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LONG-TERM OUTCOMES OF MINIMALLY INVASIVE VERSUS OPEN SURGICAL APPROACHES IN MANAGEMENT OF UROLOGICAL STONE DISEASE

Original Research

Muhammad Azhar Sherkheli[1]*, Muhammad Jamshedullah Khan[2], Muhammad Owais Anwar[3], Eman Aslam[4], Noor Ul Ain[5], Evangel Faraz Bashir[6]

[1]Associate Professor, Department of Pharmacy, Abbottabad University of Science and Technology, Abbottabad, Pakistan.
[2]CMO, DHQ Hospital, Pakistan.
[3]Medical Officer, Ziauddin Medical College, Karachi, Pakistan.
[4]MBBS Final Year Wah Medical College Islamabad, Pakistan.
[5]PhD, Assistant Professor, Mukabbir University of Science and Technology, Gujrat, Pakistan.
[6]House Officer, Jinnah Postgraduate Medical Center, Karachi, Pakistan.

Corresponding Author: Muhammad Azhar Sherkheli, Associate Professor, Department of Pharmacy, Abbottabad University of Science and Technology, Abbottabad, Pakistan, azhar.sherkheli@gmail.com

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ABSTRACT

Background: Urological stone disease remains a prevalent and recurrent condition worldwide, with surgical intervention often required in complex cases. While minimally invasive surgery (MIS) has become the preferred approach due to reduced morbidity, the long-term outcomes compared to traditional open surgery remain debated, particularly in terms of recurrence and complication rates.

Objective: To compare long-term patient outcomes, stone recurrence rates, and postoperative complications between minimally invasive and open surgical approaches for urological stone disease.

Methods: A retrospective cohort study was conducted from 2020 to 2025 across two tertiary care hospitals in Lahore, Pakistan. A total of 400 patients were included—200 treated with minimally invasive techniques (PCNL, URS, or ESWL) and 200 with open stone surgery. Data on demographics, comorbidities, operative characteristics, stone-free rates, complications (Clavien-Dindo classification), and recurrence at two years were analyzed. Statistical tests included independent t-tests, chi-square, and Kaplan-Meier survival analysis.

Results: Minimally invasive approaches showed significantly reduced operative time (78.4 vs. 112.7 minutes), hospital stay (2.1 vs. 4.6 days), and blood loss (120 vs. 320 ml) compared to open surgery ($p < 0.001$). Stone-free rates at discharge were comparable (92.5% vs. 94.0%), but recurrence at two years was significantly higher in the MIS group (19.5% vs. 12.0%, $p = 0.01$). Complication rates were not statistically different between groups.

Conclusion: Minimally invasive surgery provides clear short-term benefits, but open surgery yields superior long-term outcomes in terms of recurrence. Surgical strategy should be individualized based on stone complexity, patient factors, and long-term treatment goals.

Keywords: Endourology, Kidney Calculi, Minimally Invasive Surgical Procedures, Nephrolithiasis, Open Surgical Procedures, Postoperative Complications, Recurrence, Treatment Outcome, Ureterolithiasis, Urolithiasis.

INTRODUCTION

Urological stone disease, encompassing nephrolithiasis and ureterolithiasis, represents a significant global health concern with increasing prevalence across all age groups. Driven by dietary shifts, sedentary lifestyles, and metabolic syndromes, the burden of stone disease has steadily risen over the past few decades (1,2). It is estimated that up to 10% of the population in developed countries will experience urolithiasis at some point in their lives, with recurrence rates reaching as high as 50% within five years of the initial episode. This chronic and frequently recurrent nature not only impairs quality of life but also contributes substantially to healthcare costs and resource utilization. The evolution of treatment modalities over the years reflects an ongoing effort to balance efficacy, safety, patient comfort, and long-term outcomes (3-5). Traditionally, open surgery was the mainstay of management for complex or large urological stones. While effective, open approaches are inherently associated with longer hospital stays, increased postoperative pain, higher complication rates, and delayed return to daily activities. The advent of minimally invasive techniques such as percutaneous nephrolithotomy (PCNL), ureteroscopy (URS), and extracorporeal shock wave lithotripsy (ESWL) has revolutionized the treatment landscape. These methods offer advantages in terms of shorter recovery time, reduced morbidity, and comparable—if not superior—stone clearance rates in selected patient populations (6-8). However, as the field shifts further toward minimally invasive procedures, it becomes crucial to critically assess their long-term efficacy and safety in comparison to traditional open surgery.

