] [7]. However, empirical treatment decisions are often made before complete susceptibility data are available, and antibiotic duration may extend unnecessarily when definitive stone management is delayed. Although the present review does not permit quantitative estimation of optimal treatment duration, owing to heterogeneity and limited prospective evidence, the mapped findings support a cautious clinical principle: once source control has been achieved and the patient is clinically improving, antibiotic exposure should be actively reviewed, narrowed where microbiology permits, and not continued by default as an indefinite bridge to definitive treatment.

4.3. Microbiology Pitfalls: Culture Discordance and Hidden Reservoirs

One of the most consistent themes across the included studies is that microbiological sampling strategy materially influences both risk estimation and downstream antibiotic decisions. Discordance between pre-operative midstream or bladder urine cultures and intra-operative cultures obtained from renal pelvic urine or stone fragments has been repeatedly documented, particularly in PCNL-related cohorts [11] [12]. This finding is clinically important because it supports the concept that stones may act as protected microbial reservoirs, including reservoirs of resistant organisms that are not adequately captured by conventional lower-tract urine sampling [11] [12].

The biological plausibility of this phenomenon is considerable. Bacteria may persist within the stone matrix or within biofilm-like communities adherent to stone surfaces or adjacent devices, thereby reducing antimicrobial penetration and enabling persistence despite apparently appropriate therapy [11]-[13]. In practical terms, this means that reliance on bladder or midstream urine alone may underestimate microbiological burden before higher-risk procedures [11] [12]. It also provides a potential explanation for situations in which post-operative deterioration prompts reactive broadening of antibiotics despite apparently reassuring pre-operative urine results.

From a stewardship perspective, the value of expanded microbiological sampling lies not in sampling intensity alone, but in whether additional cultures are linked to an actionable management plan. A risk-aligned approach would reserve renal pelvic urine or stone culture sampling for patients and procedures in which the incremental diagnostic yield is most likely to alter treatment, such as PCNL in the context of suspected infection stones, recurrent infection, prior severe infectious complications, indwelling devices, or complex obstruction [11] [12]. In such settings, intra-operative culture results may support more targeted therapy and earlier de-escalation, potentially reducing unnecessary broad-spectrum exposure.

A further interpretive challenge is that the current literature rarely provides consistent diagnostic criteria for distinguishing colonisation from true infection in stone-associated pathways. Across many included studies, microbiological positivity was reported without uniform reference to colony count thresholds, symptom burden, inflammatory markers, or clear clinical correlation, particularly in the setting of indwelling devices and upper-tract sampling. This definitional ambiguity is important for stewardship because microbiological detection alone may not reliably indicate clinically significant infection, yet may still prompt escalation, prolongation, or unnecessary broadening of antibiotic therapy. More standardised reporting that integrates microbiological findings with symptomatology and clinical severity would therefore improve both interpretation of the evidence base and the stewardship relevance of future studies.

Nevertheless, the present review also highlights important limitations in the underlying evidence base. Definitions of sampling source, timing, laboratory methods, and contamination control vary across studies, and infection endpoints are not uniformly defined. In addition, older and newer studies may not be directly comparable because severe infectious outcomes have been framed using evolving sepsis definitions [14]. These sources of heterogeneity reduce the precision with which the incremental predictive value of stone or renal pelvic cultures can be estimated, even where the biological rationale for culture discordance is compelling.

4.4. AMS Implications for Kidney Stone Therapies

The findings presented in Supplementary data (**Tables S1-S3**) suggest that stewardship opportunities in KSD are largely pathway-based rather than confined to antibiotic selection alone. Several practical leverage points emerge from the mapped evidence.

First, microbiological risk stratification should be made more explicit within stone care pathways. The review indicates that higher resistance burden is repeatedly associated with recurrent stone disease, prior antibiotic exposure, indwelling devices, obstruction, and more complex interventions such as PCNL, as summarised in Supplementary data (**Table S2**). These variables are generally available during routine pre-operative assessment and could be incorporated into structured risk-assessment tools to guide culture acquisition, review of prior microbiology, and alignment of prophylaxis with local susceptibility patterns.

