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Efficacy and Safety of Ultrasound-Guided versus Fluoroscopy-Guided Percutaneous Nephrolithotomy in Children: A Systematic Review and Meta-Analysis

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Introduction. Ultrasound-guided percutaneous nephrolithotomy (PCNL) is a radiation-sparing alternative to conventional fluoroscopy-guided PCNL in children, yet pediatric evidence remains limited. This systematic review and meta-analysis evaluated the efficacy and safety of both modalities in pediatric patients.
Methods. Following PRISMA 2020 guidelines, PubMed, Embase, and Scopus were searched from inception to March 3, 2026. Comparative studies evaluating ultrasound-guided versus fluoroscopy-guided PCNL in children were included. Three reviewers independently performed study selection, data extraction, and quality assessment. Risk of bias was evaluated using the Cochrane Risk of Bias 2 tool for randomized controlled trials and the Newcastle-Ottawa Scale for non-randomized studies. Meta-analyses were performed in RStudio using a random-effects model with restricted maximum likelihood estimation and Hartung-Knapp-Sidik-Jonkman adjustments.
Result. Five comparative studies involving 300 pediatric patients (136 ultrasound-guided; 164 fluoroscopy-guided) were included. There was no significant difference between groups in stone-free rate (RR 0.99, 95% CI 0.90–1.09; I^2=0.0%) or overall complication rate (RR 0.82, 95% CI 0.29–2.28; I^2=66.4%). Ultrasound guidance was associated with reduced fluoroscopy screening time (SMD -1.48, 95% CI -2.97 to 0.00; I^2=88.8%). No significant differences were observed in operative time, puncture/access time, or radiation dose.
Conclusion. Ultrasound-guided PCNL demonstrates comparable efficacy and safety to fluoroscopy-guided PCNL in children while reducing fluoroscopy exposure. Further prospective multicenter randomized studies are needed to confirm these findings.

Keywords: children, fluoroscopy, percutaneous nephrolithotomy, ultrasound

Introduction

Pediatric urolithiasis is an increasingly recognized clinical problem, with population-based U.S. data estimating pediatric stone incidence at approximately 65 per 100,000 person-years (2005–2016), rising markedly from about 18 per 100,000 person-years in 1999 [1]. Children also carry a substantial long-term disease burden because recurrence is common, with reports suggesting symptomatic recurrence rates of up to 50% within 3 years despite intervention, and even higher without preventive management [1-2]. These epidemiologic trends are clinically important because children have a longer lifetime at risk for repeat imaging and repeat procedures, making treatment selection particularly consequential. Ultrasonography is already recommended as the preferred first-line imaging modality in suspected pediatric stone disease to reduce radiation exposure, which strengthens the rationale for exploring ultrasound-guided operative approaches as well [3-4].

Percutaneous nephrolithotomy (PCNL) remains a key treatment for large or complex renal stones in children, and guideline-based pediatric series report single-session stone-free rates of 71.4%–95% with an overall complication rate around 20% [5–7].

Traditionally, fluoroscopy-guided access has been widely used, but ultrasound guidance may offer advantages in children by reducing or avoiding ionizing radiation while potentially maintaining comparable efficacy and safety.6 In broader evidence, ultrasound-guided versus fluoroscopy-guided PCNL showed no significant difference in stone-free rate (RR 1.02) or overall complications, while significantly reducing radiation exposure;8 however, pediatric-specific evidence remains comparatively limited and scattered. Therefore, this systematic review aims to evaluate and compare the efficacy and safety of ultrasound-guided versus fluoroscopy-guided percutaneous nephrolithotomy in children.

Materials and Methods

Protocol and Registration

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guideline [9]. The review methods were defined before the study selection and analysis processes were carried out.

Search Strategy and Information Sources

A comprehensive literature search was conducted in three electronic databases, namely PubMed, Embase, and Scopus, from database inception until March 3, 2026. The search strategy combined controlled vocabulary terms, including Medical Subject Headings (MeSH) where applicable, with free-text keywords. Boolean operators such as AND and OR were used to combine the search terms. Keywords and term variations related to percutaneous nephrolithotomy, PCNL, ultrasound-guided, fluoroscopy-guided, pediatric, and children were included in the search strategy. To ensure that no relevant studies were missed, the reference lists of included articles and relevant review papers were also screened manually.

