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Microbiological Characteristics of Infection-Related Urolithiasis: Comparative Analysis of Renal Pelvic Urine and Stone Cultures

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Abstract: Background. Infection-related urolithiasis is characterized by persistent microbial colonization and a high risk of recurrence, largely due to biofilm formation and the presence of bacteria within stone structures. Standard diagnostic approaches based on urine cultures may not fully reflect the underlying infectious process. Objective. To investigate the microbiological characteristics of infection-related urolithiasis by comparing bacteriological findings in renal pelvic urine and stone fragments obtained during percutaneous nephrolithotripsy (PCNL), and to assess their clinical significance. Materials and Methods. This study included 268 patients with infection-related urolithiasis who underwent PCNL. Bacteriological analysis of renal pelvic urine and intraoperatively obtained stone fragments was performed using standard culture techniques. Clinically significant bacteriuria was defined as $\geq 10^4$ CFU/mL. The distribution of microorganisms, concordance between urine and stone cultures, and intergroup comparability were evaluated using appropriate statistical methods. Results. Microbial colonization of stone fragments was detected in 61.2% of patients, while renal pelvic urine cultures were positive in 51.5% of cases. The most frequently isolated pathogens were Escherichia coli, Proteus mirabilis, and Enterococcus faecalis. Complete concordance of sterility between urine and stone cultures was observed in 37.3% of patients, whereas simultaneous infection of both materials was identified in 39.2%. In 16.4% of cases, stones were infected despite sterile urine, indicating the presence of hidden microbial reservoirs. No significant differences were found between study groups in baseline microbiological characteristics ($p > 0.05$). Conclusion. Infection-related urolithiasis is associated with a high prevalence of microbial colonization and frequent discordance between urine and stone cultures, highlighting the role of calculi as reservoirs of persistent infection and emphasizing the importance of comprehensive intraoperative microbiological assessment.

Keywords: Infection-related urolithiasis; renal pelvic urine; stone culture; microbial colonization; bacteriological discordance.

Introduction: Urolithiasis is a widespread urological condition characterized by a high prevalence and a pronounced tendency toward recurrence. Among its various forms, infection-related nephrolithiasis occupies a special place due to its complex pathogenesis, rapid stone growth, and strong association with urinary tract infections. These stones are most commonly composed of struvite and carbonate apatite and are formed under conditions of persistent bacterial colonization by urease-producing microorganisms [1,2,3].

The development of infection stones is closely linked to the ability of uropathogens to produce urease, leading to urine alkalinization and subsequent crystallization processes. In addition, bacterial biofilm formation within the pelvicalyceal system and on the surface of calculi plays a key role in maintaining chronic infection. Biofilms protect microorganisms from host immune responses and significantly reduce the effectiveness of systemic antibiotic therapy, thereby contributing to persistence of infection and recurrence of stone formation. Percutaneous nephrolithotripsy (PCNL) is currently considered the method of choice for the treatment of large and complex renal calculi, including infection-related stones [1,4,5,6]. However, despite advances in surgical techniques, complete eradication of infection is not always achieved. Residual stone fragments and persistent microbial colonization remain important risk factors for postoperative infectious complications and recurrence.

Standard management strategies include systemic antibiotic therapy guided by microbiological findings and long-term metaphylaxis. Nevertheless, these approaches may be insufficient due to limited antibiotic penetration into biofilms and increasing antimicrobial resistance. Therefore, additional strategies aimed at improving local infection control are of considerable interest. Intraoperative bacteriological assessment of both urine and stone material has gained increasing attention, as it allows for a more accurate evaluation of the infectious process. In particular, discrepancies between urine and stone cultures may indicate the presence of hidden microbial reservoirs within the calculi [2,7,8,9].

The aim of this study was to investigate the microbiological characteristics of infection-related urolithiasis by comparing bacteriological findings in renal pelvic urine and stone fragments obtained during PCNL, as well as to assess their clinical significance in understanding the persistence of infection.

METHODS

The clinical phase of the study was conducted in the Department of Urology at Nasaf Medical Center (Karshi, Uzbekistan) and included 268 patients (active and former military personnel) diagnosed with infection-related urolithiasis who underwent PCNL. All patients were examined and treated according to a unified study protocol. The study population was formed using a consecutive sampling method based on predefined inclusion criteria.

The patients' age ranged from 18 to 79 years, with a mean age of 48.7±12.4 years and a median of 49 years.

Screening was performed based on the following criteria: confirmed infectious etiology of the stones, positive bacteriological culture of urine and/or stone material, and established indications for PCNL. After screening, all 268 patients were enrolled and allocated into parallel groups. The control group consisted of 130 patients who received standard prophylaxis, including systemic antibiotic therapy guided by antibiotic susceptibility testing (antibiogram) and conventional metaphylaxis. The main group included 138 patients who, in addition to standard therapy, underwent intrapelvic administration of dioxidine via an indwelling nephrostomy drain in the early postoperative period.