Second, prophylaxis should remain procedure-appropriate but increasingly informed by local resistance epidemiology and patient-specific risk. Current guidance appropriately discourages unnecessary antibiotics for SWL in patients with sterile urine [4]. However, the phenotype distributions mapped in this review indicate that ESBL and MDR signals may materially affect empirical reliability in selected settings [7] [8]. This creates a clear tension: routine broad-spectrum prophylaxis for all patients would be stewardship-poor and likely harmful, yet failure to incorporate local epidemiology and patient risk may lead to inadequate coverage in high-risk subgroups. A defensible position is therefore one of stratified prophylaxis, integrating procedure type, patient-level risk factors, and local susceptibility data, with explicit expectations for narrowing and discontinuation once culture results and clinical response permit.

Third, antibiotic duration should itself be treated as a stewardship endpoint. In stone pathways, avoidable exposure often accumulates through extended post-operative courses, repeated attempts to sterilise urine, or continuation of antibiotics during delays to definitive source control. Evidence relating to PCNL prophylaxis suggests that extended regimens beyond short peri-operative strategies may offer limited additional benefit while increasing exposure burden [6]. Where prolonged therapy is used, the rationale should be clearly linked to microbiology, source control status, and clinical trajectory rather than applied routinely.

Fourth, device management should be understood as a stewardship intervention. Indwelling devices may sustain colonisation and biofilm persistence and may trigger repeated antibiotic prescribing [5]. Reducing device dwell time where feasible, expediting definitive stone clearance, and avoiding inappropriate treatment of asymptomatic colonisation may therefore reduce antibiotic exposure without compromising patient safety, provided that microbiology is interpreted within the broader clinical context.

Finally, the present review suggests that the KSD literature remains relatively underdeveloped in relation to stewardship evaluation. As presented in Supplementary data (**Table S3**), only a minority of included studies used explicit stewardship framing, and many did not report antibiotic indication, duration, or de-escalation with sufficient clarity to permit meaningful assessment. Future studies should therefore treat antibiotic exposure as an outcome in its own right, alongside clinical endpoints and resistance phenotypes, and should report microbiological sampling strategies transparently to enable comparison of discordance and reservoir-related findings across settings.

4.5. Limitations and Research Gaps

Several limitations constrain interpretation of the present evidence base and should be regarded as priorities for future work. First, much of the available literature is retrospective and single-centre, which limits generalisability and increases susceptibility to bias and confounding. Second, substantial heterogeneity exists in procedure categorisation, microbiological sampling strategy, laboratory methodology, timing of cultures, and definitions of infectious outcomes. This heterogeneity complicates cross-study comparison and precludes robust quantitative estimation of procedure-specific risk or the incremental value of specific sampling sources.

An additional methodological limitation is that the current evidence base is derived almost exclusively from conventional aerobic culture methods. As a result, the possible contribution of anaerobic bacteria, fastidious organisms, and other atypical pathogens to stone-associated infection ecology remains poorly characterised. This represents an important gap because reliance on standard aerobic culture alone may underestimate the full microbiological complexity of infected stones, biofilm-associated reservoirs, and discordant culture states. Future studies should therefore consider broader microbiological detection frameworks, including methods capable of identifying anaerobic and non-conventionally recovered organisms.

Confounding also remains a major challenge. Prior antibiotic exposure, indwelling devices, obstruction severity, stone burden, and comorbidity often cluster together and are not consistently adjusted for in the included studies. As a result, it remains difficult to disentangle whether resistant microbiology is driven primarily by healthcare exposure and cumulative antibiotic use, by particular procedural characteristics, or by underlying patient phenotype. Resistance phenotyping is also reported inconsistently, and longitudinal follow-up across recurrent episodes of care is uncommon despite the chronic and relapsing nature of KSD.

A further gap lies in the limited prospective evaluation of stewardship interventions within stone pathways. Although many studies describe resistance patterns, comparatively few examine pathway modifications such as structured microbiological risk stratification, risk-aligned culture acquisition, shortened antibiotic durations, or device dwell-time governance. Fewer still link such interventions to both patient outcomes and downstream resistance burden. High-value future work would include multicentre prospective cohorts using harmonised infection definitions, standardised sampling frameworks, structured capture of antibiotic exposure, and longitudinal follow-up across recurrent interventions. Such designs would improve causal inference and generate evidence that is more directly translatable to clinical stewardship policy and service redesign.