Eligibility Criteria (PICO)

The eligibility criteria were developed based on the PICO framework. The population included pediatric patients aged 18 years or younger who underwent percutaneous nephrolithotomy for renal stones. The intervention of interest was ultrasound-guided or ultrasound-assisted percutaneous access and tract dilation during PCNL, while the comparator was conventional fluoroscopy-guided percutaneous access and tract dilation during PCNL. The primary outcomes of interest were stone-free rate (SFR) and overall complication rate. Secondary outcomes included perioperative continuous variables, such as operative time, fluoroscopy screening time, access or puncture time, and radiation dose.

Studies were excluded if they did not include a comparative fluoroscopy-guided group, such as single-arm studies. Case reports, editorials, letters, and review articles were also excluded. Studies that focused exclusively on adult populations were not considered eligible. In addition, non-English publications were excluded when a reliable translation could not be obtained.

Study Selection and Data Extraction

Study selection and data extraction were performed independently by three reviewers in a blinded fashion. The selection process began with title and abstract screening to identify potentially relevant studies, followed by full-text assessment to confirm eligibility based on the predefined criteria.

A standardized data extraction form was used to collect relevant information from the included studies. The extracted data included the first author's name, year of publication, study design, sample size, patient characteristics (such as age and sex), stone-related variables (including stone burden and location), and outcomes based on the predefined PICO framework. Any disagreements that occurred during study selection or data extraction were resolved through discussion until consensus was reached between the three reviewers.

Risk of Bias Assessment

The methodological quality and risk of bias of the included studies were evaluated independently by three reviewers in a blinded manner. Any disagreements were resolved through discussion. For randomized controlled trials (RCTs), risk of bias was assessed using the Cochrane Risk of Bias 2 (RoB v2) tool, which examines domains including the randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of the reported results. For non-randomized studies (e.g., cohort and case-control studies), the Newcastle–Ottawa Scale (NOS) was used, with assessment based on the selection of study groups, comparability of groups, and ascertainment of exposure/outcomes.

Statistical Analysis

All meta-analyses were performed using RStudio (R Foundation for Statistical Computing, Vienna, Austria), using the meta package. Dichotomous outcomes, including stone-free rate (SFR) and overall complication rate, were pooled using risk ratios (RRs) with 95% confidence intervals (CIs). Continuous outcomes, such as operative time, access time, fluoroscopy time, and radiation dose, were analyzed using the standardized mean difference (SMD) with 95% CIs to account for differences in measurement units and reporting scales across studies.

A random-effects model was applied for all pooled analyses because clinical and methodological heterogeneity among studies was anticipated. The between-study variance (τ^2) was estimated using the restricted maximum likelihood (REML) method. To improve the robustness of the pooled estimates, particularly when the number of included studies was limited, the Hartung–Knapp–Sidik–Jonkman (HKSJ) adjustment was applied. Statistical heterogeneity was assessed using the I^2 statistic, and potential publication bias was explored through visual inspection of funnel plots.

Result

Study Selection

The literature search identified a total of 498 records from PubMed (n=181), EMBASE (n=153), and Scopus (n=164), as shown in Figure 1 (PRISMA flow diagram). After removal of 67 duplicate records, 431 records underwent title and abstract screening. A total of 405 records were excluded at this stage, and 26 reports were assessed for full-text eligibility. Following full-text review, 21 reports were excluded, including studies involving adult PCNL populations (n= 13), mixed adult and pediatric populations without separate pediatric data (n=4), review/editorial/letter/commentary articles (n=3), and one unavailable full text (n=1). Five studies were ultimately included in the systematic review and meta-analysis (Figure 1) [10–14].

Characteristics of Included Studies

The review included five comparative studies with a total of 300 pediatric patients, comprising 136 patients in the ultrasound-guided groups and 164 patients in the fluoroscopy-guided groups, as summarized in Table 1. Across the included studies, the reported mean or median age ranged from 5 years to 9.6 years. The included cohorts were predominantly male. Reported stone burden/size varied across studies, ranging from a mean linear stone size of 15.94 ± 3.69 mm to a median stone surface area of 277 mm² (Table 1).

