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UROLITHIASIS

# The comparison of synchronous bilateral and unilateral percutaneous nephrolithotomy: Meta-analysis

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**Introduction** The objective of this meta-analysis was to evaluate the efficacy and safety of synchronous bilateral PCNL (B-PCNL) compared with staged unilateral PCNL (U-PCNL) in patients with bilateral kidney stones.

**Material and methods** This analysis was conducted in accordance with the PRISMA guidelines and was registered with PROSPERO (CRD420251036639). The study population comprised adult patients (≥18 years) diagnosed with bilateral nephrolithiasis and treated using B-PCNL or U-PCNL. The primary outcomes were stone-free rate (SFR) and complication rates (Clavien–Dindo). A literature search was performed using the PubMed, Web of Science, and Scopus databases for studies published between 1996 and 2024. Meta-analysis was performed using a random-effects model. Statistical analyses were conducted using IBM SPSS Statistics (Version 29), and a p-value <0.05 was considered statistically significant.

**Results** Seven studies met the final inclusion criteria, with 5 retrospective cohort studies, 1 prospective cohort study, and 1 prospective randomized controlled trial. Egger's regression test (intercept = –0.61, p = 0.76) and Begg's rank correlation test (τ = 0.00, p = 1.00) revealed no significant evidence of publication bias. The overall log odds ratio for achieving SFR favoured the U-PCNL group, with an estimated log OR = –0.38 (95% CI: from –0.87 to 0.10; p = 0.12), although this difference did not reach statistical significance. There was no statistically significant difference for high-grade complications; the log odds ratio was 0.03 (95% CI: from –0.57 to 0.63, p = 0.91).

**Conclusions** Based on low-certainty evidence, synchronous B-PCNL may be considered a selective option at experienced centres.

Key Words: nephrolithiasis ‹› bilateral ‹› percutaneous nephrolithotomy ‹› meta-analysis

## INTRODUCTION

The rising global prevalence of nephrolithiasis [1, 2] has driven the need for improved and optimized surgical management strategies. Urolithiasis significantly impacts patients' quality of life and poses a substantial economic burden on healthcare systems and society [3].

Percutaneous nephrolithotomy (PCNL) is currently regarded as the first-line minimally invasive treatment for patients with large or multiple renal calculi [4]. In cases of bilateral nephrolithiasis, however, the choice between synchronous bilateral PCNL (B-PCNL) and staged unilateral PCNL (U-PCNL) remains a topic of ongoing debate due to concerns surrounding safety, efficacy, and resource utilization [5, 6].

The objective of this meta-analysis was to evaluate the efficacy and safety of synchronous B-PCNL compared with staged U-PCNL in patients with bilateral kidney stones, and to determine whether B-PCNL may be considered a viable alternative to conventional staged approaches.

## MATERIAL AND METHODS

This analysis was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines and was registered with PROSPERO (CRD420251036639). The study population comprised adult patients (≥18 years) diagnosed with bilateral nephrolithiasis and treated using PCNL. The intervention group included patients undergoing synchronous B-PCNL, while the control group underwent staged U-PCNL in two separate sessions. The primary outcomes of interest were stone-free rate (SFR) and complication rates, classified according to the Clavien-Dindo grading system. Given the anticipated heterogeneity in SFR assessment across included studies, SFR was extracted as reported and defined in each included study with radiological evidence of residual fragments <4 mm.

A comprehensive literature search was performed using the PubMed, Web of Science, and Scopus databases for studies published between January 1996 and January 2024. The search strategy incorporated MeSH terms and key words for PubMed ((“percutaneous nephrolithotomy”[Title/Abstract] AND “bilateral”[Title/Abstract]), for Scopus (TITLE-ABS-KEY(“percutaneous nephrolithotomy”) AND (TITLE-ABS-KEY(“bilateral”))), for WoS TS=(“percutaneous nephrolithotomy”) AND TS=(“bilateral”).

