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Safety and efficacy of standard vs. tubeless percutaneous nephrolithotomy in pediatric populations: an updated systematic review and meta-analysis

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Abstract

Objective This study aims to compare the safety and efficacy of standard versus tubeless percutaneous nephrolithotomy (PCNL) in pediatric populations.

Methods A systematic search was conducted in the Web of Science, Cochrane Library, PubMed, and Embase databases to identify studies that met the inclusion criteria. Two authors independently screened the literature and extracted data. A meta-analysis was performed using RevMan 5.4 software. This study has been prospectively registered with PROSPERO (ID: CRD42024622238). Sensitivity analysis was performed using Stata 17.0 to assess the impact of low-quality studies, and publication bias was evaluated using funnel plots.

Results A total of 3 randomized controlled trials and 10 case-control studies were included, comprising 661 cases. The meta-analysis revealed that, in pediatric populations, the tubeless PCNL group had significantly shorter hospital stays compared to the standard PCNL group (WMD = -1.60, 95% CI: -2.27 to -0.92, $P<0.01$), as well as shorter operative times (WMD = -2.06, 95% CI: -4.02 to -0.10, $P=0.04$). The stone clearance rate was higher in the tubeless PCNL group than in the standard group (OR = 2.18, 95% CI: 1.09 to 4.34, $P=0.03$). Additionally, the tubeless PCNL group had lower rates of postoperative fever (OR = 0.46, 95% CI: 0.27 to 0.78, $P<0.01$) and postoperative urine leakage (OR = 0.20, 95% CI: 0.08 to 0.50, $P<0.01$) compared to the standard group. The tubeless PCNL group also had shorter pain management times (WMD = -2.00, 95% CI: -2.44 to -1.56, $P<0.01$) and lower visual analog scale (VAS) scores (WMD = -2.52, 95% CI: -2.81 to -2.22, $P<0.01$). However, no significant differences were observed between the two groups in terms of hemoglobin decline, overall complications (including perinephric fluid collections, urinary tract infections, and blood transfusion requirements), and reoperation rates.

Conclusion In children with kidney stones and low stone burden or an uneventful procedure, tubeless PCNL offers clear clinical advantages, including shorter hospital stays, higher stone clearance rates, and lower postoperative fever. Additionally, it improves surgical efficiency, reduces postoperative complications, and decreases the need for

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analgesia. These benefits suggest that tubeless PCNL can be safely applied in pediatric patients, yielding outcomes comparable to standard PCNL, provided that indications are properly managed".

Clinical trial number Not applicable.

Keywords Pediatrics, Percutaneous nephrolithotomy, Tubeless, Meta-analysis

Introduction

In recent years, the incidence of pediatric renal stones has been increasing annually, with an estimated incidence of 54.1 cases per 100,000 person-years, and an annual increase of 4–16% [1, 2]. Percutaneous nephrolithotomy (PCNL) has become the preferred treatment for large and complex renal stones in children and has been widely applied in recent years [3]. Since the introduction of PCNL, postoperative drainage has been a routine part of care to reduce complications and facilitate recovery.

However, further research has shown that nephrostomy tube placement increases complication rates (e.g., urine leakage and secondary infections), economic burden, and patient discomfort [4]. With continuous advancements in technology, tubeless PCNL—defined as the omission of drainage tube placement after surgery—has emerged as a novel technique and is gradually gaining attention [5]. Compared to standard PCNL, tubeless PCNL is theoretically considered to shorten hospital stays, reduce postoperative pain, and minimize complications related to drainage tubes [6, 7].

Compared to adults, children have distinct anatomical characteristics, such as smaller size, greater mobility, and increased tissue fragility [8]. Thus, although tubeless PCNL has shown promising results in adults [7, 9], its safety and efficacy in pediatric patients remain controversial. A previous meta-analysis of three randomized controlled trials (RCTs) [10]compared the outcomes of tubeless PCNL and standard PCNL in pediatric patients, finding no significant differences between the two in terms of hospital stay, hemoglobin decline, postoperative fever, stone clearance rates, or reoperation rates. However, recent studies [5, 11, 12] have suggested that tubeless PCNL in pediatric patients may reduce operative and hospitalization times while lowering complication rates. Despite these findings, existing studies remain inconclusive due to small sample sizes and methodological variability.

To address these limitations, this meta-analysis incorporates the latest evidence for a more comprehensive evaluation of tubeless versus standard PCNL in pediatric patients. By systematically comparing postoperative complications, stone clearance rates, hospital stay duration, and other key outcomes, this study aims to clarify the advantages and disadvantages of both surgical approaches.