5. Conclusions

AMR is an increasingly important and integrated dimension of KSD management. Across contemporary medical and procedural pathways, the evidence synthesised in this review indicates that stone care frequently operates within an AMR-prone clinical ecology in which resistant infections function as clinically meaningful modifiers of risk rather than incidental microbiological findings. Resistant Gram-negative uropathogens predominated across study contexts, with repeated reporting of MDR and ESBL-producing Enterobacterales, alongside less frequent but clinically important signals relating to fluoroquinolone resistance, carbapenem resistance, and XDR phenotypes. These resistance patterns are important because they influence post-procedural infection risk, the adequacy of empirical therapy, the need for escalation to broader-spectrum agents, and the likelihood of severe outcomes, including urosepsis and sepsis.

The burden of resistance was concentrated in recognisable higher-risk scenarios, including recurrent stone disease, recent or repeated antibiotic exposure, indwelling ureteric stents or percutaneous nephrostomy catheters, obstructive presentations requiring urgent decompression, and more complex interventions, particularly PCNL. A further recurring signal was microbiological discordance between bladder or midstream urine cultures and renal pelvic urine or stone cultures, supporting the concept that stones may function as protected microbial reservoirs and that urine culture alone may underestimate microbiological risk in selected pathways.

Taken together, these findings support a more resistance-aware approach to stone care. Microbiological risk stratification should be embedded into pre-procedural assessment, culture acquisition should be aligned with patient- and procedure-level risk, and prophylactic and empirical strategies should be informed by local susceptibility epidemiology and prior microbiological history. Unnecessary antibiotic exposure should be actively minimised once source control is achieved and clinical stability permits. Future research should prioritise prospective multicentre designs with harmonised infection outcome definitions, standardised sampling frameworks, and consistent resistance phenotyping, while also treating stewardship process measures as core outcomes. Such work will be essential to identify interventions that improve patient safety while limiting avoidable antimicrobial exposure.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Supplementary Data

Table S1. Study-level extraction summary of procedural or clinical context, organisms reported, and key microbiological observations.

Author	Year	Journal	Procedure/Context	Bacteria/ Organism(s)	Extracted Note
Zafar	2019	Microbial Pathogenesis	Non-interventional observational microbiological study in patients with kidney stones, stratified by presence or absence of complicated UTI (cUTI)	*Klebsiella pneumoniae* (cKP; hypermucoviscous hvKP phenotype)	cKP/hvKP were significantly associated with cUTI and strong biofilm formation; 33% of isolates were multidrug resistant (MDR).
Gu	2022	BMC Geriatrics	Retrospective observational cohort of urolithiasis with UTI	*Escherichia coli*; *Enterococcus faecalis*; *Candida glabrata*	*E. coli* was dominant across age groups; older patients had a higher prevalence of *K. pneumoniae* and *E. faecium*; younger patients' uropathogens were more susceptible.
Mei	2024	BMC Urology	Preoperative midstream urine cultures from patients with urinary calculi	*Escherichia coli*; *Enterococcus faecalis*	Gram-negative predominance declined and Gram-positive organisms increased over time; rising resistance in *E. coli* to piperacillin and cefotaxime was reported, alongside declining resistance to gentamicin, fluoroquinolones, and co-trimoxazole; *E. faecalis* resistance increased to ampicillin, gentamicin, and tetracycline, with near-zero resistance to vancomycin and linezolid.
Jenrette	2024	Academic Emergency Medicine	Single-dose intravenous aminoglycoside therapy for complicated cystitis in emergency department patients	Gram-negative Enterobacterales	Single-dose aminoglycosides were effective for most patients without oral options; no serious renal or ototoxic adverse events were reported; treatment failure was linked to kidney stones or urinary hardware.
Senocak	2018	Endourology and Stone Diseases	Flexible uretero-renoscopy with laser lithotripsy (FURSLL)	*Escherichia coli*; *Enterococcus* spp.	Preoperative MDR urine culture increased postoperative infection risk after FURSLL; most infections were Gram-negative, predominantly *E. coli*; standard prophylaxis did not fully prevent infection in MDR cases.
Wang	2020	Endourology and Stone Diseases	Percutaneous nephrolithotomy (PCNL) and flexible ureteroscopy (FURS)	*Escherichia coli*; *Enterococcus faecalis*	*E. coli* was the most common pathogen, especially in females; males showed a broader organism spectrum and higher rates of resistant species; longer preoperative antibiotics (>3 days) were associated with reduced urosepsis risk.