Inclusion criteria were as follows: studies reporting outcomes of both B-PCNL and U-PCNL; randomized controlled trials (RCTs); and prospective and retrospective cohort studies. Exclusion criteria included case reports, studies lacking explicit comparative data between B-PCNL and U-PCNL, and non-English publications without accessible full texts.

Two independent reviewers screened the identified studies for eligibility. Discrepancies were resolved through consensus or by consulting a third reviewer. Study selection was performed in two stages: initial screening of titles and abstracts, followed by full-text review of eligible studies. Duplicate records were removed before screening.

Risk of bias for RCTs was assessed using the Cochrane RoB 2 tool, and for observational studies, the ROBINS-I tool was employed. Two reviewers independently conducted the assessments, with discrepancies resolved through discussion or consultation with a third reviewer.

The certainty (confidence) in the body of evidence for each outcome was evaluated using the GRADE (Grading of Recommendations, Assessment, Development and Evaluation) framework. Each critical outcome was assessed across five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Each domain was judged as “serious” or “not serious” based on predefined criteria.

Publication bias was assessed using both Egger’s regression test and Begg’s rank correlation test. A p-value <0.05 in either test was considered indicative of significant publication bias. Funnel plot visualization was also employed to complement the statistical evaluation.

Data were extracted into a standardized form, including demographic data, operative details, and post-procedural complications. Meta-analysis was performed using a random-effects model due to expected clinical and methodological variability among the included studies. Results were reported as odds ratios (ORs) with corresponding 95% confidence intervals (CIs). Heterogeneity among studies was assessed using the $I^2$ statistic, with thresholds of 25%, 50%, and 75% representing low, moderate, and high heterogeneity, respectively. Additional measures of heterogeneity included Tau-squared ($\tau^2$) and H-squared ($H^2$). Cochran’s Q test was used to determine the statistical significance of heterogeneity. Statistical analyses were conducted using IBM SPSS Statistics (Version 29), and a p-value <0.05 was considered statistically significant.

## RESULTS

A total of 914 articles were retrieved through database searches. After the removal of duplicates and screening for eligibility, 74 studies were identified. Of these, seven met the final inclusion criteria (Figure 1). The included studies comprised five retrospective cohort studies [7–11], one prospective cohort study [12], and one prospective randomized controlled trial [13].

This meta-analysis included 1,389 patients (851 males and 538 females), with a mean age range of 35–58 years. In total, 436 patients underwent synchronous B-PCNL and 953 underwent staged U-PCNL (Table 1). One study (14) utilized the mini-PCNL technique.

Egger’s regression test (intercept = −0.61, p = 0.76) and Begg’s rank correlation test ($\tau$ = 0.00, p = 1.00) revealed no significant evidence of publication bias. This was further supported by visual assessment of the funnel plot (Figure 2), which focused on complication rates. These findings suggest that the meta-analysis was not significantly affected by publication bias.

Risk of bias was assessed for each study. The randomized controlled trial by Wang et al. [13]

was rated as having an overall low risk of bias. The prospective cohort study by El-Sheemy et al. [12] was assessed as having a moderate risk of bias. All five retrospective cohort studies (Rivera et al. [7], Torricelli et al. [8], Holman and Tóth [9], Kadlec et al. [10], and Silverstein et al. [11]) were judged to have a high risk of bias, primarily due to limitations in randomization, blinding, and outcome assessment. The most common sources of bias among these studies were selection and performance bias. A summary of the risk of bias assessment is presented in Table 2.

Each critical outcome was assessed using the GRADE framework across five domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Judgments for each domain were categorized as "serious" or "not serious," contributing to an overall certainty rating. The overall certainty of evidence was graded as low for all outcomes (Table 3).

## Stone-free rate and complication rate analysis

The overall log odds ratio for achieving stone-free status favoured the staged U-PCNL group, with an estimated log OR = –0.38 (95% CI: from –0.87 to 0.10; p = 0.12), although this difference did not reach statistical significance. Heterogeneity among the included studies was moderate to substantial, as indicated by an $I^2$ value of 71 %. Tau-squared ($\tau^2$) was 0.04, and H-squared ($H^2$) was 1.22. These values justify the use of a random-effects model, which was applied accordingly. Cochran's Q test did indicate statistically significant heterogeneity with $Q \approx 14.69$, df = 6, $p \approx 0.023$.