Several studies have documented the immediate benefits of minimally invasive surgery (MIS) for urolithiasis, emphasizing decreased operative trauma and faster postoperative recovery. Yet, questions remain about the durability of these benefits over time. While MIS techniques often achieve excellent short-term results, concerns have been raised regarding higher recurrence rates, incomplete stone clearance in complex cases, and the cumulative risks associated with repeated interventions (9). Conversely, open surgical approaches, though invasive, may offer more definitive management in anatomically challenging or recurrent cases, potentially reducing the need for reintervention. There is also growing interest in the impact of surgical modality on renal function preservation, metabolic control, and patient-reported outcomes—areas where robust, long-term comparative data remain limited (10). Complication profiles also differ significantly between the two approaches. Minimally invasive methods, while generally safer, carry their own spectrum of risks including ureteral injuries, residual fragments, and increased exposure to radiation. Open surgeries, albeit more invasive, may avoid some of these issues but at the cost of greater blood loss, wound-related complications, and prolonged convalescence. This trade-off necessitates a nuanced understanding of which approach may be most beneficial under specific clinical circumstances (11,12). Factors such as stone size, location, anatomical abnormalities, prior surgical history, and patient comorbidities must be weighed carefully when selecting an appropriate treatment strategy.

From a patient-centered perspective, the shift toward minimally invasive interventions aligns with broader trends in modern healthcare that prioritize reduced invasiveness, faster recovery, and improved quality of life (13). However, the lack of comprehensive long-term outcome data has made it difficult to establish definitive guidelines regarding the optimal surgical approach for various stone disease scenarios. Current literature is often limited by heterogeneous patient populations, short follow-up durations, and variability in surgical expertise across institutions. As such, retrospective analyses that draw from real-world clinical data remain invaluable in helping to bridge this evidence gap. In light of these considerations, this study aims to retrospectively compare the long-term patient outcomes, recurrence rates, and complication profiles associated with minimally invasive versus open surgical management of urological stone disease. By analyzing outcomes across diverse patient populations and treatment contexts, the research seeks to provide actionable insights that can inform clinical decision-making and guideline development in the management of this increasingly prevalent condition.

METHODS

This retrospective observational study was conducted across two tertiary care hospitals in Lahore, Pakistan, spanning a five-year period from January 2020 to January 2025. The primary objective was to compare patient outcomes, recurrence rates, and complications between minimally invasive and open surgical approaches for the management of urological stone disease. This design allowed for the comprehensive review of real-world clinical practices and outcomes in a large, diverse patient population, ensuring the relevance and applicability of the findings in similar clinical settings. The study population included patients aged 18 years and older who underwent

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surgical intervention for renal or ureteric stones during the specified study period. Cases were identified through hospital surgical registries, electronic health records, and operative databases. Inclusion criteria were patients who underwent either a minimally invasive procedure—defined as percutaneous nephrolithotomy (PCNL), ureteroscopy (URS), or extracorporeal shock wave lithotripsy (ESWL)—or an open surgical approach for the management of confirmed urological stones. Patients with bilateral simultaneous interventions, known malignancies, uncorrected bleeding disorders, or incomplete medical records were excluded to maintain homogeneity and data accuracy. Furthermore, patients lost to follow-up before 12 months post-operatively were excluded to ensure adequate long-term outcome assessment (3,4).