Continued

Wagenius	2020	Scandinavian Journal of Urology	PCNL	Urine cultures: *Enterococcus faecalis*; stone cultures: *Enterococcus faecalis*	Infection was the most common complication after PCNL; positive urine or stone cultures increased complication risk; *E. faecalis* was frequently identified.
Mohammed	2022	Archives of Razi Institute	Non-surgical laboratory-based experimental study using urine samples from patients with UTI, kidney stones, or catheter-associated infection	*Escherichia coli* (MDR strains)	MDR *E. coli* were isolated across study groups; lipopolysaccharide (LPS), particularly in liposome-formulated form, inhibited multiple pathogens; LPS-based nanoparticles were proposed as a potential future antimicrobial approach.
Mohseni	2022	Western Journal of Emergency Medicine	Retrospective observational study of emergency department UTI patients (women aged ≥ 18 years); kidney stone history assessed	Not specified individually	Kidney stone history was strongly associated with nitrofurantoin resistance; urinalysis findings were poor predictors of resistance; avoidance of nitrofurantoin was suggested in patients with stone history.
Gu	2022	Journal of Clinical Laboratory Analysis	Retrospective observational study of midstream urine cultures from patients with urinary stones	Predominantly Gram-negative organisms; *Escherichia coli*; *Enterococcus faecalis*; *Candida albicans*	*E. coli* was the most common pathogen, especially in females; males had a higher prevalence of *Enterococcus* and greater resistance; antibiotic selection was suggested to take sex into account.
Walton-Diaz	2017	International Urology and Nephrology	PCNL; prospective multicentre observational cohort	*Enterococcus faecalis*; *Escherichia coli*; *Candida albicans*	Midstream urine culture failed to detect some stone-associated bacteria; renal pelvic urine and stone cultures better predicted post-PCNL sepsis; stone-associated pathogens were frequently MDR or fungal.
Patel	2025	BMJ Case Reports	Percutaneous nephrostomy (PCN) followed by robotic-assisted laparoscopic nephrectomy; case report	Non-typhoidal *Salmonella* (NTS)	Stones acted as a persistent reservoir despite antibiotics and drainage; MDR *Salmonella* infection was not eradicated conservatively; nephrectomy achieved infection resolution.
Albayrak	2020	European Journal of Hospital Pharmacy	Double-J ureteral stent in situ; nephrolithiasis with repeated urological interventions	Extensively drug-resistant *Pseudomonas aeruginosa*	XDR UTI occurred in the setting of stones and an indwelling stent; colistin toxicity led to discontinuation; meropenem, gentamicin, and rifampicin achieved microbiological clearance despite in vitro resistance.
Taheri	2023	Ethiopian Journal of Health Sciences	Transureteral lithotripsy (TUL); double-blind randomised controlled trial of cefazolin prophylaxis versus placebo	*Escherichia coli*	Cefazolin prophylaxis did not reduce post-TUL infection compared with placebo; *E. coli* was the main pathogen and showed high ampicillin resistance; routine prophylaxis was not recommended.