No statistically significant difference in the overall complication rate was observed between B-PCNL and U-PCNL. For high-grade complications (Clavien–Dindo III–V), the log odds ratio was 0.03 (95% CI: from –0.57 to 0.63, p = 0.91). The overall log odds ratio for the complications rate was –0.25

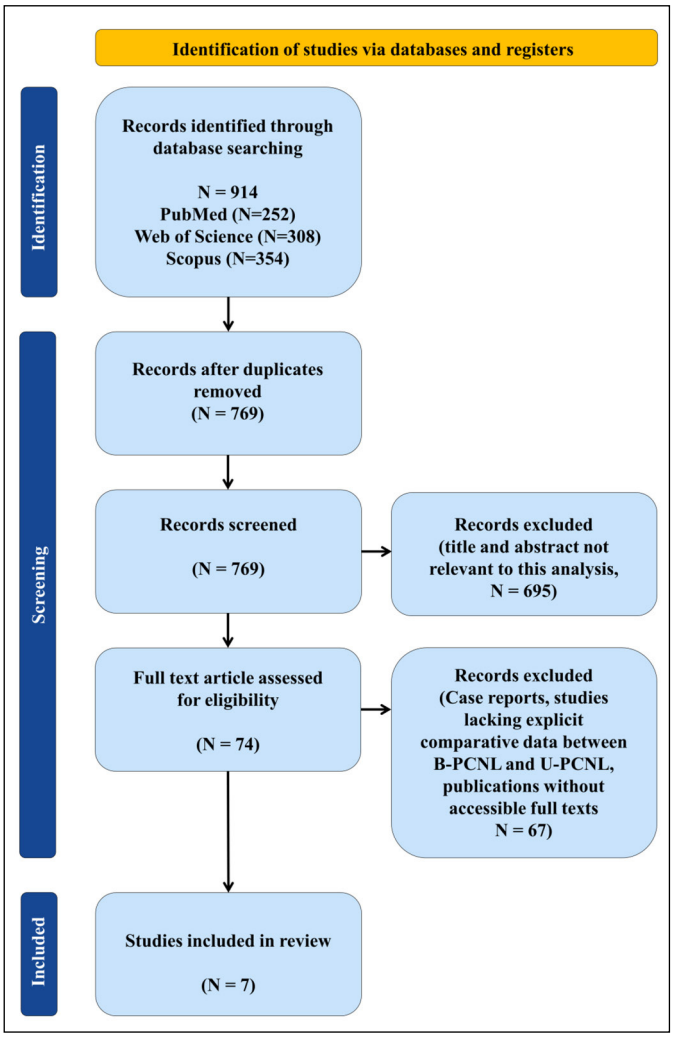


**Figure 1.** *Article selection.*

**Table 1.** *Summary of included studies*

| Study | Study type | Total participants | U-PCNL cases | B-PCNL cases |
|---|---|---|---|---|
| Rivera et al. [7] (2018) | Retrospective | 563 | 434 | 129 |
| Torricelli et al. [8] (2020) | Retrospective | 26 | 18 | 8 |
| Wang et al. [13] (2011) | RCT | 99 | 49 | 50 |
| ElSheemy et al. [12] (2018) | Prospective | 100 | 45 | 55 |
| Holman and Tóth [9] (2002) | Retrospective | 450 | 300 | 150 |
| Kadlec et al. [10] (2012) | Retrospective | 125 | 78 | 47 |
| Silverstein et al. [11] (2004) | Retrospective | 26 | 19 | 7 |