Bacteriological analyses were performed in a specialized laboratory. Urine cultures were obtained using a standard calibrated loop technique on 5% blood agar, followed by quantification of colony-forming units (CFU) and assessment of bacteriuria severity. Clinically significant bacteriuria was defined as $\geq 10^4$ CFU/mL. For stone culture, a fragment of the calculus obtained intraoperatively under sterile conditions was placed in a sterile container and immediately transported to the microbiology laboratory. In parallel, a portion of the stone fragments was analyzed for mineral composition using infrared spectroscopy.

Statistical analysis was performed using Statistica for Windows, version 6.1 (StatSoft Inc., USA).

RESULTS

Bacteriological analysis of stone fragments obtained during percutaneous nephrolithotripsy revealed microbial colonization in 61.2% of patients in the overall cohort. No microbial growth was detected in 38.8% of cases, with no significant differences observed between the main and control groups (p=0.706). Among the identified pathogens, the most frequently isolated microorganisms were Proteus mirabilis (12.7%), Escherichia coli (11.9%), and Enterococcus faecalis (10.8%). These microorganisms are traditionally associated with infection-related nephrolithiasis and contribute to the formation of struvite and carbonate apatite calculi. Pseudomonas aeruginosa was detected in 7.1% of cases,

predominantly in patients with a complicated urological history. No statistically significant differences in the microbial composition of the stones were found between the main and control groups ($p > 0.05$ for all comparisons), confirming the comparability of the groups in terms of baseline infectious status. Thus, the bacteriological profile of the stones reflects the predominance of typical uropathogens involved in the pathogenesis of infection-related stone formation and provides a pathogenetic rationale for the use of local antimicrobial prophylaxis (Fig. 1).