Continued

Koksal	2019	Investigative and Clinical Urology	Prospective case-control study of community-acquired UTI risk factors (non-surgical)	*Escherichia coli*; *Klebsiella* spp. (ESBL focus)	Kidney stone history increased the risk of ESBL-positive UTI; prior urological procedures and catheter use also increased ESBL risk; ESBL infections showed high cephalosporin and fluoroquinolone resistance.
Chen	2018	International Journal of Clinical Practice	Retrospective observational study of urine cultures from hospitalised patients with urinary stones and UTI	*Escherichia coli*; *Enterococcus faecalis*	A complex microbiological spectrum with high MDR burden was reported; ESBL *E. coli* and *K. pneumoniae* were common, especially in females and older patients; empirical antibiotics were suggested to follow local resistance data.
Cho	2021	Journal of Korean Medical Science	Retrospective multicentre study of febrile upper urinary tract calculi and UTI; empirical resistance focus	*Escherichia coli*; *Enterococcus* spp.	Quinolone resistance was high; multiple stones predicted quinolone resistance; recurrent UTI predicted cefotaxime resistance.
Lian	2024	Microbiology Spectrum (ASM)	Genomic comparative analysis of 1267 *Proteus mirabilis* genomes from public databases	*Proteus mirabilis*	High resistance to beta-lactams, carbapenems, and quinolones was reported; urease gene clusters were widespread; resistance genes were frequently plasmid-mediated.
Lee	2016	Medicine (Baltimore)	Retrospective observational study of bacteraemic UTI due to Enterobacteriaceae; risk factors and empirical therapy	*Escherichia coli*	MDR Enterobacteriaceae increased the risk of severe sepsis and shock; stones, hydronephrosis, and indwelling catheters were more common in MDR infections.
Mert	2023	Medicine (Baltimore)	Percutaneous nephrostomy (PN) catheter; recurrent PN-related UTI in cancer patients	ESBL *E. coli*; *Enterococcus faecalis*; *Candida albicans*	Long PN catheter duration and kidney stones increased recurrent infection risk; recurrent infections included ESBL and carbapenem-resistant organisms; broad-spectrum empirical therapy was frequently required.
Reasoner	2022	Journal of Cystic Fibrosis	Retrospective observational review of UTIs in cystic fibrosis; nephrolithiasis subgroup	*Enterococcus faecalis*; *Escherichia coli*; *Candida* spp.	Nephrolithiasis increased UTI risk; Gram-negative organisms were less frequent and *E. faecalis* was more prominent; culture-guided therapy was suggested.
Zhang	2023	Pakistan Journal of Pharmaceutical Sciences	Retrospective observational study of urine cultures in upper urinary tract stones with UTI	*Escherichia coli*; *Enterococcus faecalis*; *Candida* spp.	High fluoroquinolone resistance was reported; carbapenems, piperacillin/tazobactam, cefoperazone/sulbactam, and amikacin remained active options for severe infection.
Paranjpe	2021	Journal of Endourology	Emergent decompression for urosepsis due to obstructing ureteral stone; ureteral stent placement	*Escherichia coli*; *Enterococcus* spp. (others)	Prior ureteroscopy predicted resistance (OR ≈ 7); most patients with obstructive urosepsis had resistant urine cultures.

Continued

He	2025	Phytotherapy Research	Narrative review of non-antibiotic adjunctive or prophylactic approaches for UTIs	UPEC; *Proteus mirabilis*; *Pseudomonas aeruginosa*; *Enterococcus faecalis*; *Staphylococcus aureus*	Phytoestrogens were described as reducing adhesion and biofilm formation and enhancing antibiotic activity; they were positioned as adjunctive or prophylactic options rather than stand-alone therapy.
Orr	2023	Urology	Urgent renal decompression for obstructing ureteral calculi (double-J stent or PCN) followed by definitive stone treatment (URS or PCNL)	Not specified	Antibiotic duration after decompression did not reduce post-procedure urosepsis risk; timing from decompression to definitive stone surgery showed no impact on urosepsis rates.
Cai	2021	European Urology Focus	Retrograde intrarenal surgery (RIRS) with laser vaporisation	Irrigation fluid isolates: *E. coli*, *K. pneumoniae*, *P. aeruginosa*; blood isolates rare	Bacteria were identified in irrigation fluid; prior fluoroquinolone use was a major risk factor for postoperative UTI; caution regarding fluoroquinolone-based prophylaxis was reported.
Li	2024	Not Reported	Ureteroscopic lithotripsy; metagenomic analysis of urine and infected stone samples	Urease-producing bacteria; Enterobacteriaceae; others	Infected stones contained more bacteria, resistance genes, and virulence genes than urine; Enterobacteriaceae carried most resistance genes; piperacillin-tazobactam reduced the resistance gene burden in both urine and stones.
Gao	2020	World Journal of Urology	PCNL; retrospective propensity score-matched comparison of struvite versus non-struvite stones; postoperative sepsis	Urease-producing bacteria; other common uropathogens	Preoperative MDR bacteriuria increased sepsis risk after PCNL; higher serum creatinine predicted postoperative sepsis; struvite stones had higher sepsis rates.
Wang	2020	World Journal of Urology	Retrospective observational study of mixed stone procedures (PCNL/URS/SWL); MDR focus	*Escherichia coli* (29.3%); Gram-positive organisms	Forty-four percent of isolates were MDR; recent antibiotic use and indwelling catheters predicted MDR; MDR pathogens showed high resistance to cephalosporins and fluoroquinolones.
Patel	2023	World Journal of Urology	PCNL; prospective randomised controlled trial of long-course versus short-course culture-sensitive antibiotics	Gram-negative and Gram-positive organisms	PCNL-associated sepsis was not reduced by prolonged antibiotics despite positive cultures; ESBL *E. coli* predominated; longer pre-PCNL antibiotic exposure increased treatment burden without improving outcomes.