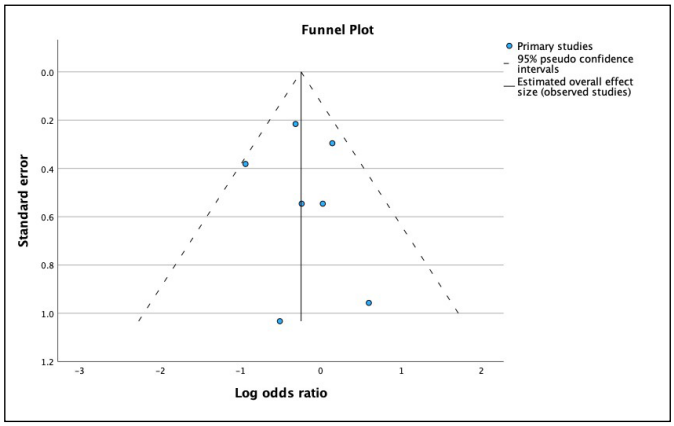


**Figure 2.** *Funnel plot for all-complication rates.*

(95% CI: from –0.59 to 0.10; p = 0.16), favouring staged U-PCNL, although the result was not statistically significant. The funnel plot depicting publication bias for all complication rates is shown in Figure 2, and the forest plot summarizing complication rates is presented in Figure 3. Assessment of heterogeneity revealed $I^2$ value of 19 %, indicating low heterogeneity among the included studies. Tau-squared ($\tau^2$) was 0.04 and H-squared ($H^2$) was 1.24. These values indicate mild between-study variability, supporting the appropriateness of the random-effects model. Cochran's Q test did not indicate statistically significant heterogeneity with $Q \approx 7.44$, df = 6, $p \approx 0.28$.

Across the included studies, B-PCNL was associated with a longer operative time per session, but a shorter overall hospital stay compared to staged U-PCNL. B-PCNL procedures also resulted in greater intraoperative blood loss, although the difference in transfusion rates between the two

**Table 2.** *A risk of bias assessment summary*

| Study | Study Type | Randomization Bias | Selection Bias | Performance Bias | Detection Bias | Attrition Bias | Overall Risk of Bias |
|---|---|---|---|---|---|---|---|
| Rivera et al. [7] | Retro-spective | High | Moderate | High | Moderate | Moderate | High |
| Torricelli et al. [8] | Retro-spective | High | Moderate | High | Moderate | Moderate | High |
| Wang et al. [13] | RCT | Low | Low | Low | Low | Low | Low |
| El-Sheemy et al. [12] | Pro-spective | Moderate | Moderate | Low | Moderate | Moderate | Moderate |
| Holman and Tóth [9] | Retro-spective | High | Moderate | High | Moderate | Moderate | High |
| Kadlec et al. [10] | Retro-spective | High | Moderate | High | High | Moderate | High |
| Silversteinet al. [11] | Retro-spective | High | High | High | High | High | High |

RCT – randomized controlled trial

**Table 3.** *GRADE evidence profile*

| Outcome | No. of studies | Risk of bias | Inconsistency | Indirectness | Imprecision | Publi-cation bias | Overall certainty |
|---|---|---|---|---|---|---|---|
| All complications | 7 | Serious | Not serious | Not serious | Not serious | None detected | Low |
| SFR | 7 | Serious | Not serious | Not serious | Not serious | None detected | Low |