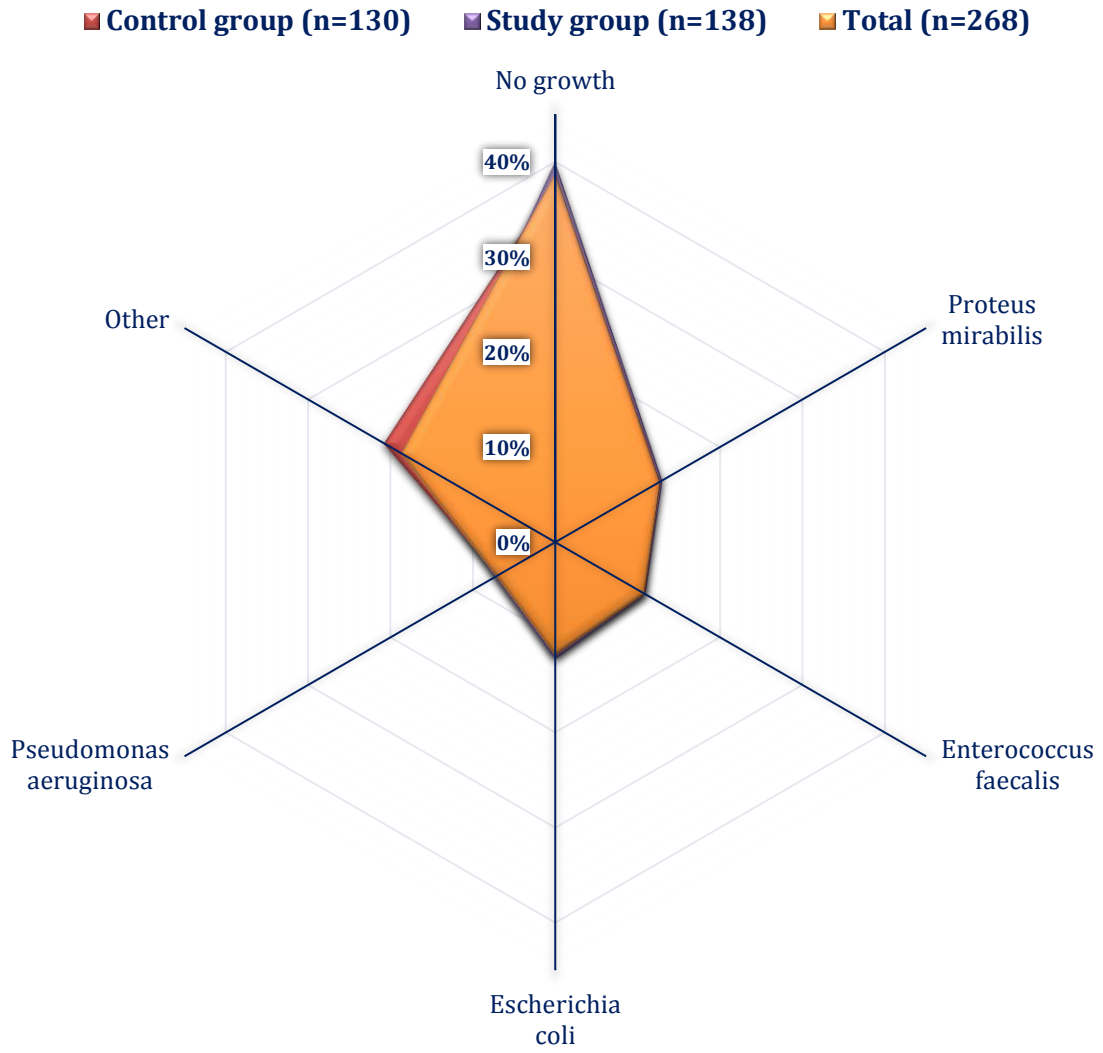

Figure 1. Petal diagram showing the distribution of microorganisms identified in bacteriological analysis of stone fragments obtained during PCNL.

Bacteriological analysis of urine obtained from the renal pelvis intraoperatively revealed microbial contamination in 51.5% of patients in the overall cohort. No microbial growth was detected in 48.5% of cases. The rate of sterile cultures did not differ significantly between the main and control groups ($p = 0.798$). Among the identified uropathogens, the most frequently isolated microorganisms were Escherichia coli (14.6%), Enterococcus faecalis (11.9%), and Proteus mirabilis (11.2%). These organisms are typical causative agents of infection-related nephrolithiasis and are involved in the formation of struvite and carbonate apatite stones.

Pseudomonas aeruginosa was detected in 6.3% of cases, predominantly in patients with a complicated urological history. No statistically significant differences in the microbial composition of renal pelvic urine were observed between the main and control groups ($p>0.05$ for all comparisons), confirming baseline comparability of the groups in terms of infectious status (Fig. 2). Overall, these findings indicate a high prevalence of microbial colonization of the pelvicalyceal system in infection-related nephrolithiasis and support the need for active intraoperative and postoperative antimicrobial prophylaxis.

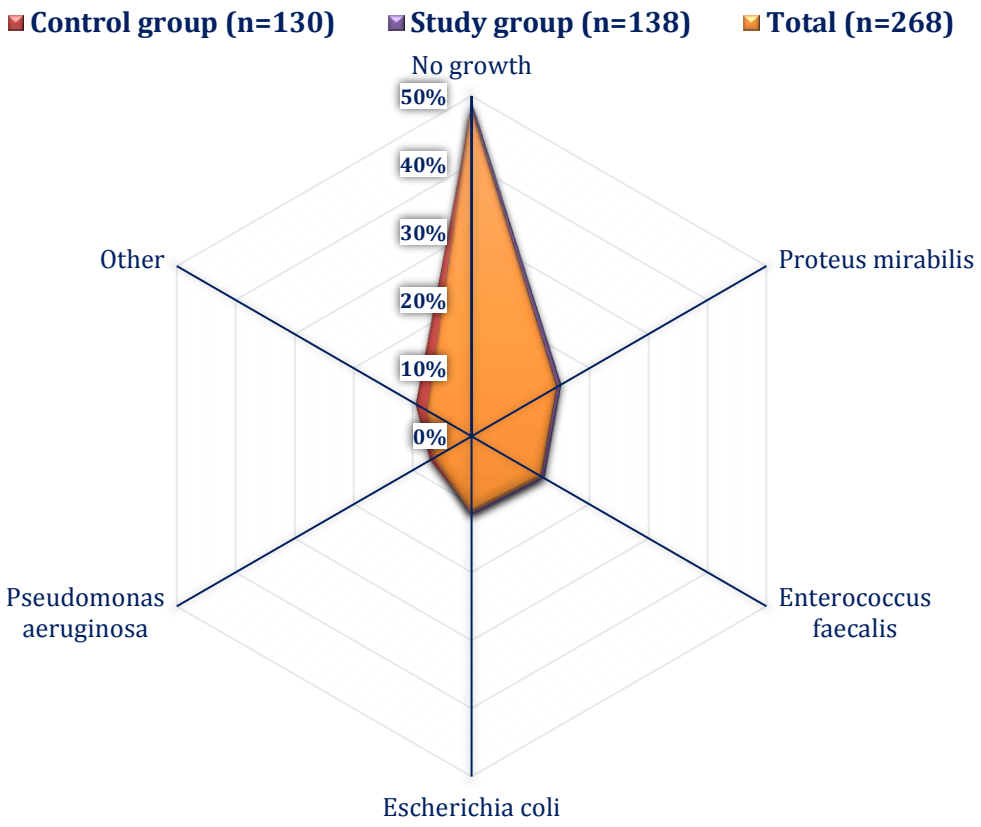

Figure 2. Petal diagram showing the distribution of microorganisms identified in bacteriological analysis of renal pelvic urine obtained during PCNL.