Continued

Artiles-Medina 2021	BMC Urology	Xanthogranulomatous pyelonephritis (XGP) management; antibiotics plus definitive nephrectomy; case series with systematic literature review	Mixed Gram-negative and Gram-positive organisms	XGP was described as an end-stage stone-associated infection; urease-producing bacteria, especially *Proteus*, were highlighted; resistance to broad-spectrum agents was reported, with nephrectomy serving as definitive source control.

Abbreviations: AMR, antimicrobial resistance; cUTI, complicated urinary tract infection; ED, emergency department; ESBL, extended-spectrum beta-lactamase; FURS, flexible ureteroscopy; FURSLL, flexible uretero-renoscopy with laser lithotripsy; MDR, multidrug resistant; PCNL, percutaneous nephrolithotomy; PCN, percutaneous nephrostomy; PN, percutaneous nephrostomy catheter; RCT, randomised controlled trial; RIRS, retrograde intrarenal surgery; SWL, shock-wave lithotripsy; TUL, transureteral lithotripsy; UPEC, uropathogenic *Escherichia coli*; URS, ureteroscopy; UTI, urinary tract infection; XDR, extensively drug resistant; XGP, xanthogranulomatous pyelonephritis. **Note:** Table S1 summarises study-level extraction fields used in the review and presents the primary procedural or clinical context, principal organisms reported, and key microbiological observations as extracted from each included study.

Table S2. Extracted patient subgroup characteristics, clinical scenarios, and resistant infection signals from selected included studies.

Author	Year	Journal	Context/ Procedure	Patient Subgroup	Clinical Scenario(s)	Resistant Infection Signal	Extracted Note
Gu	2022	BMC Geriatrics	Urolithiasis	Male 47.3% (older) vs 34.9% (younger); female 52.7% (older) vs 65.1% (younger); age ≥ 60 vs <60; China	Urinary stones with UTI, including cystitis, pyelonephritis, asymptomatic bacteriuria, and rare urosepsis; recent antibiotic use excluded	ESBL *E. coli*; fluoroquinolone-resistant *E. coli*; *K. pneumoniae*; *E. faecium*; MDR uropathogens	Older age and male sex were associated with lower susceptibility and higher resistance to penicillin-class agents, tetracycline, ampicillin, and fluoroquinolones. Higher susceptibility to piperacillin-tazobactam, carbapenems, and amikacin was reported.
Mei	2024	BMC Urology	Preoperative cultures (non-procedure-specific)	Adults; China	Urinary calculi predisposed to UTI, SIRS, and sepsis; antibiotic exposure heterogeneous across 2002-2022	Rising resistance to piperacillin and cefotaxime; low carbapenem resistance	Gram-negative predominance declined over time with a relative increase in Gram-positive organisms. Resistance was higher in males and older adults in subgroup analyses.
Jenrette	2024	Academic Emergency Medicine	Complicated cystitis (non-procedure-specific)	31% male; median age 63; USA	Complicated cystitis in patients with factors including kidney stones, catheters or urinary hardware, immunocompromise, prior MDR organisms, and lack of viable oral options	MDR Enterobacterales; preserved aminoglycoside susceptibility	Single-dose intravenous aminoglycosides were reported as effective and safe. Treatment failure was linked to stones or hardware and the need for source control.