SFR – stone-free rate

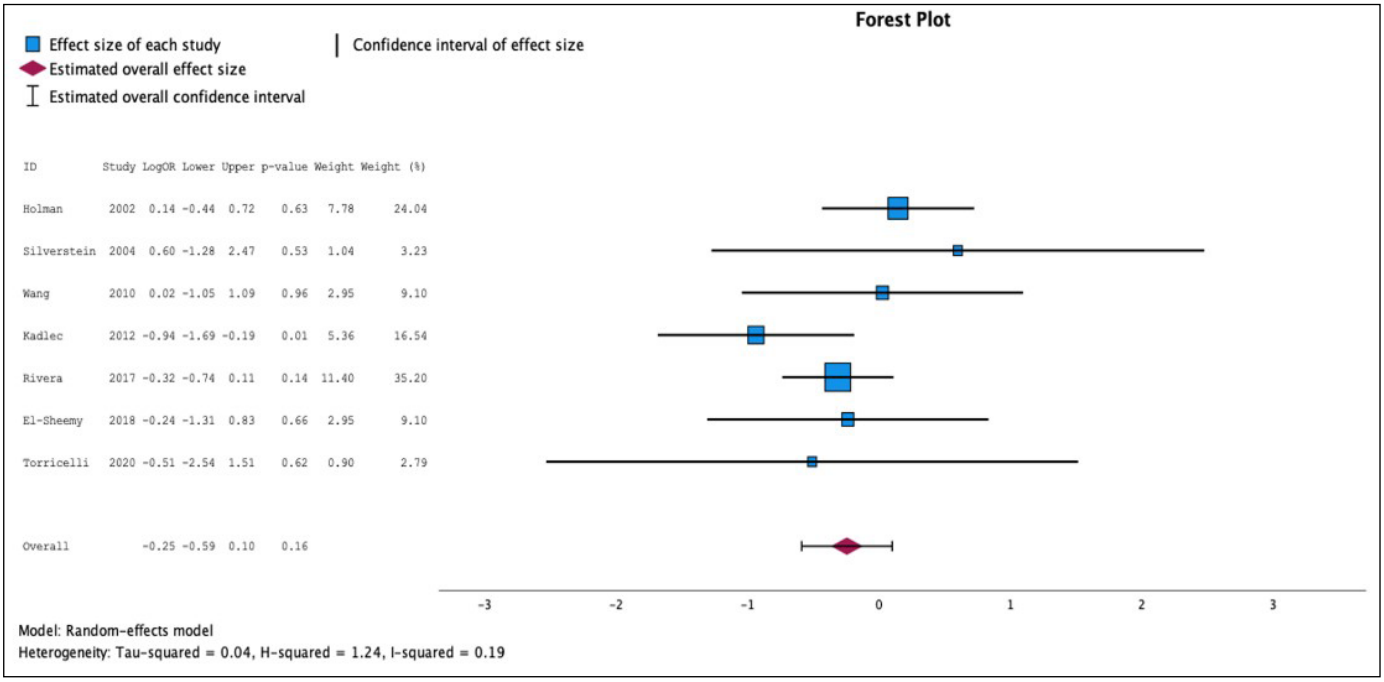


**Figure 3.** *Forest Plot for all complication rates.*

groups was not statistically significant. The extent of blood loss was primarily influenced by stone size and patient-specific factors such as baseline haemoglobin levels and coagulation profiles.

## DISCUSSION

Large or multiple bilateral kidney stones continue to present a significant challenge, even for skilled endourologists. Although the B-PCNL technique has long been described as safe [14–18], it has not yet been widely adopted as routine practice in daily clinical settings.

The systematic search for eligible comparative clinical studies was conducted up to January 2024; more recent publications are cited for background context and did not influence study inclusion.

In the included studies, operative time was generally reported to be longer in B-PCNL procedures due to the need to access both kidneys within a single surgical session. However, Holman and Tóth [9] indicated that B-PCNL reduces overall hospitalization time and procedural burden by eliminating the need for multiple staged procedures. ElSheemy et al. [12] reported that B-PCNL had a significantly shorter cumulative operative time and hospital stay compared to U-PCNL. In contrast, Rivera et al. [7] observed a higher likelihood of secondary procedures in patients who underwent B-PCNL. According to Torricelli et al. [8], although there was a trend toward longer hospitalization in the B-PCNL group, this difference was not statistically significant. The only randomized controlled trial [13] found that hospital stay, convalescence time, analgesic requirements, and direct costs were all significantly lower in the B-PCNL group. Interestingly, Silverstein et al. [11] reported that the total length of hospital stay for U-PCNL patients was nearly double that of those undergoing B-PCNL.