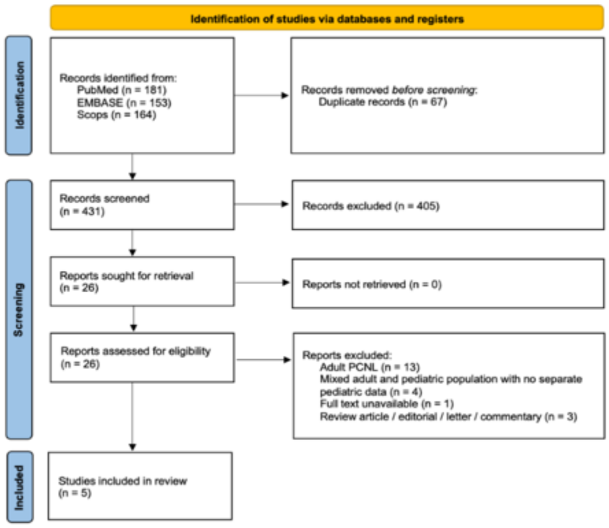

Figure 1. PRISMA flow diagram

Meta-Analysis

The pooled meta-analysis findings are presented in Figures 2–7. For stone-free ate (SFR), the pooled risk ratio (RR) was 0.99 (95% CI 0.90 to 1.09) with no detected heterogeneity ($I^2 = 0.0\%$, $p = 0.5647$), and the corresponding funnel plot was presented in Figure 2. For overall complication rate, the pooled RR was 0.82 (95% CI 0.29 to 2.28) with heterogeneity of $I^2 = 66.4\%$ ($p = 0.0180$), with funnel plot visualization shown in Figure 3. For fluoroscopy screening time, the pooled standardized mean difference (SMD) was -1.48 (95% CI -2.97 to 0.00) with heterogeneity of $I^2 = 88.8\%$ ($p < 0.0001$), and the funnel plot was presented in Figure 4. For operative time, the pooled SMD was -0.32 (95% CI -2.25 to 1.61) with heterogeneity of $I^2 = 87.1\%$ ($p = 0.0004$), with funnel plot visualization shown in Figure 5. For puncture/access time, the pooled SMD was -1.34 (95% CI -4.44 to 1.75) with heterogeneity of $I^2 = 95.1\%$ ($p < 0.0001$), and the funnel plot was presented in Figure 6. For radiation dose, the pooled SMD was -2.21 (95% CI -6.13 to 1.70) with heterogeneity of $I^2 = 35.3\%$ ($p = 0.2138$), with funnel plot visualization shown in Figure 7.

Table 1. Summary of baseline characteristics of included studies comparing ultrasound-guided and fluoroscopy-guided percutaneous nephrolithotomy in pediatric patients

Study (year)	Study Design	Group Modality	Sample Size (n)	Age (years)	Gender (male/ female)	Stone Burden/Size
Fluoroscopy-only guided vs Fluoroscopy-assisted ultrasound guided						
Salama et al. (2025)	RCT	Fluoroscopy-only guided puncture	25	7.24 ± 3.72	13/12	18.92 ± 9.60 mm
		FA-USG	25	8.0 ± 3.77	16/9	18.0 ± 7.94 mm
Ilikan et al. (2021)	Retros-pective Cohort Study	Fluoroscopy-only guided puncture	44	8.1 ± 4.8	31/13	26.9 ± 16.3 mm
		FA-USG	22	7.8 ± 6.1	15/7	25.77 ± 18.05 mm
Fluoroscopy-only guided vs Ultrasound-only guided						
Elderwy et al. (2025)	RCT	Biplanar fluoroscopy	30	5 (IQR 2.9–9.3; median)	20/10	233 mm² (median stone burden)
		Ultrasound-only guided	30	7 (IQR 4–12; median)	19/11	277 mm² (median stone burden)
Eslahi et al. (2021)	Retrospective Cohort Study	Fluoroscopy-guided mini-PCNL	35	7.47 ± 3.75	23/12	19.20 ± 7.41 mm
		Ultrasound-guided mini-PCNL	35	5.68 ± 3.05	25/10	15.94 ± 3.69 mm
Fluoroscopy-only guided vs Combined ultrasound-fluoroscopy guided						
Sezer et al. (2024)	Retrospective Cohort Study	Biplanar 0°-90° fluoroscopy	30	9.6 ± 5.3	10/20	26.6 ± 13 mm
		Combined ultrasound + fluoroscopy	24	7.6 ± 5.5	14/10	23.5 ± 14 mm