Continued

Wagenius	2020	Scandinavian Journal of Urology	PCNL	55.9% male; mean age 59.6; Sweden	Large or complex stones; positive preoperative urine and/or stone cultures; perioperative prophylaxis, mainly cefotaxime	*E. faecalis*; *E. coli* (including ESBL); rare carbapenemase-producing *E. coli*	Culture positivity was associated with post-PCNL complications. Stone culture was described as a stronger predictor than bladder urine, and the prevalence of *E. faecalis* was highlighted in relation to prophylaxis spectrum.
Mohseni	2022	Western Journal of Emergency Medicine	UTI (stone history)	Female only; median age 49; USA	Outpatient UTI in patients with prior nephrolithiasis history; empirical antibiotic treatment	Nitrofurantoin-resistant uropathogens	Stone history was associated with nitrofurantoin resistance (reported OR 3.24 in the extracted table), and ciprofloxacin resistance increased with age.
Mohammed	2022	Archives of Razi Institute	Stones/ catheter-associated UTI	Adults; Iraq	Recurrent UTI, kidney stones, and long-term catheter use	MDR *E. coli*	MDR stone-associated isolates were reported, with a predominantly mechanistic and laboratory-based emphasis.
Walton-Diaz	2017	International Urology and Nephrology	PCNL	64.7% male; mean age 51; Chile/ Argentina	Large or staghorn stones; preoperative urine-guided therapy and prophylaxis	MDR *Enterococcus*/ *Enterobacter*/ *Staphylococcus*; fungi; discordant preoperative midstream urine culture	Renal pelvic urine and stone cultures were described as outperforming midstream urine for prediction of post-PCNL sepsis, and stones were characterised as MDR reservoirs.
Patel	2025	BMJ Case Reports	Nephrectomy	Female; mid-30s; USA	Nephrolithiasis with hydronephrosis, chronic pyelonephritis, and refractory infection; multiple prior regimens failed	MDR non-typhoidal *Salmonella*	A persistent infectious nidus was attributed to stones and a non-functioning kidney; definitive source control was achieved by nephrectomy.
Albayrak	2020	European Journal of Hospital Pharmacy	Indwelling ureteric stent	Male; 25 years; Türkiye	Nephrolithiasis with repeated instrumentation and colistin intolerance	XDR *Pseudomonas aeruginosa*	Combination therapy achieved microbiological clearance despite apparent *in vitro* resistance.

Continued

Cho	2021	Journal of Korean Medical Science	Upper tract stones (febrile UTI; non-procedure-specific)	Female 69.5%, male 30.5%; mean age 62; South Korea	Febrile UTI with stones; hydronephrosis common; multiple stones 21%; antibiotic exposure within 90 days in 29.6%; recurrent UTI in 23.2%	Quinolone-resistant organisms; cefotaxime-resistant organisms; ESBL Enterobacterales (~19.6%)	Stone multiplicity predicted quinolone resistance, while recurrent UTI predicted cefotaxime resistance.
Mert	2023	Medicine (Baltimore)	PN catheter	58.3% male (recurrent cohort); mean age approximately 58; Türkiye	Cancer-related obstruction managed with PN; antibiotic use in the prior 3 months common; repeated infection episodes	ESBL *E. coli*/*K. pneumoniae*; carbapenem-resistant *Klebsiella*	Kidney stones were reported as an independent risk factor for recurrent PN-related UTI with MDR pathogens, and prolonged catheterisation amplified this risk.

Note: Table S2 presents selected extracted examples from the included literature and is intended to illustrate patient subgroup characteristics and clinical scenarios in which antimicrobial resistance burden was reported. It does not represent an exhaustive subgroup extraction for all 31 included studies.

Table S3. Stewardship-related content extracted from included studies, grouped according to whether AMS was explicitly framed in the source publication.

AMS Framing	Patient/ Context	Organism(s)	Antibiotic(s) Mentioned	Key Point on Antibiotic Management	Reference
Implicit	Nephrolithiasis with complicated UTI	cKP; hvKP	Gentamicin; tobramycin; amikacin; ciprofloxacin; ofloxacin; ceftriaxone; ceftazidime; cephalothin; trimethoprim-sulfamethoxazole; tetracycline; amoxicillin; clindamycin; nitrofurantoin; imipenem	Antimicrobial selection was described as patient-specific, and MDR risk was reported.	Zafar 2019
Implicit	Urinary stone disease with UTI	*E. coli*; *K. pneumoniae*; *Enterococcus* spp.; *P. aeruginosa*; *P. mirabilis*; *Candida* spp.	Piperacillin/tazobactam; imipenem; meropenem; amikacin; gentamicin; tobramycin; levofloxacin; ciprofloxacin; ceftriaxone; ceftazidime; cefoperazone/sulbactam; cefotetan; nitrofurantoin; penicillin; ampicillin; tetracycline; vancomycin; aztreonam; trimethoprim-sulfamethoxazole	Empirical selection was described as taking age and local susceptibility patterns into account; lower-resistance agents were described as candidates to reserve.	Gu 2022
Implicit	Urinary stone disease (longitudinal resistance surveillance)	*E. coli*; *K. pneumoniae*; *P. mirabilis*; *P. aeruginosa*; *A. baumannii*; *E. cloacae*; *Enterococcus* spp.; *S. aureus*	Ampicillin; ampicillin/sulbactam; piperacillin; piperacillin/tazobactam; cefazolin; cefuroxime; cefoxitin; ceftazidime; ceftriaxone; cefotaxime; cefoperazone/sulbactam; cefepime; amikacin; gentamicin; ciprofloxacin; levofloxacin; aztreonam; imipenem; co-trimoxazole; vancomycin; linezolid	Selection was described as guided by culture and susceptibility testing; long-term surveillance and avoidance of inappropriate use were described in relation to resistance prevention.	Mei 2024