Blood loss and transfusion rates are key indicators of surgical safety and remain critical when comparing B-PCNL and U-PCNL procedures. Torricelli et al. [8] reported significantly higher transfusion rates in the B-PCNL group, although no high-grade complications were observed. Kadlec et al. [10] found no statistically significant differences in complications across Clavien-Dindo grades, although low-grade complications were more frequent in the B-PCNL group. Bleeding-related complications occurred more often in the B-PCNL group (three transfusions and two terminated procedures) compared to the U-PCNL group (one transfusion and no terminated procedures). According to ElSheemy et al. [12], B-PCNL was associated with greater haemoglobin loss; however, the transfusion rates and complication profiles were comparable and not statistically significant.

A key limitation concerns SFR assessment. SFR assessment was variably defined and reported in included studies. Imaging modality (CT vs other modalities), the timing of postoperative imaging, and thresholds for residual fragments were not standardized, and some studies provided insufficient detail. The substantial heterogeneity for SFR ($I^2 = 71\%$) likely reflects clinical and methodological differences across studies, including variation in operative techniques (standard vs mini-PCNL), patient selection, perioperative pathways, and SFR definitions/assessment. Accordingly, the pooled SFR estimate should be interpreted as a general summary measure rather than a precise estimate of comparative effect [19]. Given that SFR is a primary efficacy outcome and numerically favored U-PCNL, these limitations may have influenced the pooled estimate and warrant cautious interpretation.

The results of this meta-analysis suggest that synchronous B-PCNL may reduce overall hospital stay and, consequently, procedural costs. Several included studies reported shorter cumulative hospitalization with synchronous B-PCNL; however, these observations were not pooled quantitatively due to inconsistent reporting. Therefore, potential reductions in hospital stay and downstream costs should be regarded as hypothesis-generating and require confirmation in prospective studies with standardized economic endpoints. This potential benefit must be weighed against trade-offs, most notably the lower SFR and a higher likelihood of residual fragments.

Another critical factor is the learning curve associated with B-PCNL. Surgeons with greater experience in percutaneous procedures consistently report better outcomes, including lower complication rates and higher SFRs. The standardization of techniques and development of dedicated training programs for B-PCNL could reduce the variability in outcomes observed across institutions.

Patient-reported outcomes remain underexplored in the context of B-PCNL vs U-PCNL. Although most studies focus on clinical endpoints such as SFR and complications, incorporating patient perspectives – including pain, recovery experience, and quality of life – would offer a more comprehensive understanding of the relative merits of each approach.

The economic implications of B-PCNL also warrant attention. Although synchronous procedures may initially appear more resource-intensive due to surgical complexity, they may ultimately lower total healthcare costs by reducing the need

for repeated hospital admissions and multiple anaesthesia sessions during staged procedures [5]. Further cost-effectiveness analyses are needed to better understand the long-term financial impact of B-PCNL. This meta-analysis includes one study evaluating mini-PCNL [12], while the remaining studies focused on standard PCNL. Although mini-PCNL employs smaller access tracts and may differ in complication rates, SFR, and procedural outcomes, its limited representation suggests a minimal influence on the overall findings.

This study has certain limitations. The number of prospective studies and randomized controlled trials was low. Sensitivity analysis restricted to prospective studies was planned, but not feasible and meaningful because only two prospective studies were available and outcome reporting was not sufficiently harmonized to support robust pooled estimates. Because only seven studies were included, both the statistical tests and the funnel plot (Figure 2) have limited power and should be interpreted cautiously. There was also heterogeneity in patient selection and variability in outcome reporting across studies. Furthermore, retrospective designs may have contributed to underreporting of low-grade complications. Additional high-quality randomized trials are necessary to validate the findings of this meta-analysis and further clarify the comparative efficacy and safety of B-PCNL vs U-PCNL.

## CONCLUSIONS

Based on low-certainty evidence derived predominantly from retrospective studies, synchronous B-PCNL may be considered as a selective option in experienced centres. High-grade complication rates appeared comparable to staged U-PCNL, while SFR may be lower with B-PCNL. However, confirmation in well-designed prospective studies is warranted and definitive recommendations require adequately powered randomized trials with standardized SFR assessment and reporting.

### CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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### ETHICS APPROVAL STATEMENT

The ethical approval was not required.

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