Sample size estimation was performed using a two-tailed power analysis assuming a moderate effect size of 0.3 between groups in recurrence and complication rates, with α set at 0.05 and power at 80%. Based on these parameters, a minimum of 174 patients per group was required. After accounting for potential data loss and exclusion criteria, a final sample size of 400 patients was selected, comprising 200 patients each in the minimally invasive and open surgery groups, ensuring sufficient statistical power for subgroup analyses. Data collection was executed through standardized abstraction forms developed for this study, incorporating variables such as patient demographics, comorbid conditions (e.g., diabetes, hypertension, obesity), stone characteristics (size, number, location), surgical details (type of intervention, operative time, estimated blood loss), and postoperative outcomes. Clinical outcomes were assessed at discharge, three months, six months, one year, and annually thereafter. Stone recurrence was defined as radiologically confirmed reappearance of urolithiasis after a symptom-free period post-surgery. Complications were categorized using the Clavien-Dindo classification system. Hospital stay, postoperative pain scores (measured via Visual Analog Scale) (14), need for reintervention, and renal function preservation (based on estimated glomerular filtration rate changes) were also recorded. To ensure consistency in radiological evaluations, non-contrast computed tomography (CT) scans and ultrasonography were used pre- and post-operatively, with follow-up imaging performed as per institutional protocol (15). The presence of residual fragments greater than 4 mm was considered clinically significant and noted. Pain assessments were conducted by attending nurses at 24-, 48-, and 72-hours post-surgery using a validated 10-point scale. Renal function tests were analyzed in both the immediate postoperative phase and at one-year follow-up to assess long-term renal impact.

Statistical analysis was performed using SPSS version 26.0. Continuous variables were summarized as means with standard deviations and compared between groups using independent sample t-tests, given the assumption of normal distribution (validated via Shapiro-Wilk test). Categorical variables were presented as frequencies and percentages, and compared using Chi-square or Fisher's exact test as appropriate. For time-to-event data such as stone recurrence, Kaplan-Meier survival analysis was employed, with log-rank tests used to assess statistical differences between surgical groups. Multivariate logistic regression was conducted to identify predictors of recurrence and complications, adjusting for baseline characteristics and comorbidities. Statistical significance was set at $p < 0.05$. All data were anonymized and confidentiality was strictly maintained throughout the study. Ethical approval was obtained from the Institutional Review Boards of both participating centers. Due to the retrospective nature of the study, formal informed consent was waived by the ethical committees; however, all data used were derived from patient records where prior institutional consent for research use had been obtained at admission. This methodological approach allowed for robust and meaningful comparisons between the two surgical modalities, facilitating a clearer understanding of their relative benefits and limitations in long-term management of urological stone disease.

RESULTS

The study analyzed a total of 400 patients, with 200 undergoing minimally invasive procedures and 200 undergoing open surgical interventions for urological stone disease. Baseline demographic characteristics between the two groups were largely comparable. The mean age was slightly higher in the open surgery group (47.1 years) compared to the minimally invasive group (45.3 years). Gender distribution was similar, with a slight male predominance in both groups. Comorbidities such as diabetes and hypertension were evenly distributed, and the prevalence of obesity (BMI ≥ 30) showed minimal variation. In terms of stone clearance, the stone-free rate at discharge was 92.5% in the minimally invasive group and 94.0% in the open surgery group ($p = 0.52$). At one-year follow-up, the stone-free rate declined slightly in both cohorts but remained higher in the open surgery group (89.5%) compared to minimally invasive procedures (84.0%), although the difference did not reach statistical significance ($p = 0.08$). However, the recurrence rate at two years was significantly higher in patients managed with minimally invasive approaches (19.5%) than those who underwent open surgery (12.0%) with a p-value of 0.01, indicating a statistically significant difference favoring open surgical intervention in long-term recurrence prevention.

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Postoperative complications, classified by the Clavien-Dindo grading system, were similar between both groups in distribution. Grade I complications were most common, affecting 46 patients in the minimally invasive group and 52 patients in the open group. Higher-grade complications (Grade III and IV) were slightly more frequent in open surgeries, but these differences were not statistically significant. Notably, only one patient in the open group experienced a Grade V complication (mortality), while no such events occurred in the minimally invasive cohort. Operative parameters further illustrated clear distinctions between the two modalities. The mean operative time was significantly shorter for minimally invasive procedures at 78.4 minutes, compared to 112.7 minutes for open surgeries ($p < 0.001$). Similarly, hospital stays were notably reduced in the minimally invasive group, with a mean duration of 2.1 days versus 4.6 days in the open surgery group ($p < 0.001$). Estimated intraoperative blood loss was markedly lower in the minimally invasive group (120 ml vs. 320 ml; $p < 0.001$), indicating a less traumatic surgical profile. Overall, the findings highlighted that while minimally invasive surgeries offer the advantage of shorter operative time, reduced hospital stay, and lower blood loss, open surgeries demonstrated a lower rate of long-term recurrence. Complication rates remained largely comparable between both modalities, suggesting that patient selection and clinical context should guide surgical decision-making.