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Explicit	Complicated cystitis (antibiotic-sparing strategy)	Enterobacterales	Amikacin; gentamicin; tobramycin	Single-dose aminoglycoside therapy was described as achieving high urinary concentrations while minimising exposure and avoiding admission or prolonged intravenous therapy.	Jenrette 2024
Implicit	Nephrolithiasis (postoperative infection risk stratification)	Gram-negative uropathogens	Culture-guided preoperative therapy; intraoperative prophylaxis with cefazolin for negative cultures or susceptibility-guided therapy for positive cultures; amikacin; carbapenems; fluoroquinolones; cephalosporins	Positive preoperative MDR culture was described as a strong risk factor for postoperative infection; empirical therapy was described as guided by local resistance data and culture results.	Senocak 2018
Implicit	PCNL	*E. faecalis*; *E. coli*; coagulase-negative *Staphylococcus*; *Klebsiella* spp.; *Pseudomonas* spp.; *Proteus mirabilis*	Cefotaxime; aminoglycosides; ciprofloxacin; pivmecillinam; nitrofurantoin; trimethoprim-sulfamethoxazole; occasional carbapenems; piperacillin/tazobactam	Culture-guided selection was described; broad-spectrum agents were described as reserved for treatment rather than routine prophylaxis, and unnecessary antibiotic use was described as increasing risk.	Wagenius 2020
Explicit	Obstructing ureteral calculi requiring urgent decompression	UTI-associated uropathogens	Broad-spectrum antibiotics (classes described in the study context)	Longer antibiotic duration and longer delay to stone treatment were described as not reducing postoperative urosepsis; prolonged exposure was described as increasing resistance and adverse-effect risk.	Orr 2023
Explicit	RIRS (prophylaxis individualisation)	*E. coli*; *K. pneumoniae*; *P. aeruginosa*	Fluoroquinolones; aminoglycosides; ampicillin/sulbactam; cephalosporins	Routine fluoroquinolone prophylaxis was challenged in high-resistance or prior-exposure contexts; prophylaxis was described as individualised according to resistance risk.	Cai 2021
Explicit	PCNL with positive urine culture (antibiotic minimisation trial)	ESBL *E. coli*; *K. pneumoniae*; *P. aeruginosa*; coagulase-negative *Staphylococcus*	Culture-sensitive antibiotics; long course (approximately 1 week) versus short course (48 h preoperative plus 48 h postoperative)	Short-course culture-directed prophylaxis was described as non-inferior to prolonged regimens for preventing SIRS and sepsis while limiting antibiotic exposure.	Patel 2023

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Explicit	UTI-prone populations including nephrolithiasis (review)	UPEC; *Proteus mirabilis*; *P. aeruginosa*; *Enterococcus faecalis*; MRSA; ESBL organisms	Contextual discussion of antibiotics together with non-antibiotic adjuvants, including phytoestrogens, mannosides, and methenamine	Antibiotic misuse and prolonged treatment courses were framed as drivers of resistance; antibiotic-sparing approaches and adjunctive strategies were described.	He 2025

Abbreviations: AMS, antimicrobial stewardship; ESBL, extended-spectrum beta-lactamase; MDR, multidrug resistant; MRSA, methicillin-resistant *Staphylococcus aureus*; PCNL, percutaneous nephrolithotomy; RIRS, retrograde intrarenal surgery; SIRS, systemic inflammatory response syndrome; TMP-SMX, trimethoprim-sulfamethoxazole; UPEC, uropathogenic *Escherichia coli*; UTI, urinary tract infection. **Note:** Table S3 presents stewardship-related extraction fields from studies in which antibiotic selection, prophylaxis, duration, de-escalation, or antibiotic-sparing approaches were discussed. "Explicit" indicates that antimicrobial stewardship was directly framed in the source publication, whereas "Implicit" indicates stewardship-relevant content without direct AMS terminology.