Meta-Analysis

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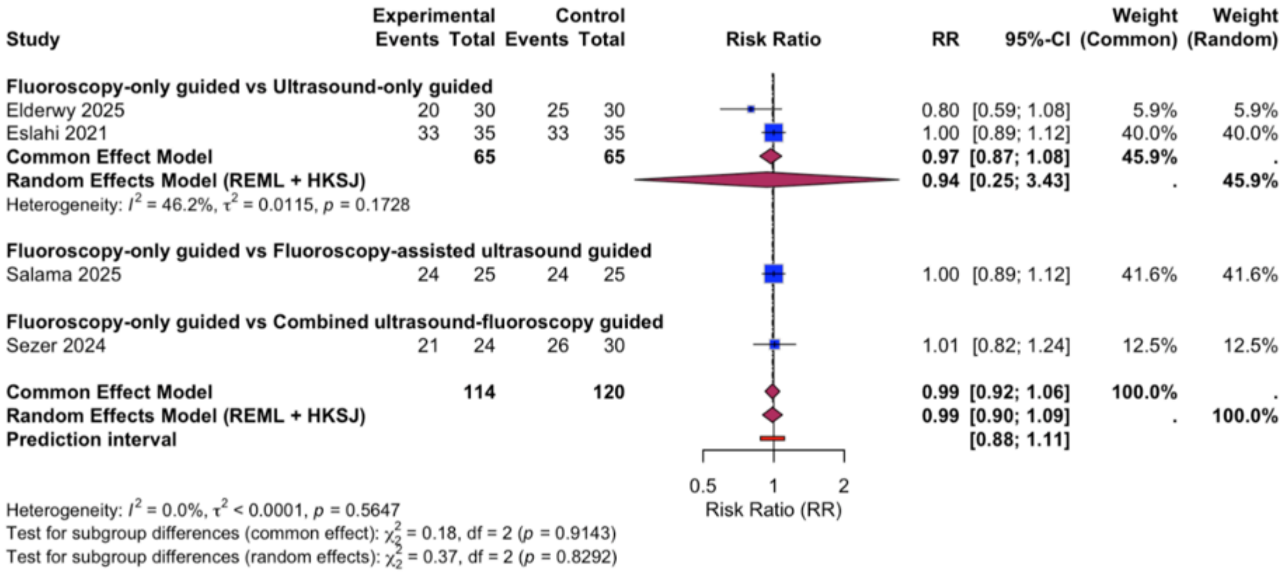