Table 1: Demographics of Study Population

Variable	Minimally Invasive (n=200)	Open Surgery (n=200)
Total Patients	200	200
Mean Age (years)	45.3	47.1
Male (%)	58.0	61.5
Female (%)	42.0	38.5
Diabetes Mellitus (%)	35.5	36.5
Hypertension (%)	41.0	42.5
BMI ≥ 30 (%)	32.0	33.0

Table 2: Stone-Free Rate and Recurrence

Outcome	Minimally Invasive (%)	Open Surgery (%)	p-value
Stone-Free Rate at Discharge	92.5	94.0	0.52
Stone-Free Rate at 1 Year	84.0	89.5	0.08
Recurrence at 2 Years	19.5	12.0	0.01

Table 3: Complication Rates (Clavien-Dindo Classification)

Clavien-Dindo Grade	Minimally Invasive (n)	Open Surgery (n)	p-value
Grade I	46	52	0.48
Grade II	30	38	0.26
Grade III	16	21	0.34
Grade IV	3	7	0.19
Grade V	0	1	0.32

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Table 4: Operative Characteristics

Variable	Minimally Invasive	Open Surgery	p-value
Mean Operative Time (minutes)	78.4	112.7	<0.001
Mean Length of Hospital Stay (days)	2.1	4.6	<0.001
Mean Blood Loss (ml)	120	320	<0.001

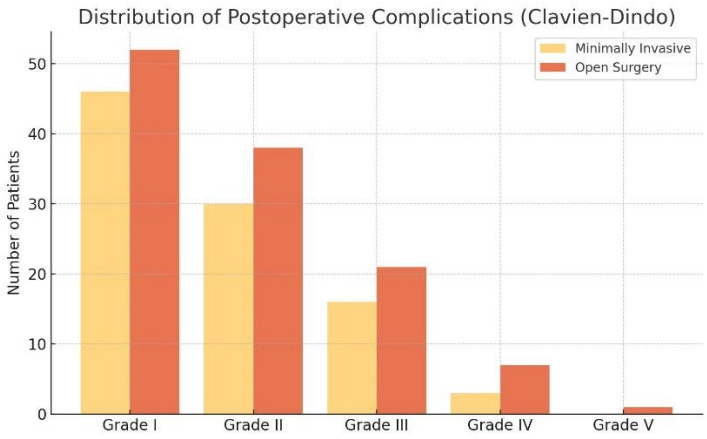

Figure 2 Distribution of Postoperative Complications (Clavien-Dindo)