Comparison of bacteriological findings from renal pelvic urine and stone fragments demonstrated complete concordance of sterility in both samples in 37.3% of patients. Concurrent infection of both urine and stone was identified in 39.2% of the overall cohort. This subgroup is of particular clinical relevance, as it indicates the presence of a persistent infectious focus within the pelvicalyceal system.

In 16.4% of cases, renal pelvic urine was sterile, whereas the stone exhibited microbial colonization. This finding supports the concept that calculi may serve as a reservoir of infection even in the absence of active bacteriuria. Conversely, infected urine with a sterile stone was observed in 7.1% of patients, which may reflect transient bacteriuria or superficial colonization without deep microbial incorporation into the stone matrix.

No statistically significant differences were found between the main and control groups ($p>0.05$), confirming their comparability in terms of baseline infectious status. These results highlight the importance of intraoperative bacteriological assessment of not only urine but also stone fragments, as infection may persist within the calculus in a substantial proportion of cases (Table 1).

Table 1.

Distribution of Microbial Findings in Renal Pelvic Urine and Stone Samples Obtained During PCNL.

Material	Control group (n=130)	Main group (n=138)	Total (n=268)	*p*
Sterile urine – sterile stone	48 (36.9%)	52 (37.7%)	100 (37.3%)	*0.893*
Sterile urine – infected stone	21 (16.2%)	23 (16.7%)	44 (16.4%)	*0.914*
Infected urine – infected stone	50 (38.5%)	55 (39.9%)	105 (39.2%)	*0.811*
Infected urine – sterile stone	11 (8.5%)	8 (5.8%)	19 (7.1%)	*0.384*
Total	130 (100%)	138 (100%)	268 (100%)	—

DISCUSSION

The present study provides a detailed analysis of the microbiological characteristics of infection-related urolithiasis, highlighting the high prevalence of microbial colonization in both stone material and renal pelvic urine. Microbial colonization of stone fragments was detected in more than half of the patients, while renal pelvic urine cultures were positive in approximately half of the cases. The predominance of Escherichia coli, Proteus mirabilis, and Enterococcus faecalis among the identified pathogens is consistent with existing data on the etiology of infection-related nephrolithiasis. These microorganisms are well known for their role in urease activity, biofilm formation, and promotion of struvite and carbonate apatite stone formation.

An important finding of this study is the observed discordance between urine and stone culture results in a substantial proportion of patients. While complete concordance of sterility was noted in only about one-third of cases, nearly 40% of patients demonstrated simultaneous infection of both urine and stone, indicating the presence of a persistent infectious focus within the pelvicalyceal system. This subgroup is particularly relevant from a clinical perspective, as it is associated with an increased risk of postoperative infectious complications and recurrence.

Of particular interest is the subgroup of patients with sterile urine but infected stones. This finding supports the concept that calculi can act as a reservoir of infection, harboring microorganisms within their structure even in the absence of detectable bacteriuria. Such hidden infection may not be adequately addressed by standard systemic antibiotic therapy, which further emphasizes the limitations of relying solely on urine culture results for clinical decision-making [2,4,8,10]. Conversely, cases of infected urine with sterile stones likely reflect transient bacteriuria or superficial colonization without deep microbial incorporation into the stone matrix. This distinction is clinically important, as it may influence both treatment strategies and prognosis.

The absence of significant differences between the study groups in terms of baseline microbiological characteristics confirms their comparability and strengthens the validity of the findings. Overall, the results underline the importance of comprehensive intraoperative microbiological assessment, including both urine and stone cultures, for accurate evaluation of the infectious process. From a clinical standpoint, these findings support the rationale for more aggressive antimicrobial strategies, particularly those targeting local infection within the pelvicalyceal system. Addressing microbial persistence within stones may be crucial for improving treatment outcomes and reducing recurrence rates.

Several limitations should be acknowledged. The study was conducted at a single center and included a relatively specific patient population, which may limit the generalizability of the results. Additionally, molecular methods for pathogen detection were not used, which may underestimate the true prevalence of microbial colonization. Future studies incorporating advanced diagnostic techniques and larger multicenter cohorts are warranted.

CONCLUSION

The results of the present study demonstrate that infection-related urolithiasis is characterized by a high prevalence of microbial colonization of both stone material and renal pelvic urine, with frequent discordance between culture findings, indicating that calculi may serve as persistent reservoirs of infection even in the absence of bacteriuria, thereby underscoring the critical importance of comprehensive intraoperative microbiological assessment and supporting the need for targeted antimicrobial strategies aimed at eradicating infection within the pelvicalyceal system.

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