Figure 2. Meta-analysis of stone-free rate between intervention vs control group

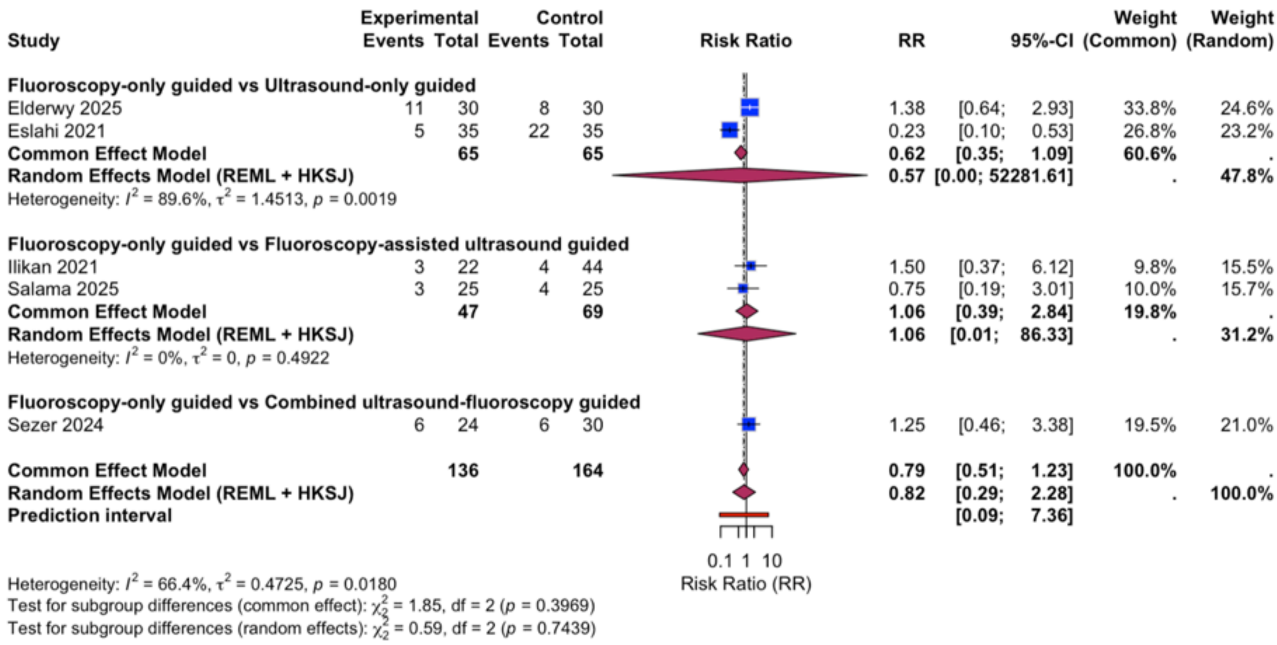

Figure 3. Meta-analysis of overall complication rate between intervention vs control group

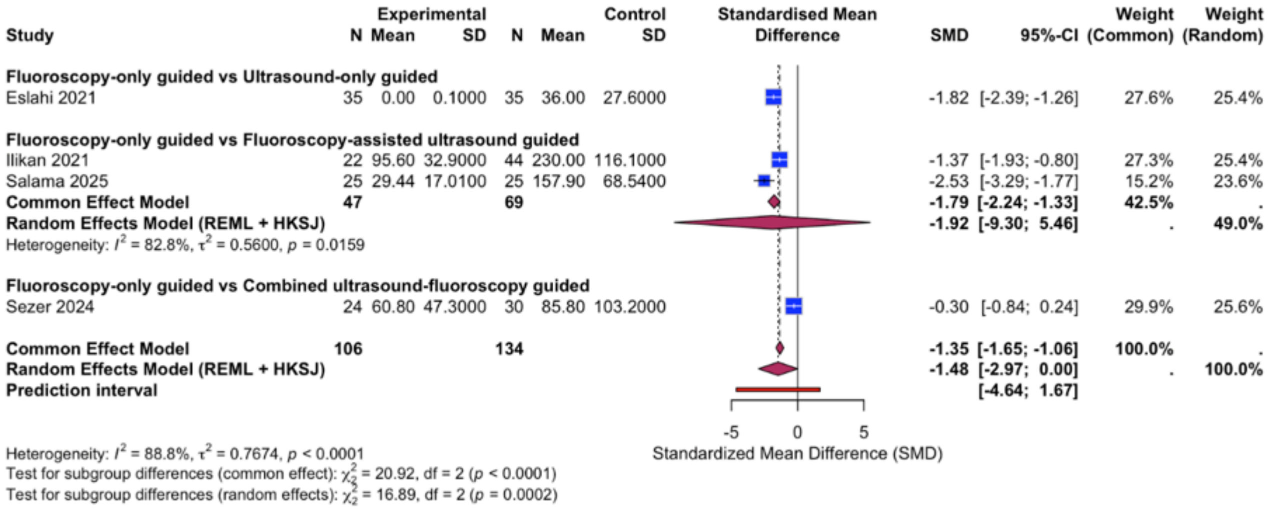

Figure 4. Meta-analysis of fluoroscopy screening time between intervention vs control group