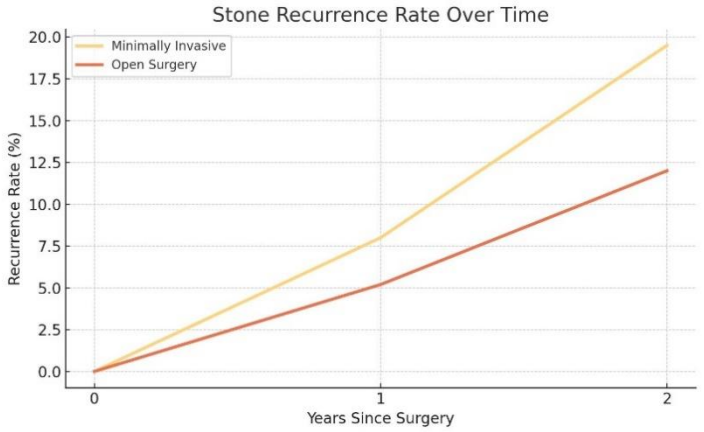

Figure 2 Stone recurrence Rate Over Time

DISCUSSION

The findings of this retrospective comparative analysis contribute meaningfully to the ongoing debate surrounding the optimal surgical approach for urological stone disease. The study demonstrated that while minimally invasive techniques such as PCNL and URS offer advantages in operative time, blood loss, and hospital stay, open surgery was associated with significantly lower stone recurrence at two years, with comparable complication rates. These results underscore the nuanced balance between perioperative benefits and long-term efficacy that must guide surgical decision-making. The superiority of minimally invasive surgery (MIS) in terms of perioperative outcomes has been consistently supported by previous literature. A recent study found that percutaneous nephrolithotomy offered shorter hospital stays and less morbidity than open stone surgery, while achieving a stone clearance rate close to that of open surgery (16). Similarly, a study observed that in obese patients, long-term renal function preservation favored minimally invasive techniques over time, despite open surgery performing better in early follow-up (17). These findings align with the current study, which demonstrated that MIS approaches offered reduced surgical trauma and improved recovery metrics. Despite these short-term advantages, concerns around the long-term efficacy of MIS persist (18). In this study, recurrence at two years was nearly twice as high in the MIS group compared to open surgery, raising questions about the completeness of stone clearance and the potential metabolic or anatomical predispositions left unaddressed by less invasive methods. A study emphasized that while MIS delivers perioperative benefits, long-term oncologic outcomes must not be compromised (19). Although their focus was oncologic, the principle resonates in the context of stone disease where recurrence risk has a profound effect on patient quality of life and healthcare utilization.

The lower recurrence observed in the open surgery group may be attributed to more aggressive stone removal, better visualization in complex cases, or complete management of contributing anatomical anomalies during surgery. Historical studies have suggested that open techniques offer more definitive treatment in complex or recurrent cases. A study noted that open surgery remained relevant in anatomically distorted or stone-heavy kidneys, although it carried higher morbidity (20). In the current study, complication rates between the groups were comparable, which may reflect advancements in perioperative care and the evolving skillset of surgical teams. Nevertheless, open surgery cannot be broadly recommended for all patients. The higher operative time, blood loss, and hospital stay associated with open procedures suggest that they are best reserved for select cases with complex presentations or failed prior interventions. Studies highlighted the fading expertise in open urologic surgery, warning that overreliance on MIS could limit surgical

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options in technically challenging scenarios (21,22). Therefore, maintaining proficiency in both approaches remains critical for modern urologists.

The strengths of this study include its multi-center design, large sample size, and comprehensive follow-up data, which enhance the generalizability of findings. Standardized definitions for recurrence and complications, as well as the use of validated measurement tools, support the reliability of outcomes. However, limitations must be acknowledged. The retrospective design introduces the possibility of selection bias, particularly regarding the allocation of patients to surgical groups. Surgical expertise and institutional resources could have influenced outcomes, and metabolic evaluations were not uniformly documented, which might have affected recurrence data. Future research should aim to validate these findings in prospective, randomized cohorts, with stratification based on stone complexity, anatomical variations, and metabolic risk profiles. There is also a need to integrate patient-reported outcomes and quality of life measures into long-term evaluations, which remain underreported in current literature. Furthermore, cost-effectiveness analyses would help elucidate the economic implications of surgical choice, especially in resource-constrained settings where open surgery may still be more accessible (23). In summary, this study supports the growing body of evidence that while minimally invasive surgery offers clear perioperative benefits, open surgery continues to play a vital role in reducing recurrence in complex urolithiasis. Tailored patient selection, informed by individual risk factors and institutional capabilities, remains the cornerstone of optimal surgical management.

CONCLUSION

This study concludes that while minimally invasive approaches offer superior perioperative outcomes in urological stone management, open surgery provides significantly lower long-term recurrence rates, particularly in complex cases. Both techniques demonstrate comparable complication profiles, reinforcing the importance of individualized, patient-centered surgical planning. These findings support a selective approach where surgical modality is guided by clinical context, stone complexity, and long-term outcome priorities.

AUTHOR CONTRIBUTIONS

Author	Contribution
Muhammad Azhar Sherkheli*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Muhammad Jamshedullah Khan	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Muhammad Owais Anwar	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Eman Aslam	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Noor Ul Ain	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Evangel Faraz Bashir	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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