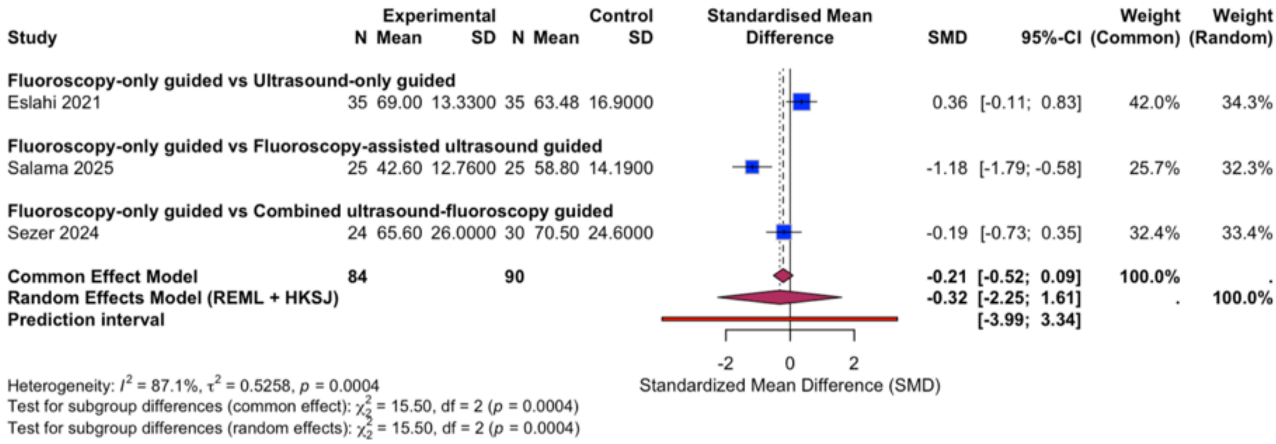

Figure 5. Meta-analysis of operative time between intervention vs control group

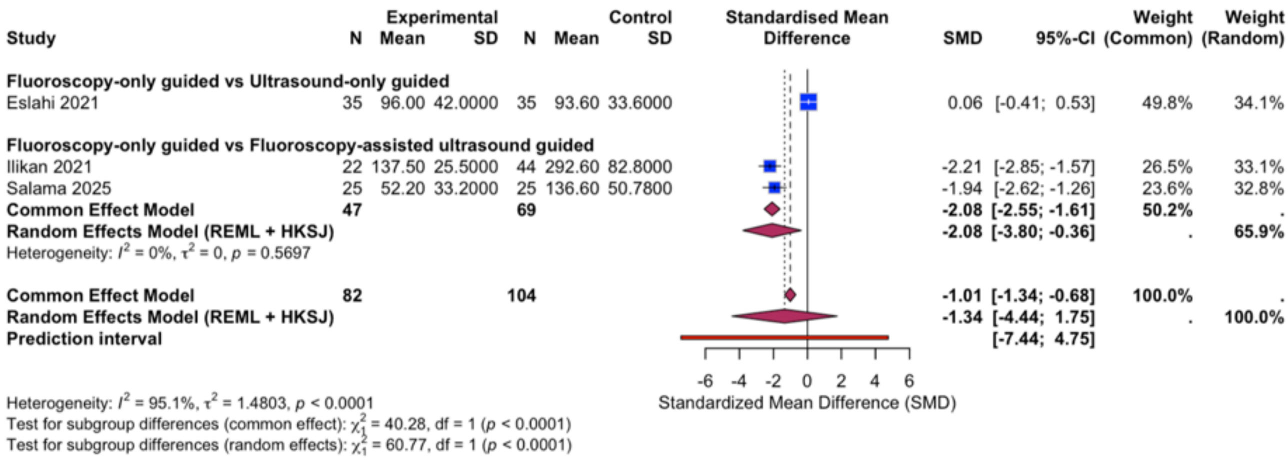

Figure 6. Meta-analysis of puncture time between intervention vs control group

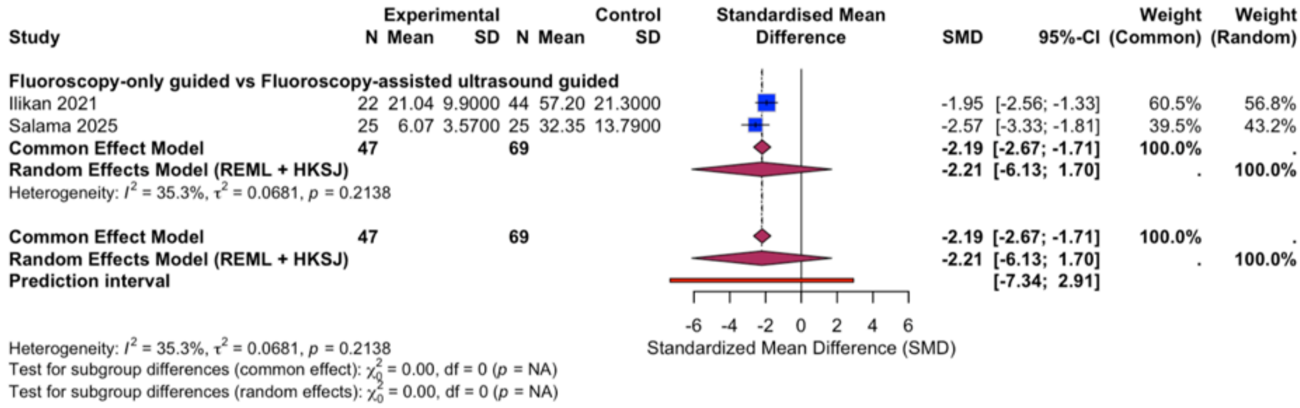

Figure 7. Meta-analysis of radiation dose between intervention vs control group

Risk of Bias Assessment

Risk of bias and methodological quality assessments are presented in Table 2 and Figure 8. Based on the Newcastle–Ottawa Scale (NOS), Sezer et al. scored 9/9, while Eslahi et al. and Ilikan et al. each scored 8/9 (Table 2). In addition, the Cochrane RoB v2 assessment showed that both Elderwy et al. (2025) and Salama et al. (2025) demonstrated low risk of bias across all evaluated domains and overall assessment (Figure 8).

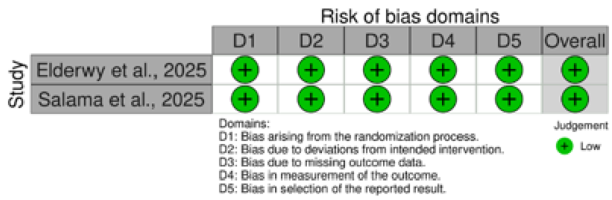

Figure 8. Cochrane RoB v2 analysis for risk of bias of included studies

Table 2. Newcastle Ottawa Scale risk of bias assessment

Study	Selection	Compatibility	Outcome/Exposure	Total NOS Score
Sezer et al., 2024	4	2	3	9/9
Eslahi et al., 2021	4	2	2	8/9
Ilikan et al., 2021	4	1	3	8/9

Discussion

This systematic review and meta-analysis compared ultrasound-guided and fluoroscopy-guided PCNL in pediatric patients and found that the two approaches had broadly comparable clinical outcomes in terms of efficacy and safety. The pooled analysis showed no significant difference in SFR between the two groups, suggesting that ultrasound-guided PCNL was able to achieve a similar level of stone clearance to the conventional fluoroscopy-guided approach. Likewise, no statistically significant difference was found in the overall complication rate. Taken together, these findings indicate that ultrasound guidance may represent a feasible alternative to fluoroscopy guidance for pediatric PCNL without compromising the main procedural outcomes. These findings are generally consistent with previous studies suggesting that ultrasound-guided PCNL can achieve comparable efficacy and safety while reducing radiation exposure.

Although the primary outcomes were comparable, the perioperative findings showed some important procedure differences. The pooled estimate for fluoroscopy screening time favored the ultrasound-guided group, indicating lower fluoroscopy exposure when ultrasound was used. This finding is clinically relevant in the pediatric setting because children are more sensitive to ionizing radiation and may undergo repeated imaging or interventions over time [15-16]. At the same time, no significant differences were observed for operative time, puncture or access time, or radiation dose as continuous outcomes. These results may reflect variation in how these outcomes were measured and reported across studies, as well as differences in operator experience, procedural protocols, and equipment availability. Therefore, while ultrasound guidance appears promising in reducing fluoroscopy screening time, the magnitude of benefit for other procedure-related outcomes remains less consistent [17-18].

An apparent discrepancy was observed between fluoroscopy screening time and radiation dose outcomes. While ultrasound-guided PCNL was associated with a significant reduction in fluoroscopy screening time, a corresponding statistically significant reduction in radiation dose was not demonstrated. This finding may be partly explained by differences in the ultrasound-based techniques included in the analysis. Some studies employed fully ultrasound-guided access, whereas others utilized fluoroscopy-assisted ultrasound-guided or combined ultrasound-fluoroscopy approaches, in which limited fluoroscopic imaging may still be required for tract confirmation or assessment of residual stone burden. Consequently, although fluoroscopy utilization was reduced, radiation exposure was not completely eliminated across all studies. Furthermore, variations in radiation measurement methods and the relatively low overall radiation exposure reported in several studies may have contributed to the lack of a statistically significant difference in pooled radiation dose outcomes.

The heterogeneity pattern in this review also warrants consideration. Very low heterogeneity was observed for SFR, which supports the consistency of the efficacy outcome across the included studies. In contrast, moderate to high heterogeneity was found for complication rate and several continuous perioperative outcomes, particularly fluoroscopy screening time, operative time, and puncture/access time. This variation may be related to differences in study design, patient selection, stone burden, surgical technique, and PCNL tract size, as well as non-uniform definitions of perioperative outcomes across centers. Despite these differences, the overall direction of the pooled estimates supports the practical use of ultrasound-guided PCNL as a radiation-sparing approach with comparable core outcomes in children. Nevertheless, future prospective studies with standardized outcome definitions and clearer reporting of ultrasound-based techniques are needed to further clarify their comparative benefits.

Study Limitations

Several limitations should be acknowledged when interpreting the findings of this review. First, the number of included studies was small, which limits the precision of pooled estimates and reduces the ability to perform extensive subgroup or sensitivity analyses across all secondary outcomes. Second, most included studies were observational in design, which increases the risk of selection bias and residual confounding despite formal risk of bias assessment. Third, there was substantial heterogeneity in several continuous outcomes, likely due to differences in operative techniques, including the use of fully ultrasound-guided, fluoroscopy-assisted ultrasound-guided, and combined ultrasound-fluoroscopy approaches. The inclusion of these distinct ultrasound-based techniques within a single intervention group may have influenced the pooled estimates, particularly for radiation-related outcomes, because the degree of fluoroscopy utilization varied across studies. Fourth, as both ultrasound-guided and fluoroscopy-guided PCNL are highly operator-dependent procedures, differences in surgeon expertise, learning curve effects, and procedural volume across centers may have affected procedural outcomes. Furthermore, detailed information regarding operator experience was not consistently reported in the included studies and therefore could not be evaluated quantitatively. Fifth, outcome reporting was not uniform, and some potentially important variables were not consistently available for quantitative synthesis. Finally, the exclusion of non-English studies without reliable translation may have introduced language bias.

Conclusion

This systematic review and meta-analysis found that ultrasound-guided PCNL and fluoroscopy-guided PCNL had comparable stone-free and overall complication outcomes in pediatric patients. Ultrasound-guided PCNL was associated with reduced fluoroscopy screening time, supporting its role as a radiation-sparing alternative in children. However, the current evidence remains limited by a small number of studies, predominance of observational designs, and heterogeneity in perioperative outcome reporting. Further well-designed prospective comparative studies with standardized outcome definitions are needed to strengthen the evidence base and clarify the procedural advantages of ultrasound guidance in pediatric PCNL.

Conflict of Interest

The authors define no conflict of interest.

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