Materials and methods

Literature search

We conducted a comprehensive search using the following electronic databases: PubMed, Web of Science, Cochrane Library, and Embase. No strict limitations were applied regarding publication year or language, and the search period was extended from database inception to December 12, 2024. Additionally, we manually searched the reference lists of identified reports, reviews, and other relevant publications. The study was prospectively registered in the PROSPERO database (ID: CRD42024622238). The search terms and search results are presented in the Table 1.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) Diagnosis of renal stones by ultrasound, kidney-ureter-bladder (KUB) plain radiography, or CT; (2) Studies comparing tubeless versus standard PCNL; (3) Inclusion of at least one outcome measure, such as stone clearance rate, operative time, hospital stay, hemoglobin decline, and surgical complications; (4) Patients in the tubeless PCNL group were contraindicated for nephrostomy tube placement but could be considered for double J stenting; (5) Age < 18 years.

The exclusion criteria were: (1) Adult renal stone patients; (2) Studies with unclear descriptions of the catheterization methods after PCNL; (3) Studies published as conference abstracts; (4) Studies that included only one type of post-PCNL catheterization method without comparison.

Literature screening and data extraction

Randomized controlled trials (RCTs) and case-control studies comparing tubeless and standard PCNL in pediatric patients that met the inclusion and exclusion criteria were included. All titles and abstracts from the literature search were screened by two researchers. In case of disagreement, a third reviewer was consulted, and a consensus was reached. The extracted information included the first author, publication year, study location and sample size, stone burden, definition of stone-free status, and relevant outcome measures. For skewed data in the original articles, the best methods for estimating the sample mean and standard deviation (SD) were applied as described by Luo [13]and Wang [14].

Table 1 Search terms and results

Medical databases	Search term	Number of papers
PubMed	((((("Child"[Mesh]) OR (Children)) OR (Pediatric)) OR (Pediatrics)) AND (((((tubeless) OR (no tube)) OR (total tubeless)) OR (nephrostomy free)) OR (ureteral stentfree))) AND ((((("Nephrolithotomy, Percutaneous"[Mesh]) OR (Nephrolithotomies, Percutaneous)) OR (Percutaneous Nephrolithotomies)) OR (Percutaneous Nephrolithotomy)) OR (PCNL))	298
Embase	('child' OR 'children' OR 'pediatric' OR 'pediatrics') AND ('tubeless' OR 'no tube' OR 'total tubeless' OR 'nephrostomy free' OR 'ureteral stentfree') AND ('percutaneous nephrolithotomy' OR 'PCNL' OR 'percutaneous nephrolithotomies' OR 'Nephrolithotomy, Percutaneous'OR 'Nephrolithotomies, Percutaneous')	122
Web of Science	((Child OR Children OR Pediatric OR Pediatrics) AND (tubeless OR "no tube" OR "total tubeless" OR "nephrostomy free" OR "ureteral stentfree") AND ("Nephrolithotomy, Percutaneous" OR "Nephrolithotomies, Percutaneous" OR "Percutaneous Nephrolithotomies" OR "Percutaneous Nephrolithotomy" OR PCNL))	110
Cochrance library	(child OR children OR pediatric OR pediatrics) AND (tubeless OR no tube OR total tubeless OR nephrostomy free OR ureteral stentfree) AND (percutaneous nephrolithotomy OR PCNL OR percutaneous nephrolithotomies OR Nephrolithotomy, Percutaneous OR Nephrolithotomies, Percutaneous)	22

Quality assessment of included studies

The Cochrane Risk of Bias Tool was used to assess the quality of randomized controlled trials, while the Newcastle-Ottawa Scale (NOS) was applied for non-randomized studies. Studies scoring 5 to 9 on the NOS were classified as high quality, while those scoring less than 5 were considered low quality. Quality assessments were performed independently by two reviewers, and any disagreements were resolved through consultation with a third reviewer.

Statistical methods

Meta-analysis was performed using RevMan 5.4 software. For continuous variables, the Weighted Mean Difference (WMD) was used; for dichotomous variables, the Odds Ratio (OR) was calculated. Heterogeneity among studies was assessed using the chi-square test, and the degree of heterogeneity was quantified by I^2. If $I^2 < 50\%$ and $P > 0.1$, a fixed-effect model was applied; otherwise, a random-effects model was used. For results with high heterogeneity, sensitivity analysis (using Stata 17.0 software) or subgroup analysis (using RevMan 5.4 software) was conducted to explore the sources of heterogeneity, and funnel plots were used to assess publication bias. A P-value of less than 0.05 was considered statistically significant.

Result

Included studies and their basic characteristics

A total of 554 relevant studies were initially identified through the literature search. After reviewing titles and abstracts, 382 studies were excluded as irrelevant, and 137 studies were excluded due to duplication. After reviewing the full texts of the remaining 35 studies, 20 were excluded for not meeting the inclusion criteria. The remaining 15 studies were further assessed and strictly screened according to the inclusion and exclusion criteria. Ultimately, 2 studies were excluded due to the participants' age being over 18 years. Thirteen studies [11, 12, 15–25] that strictly met the inclusion and exclusion criteria were ultimately included, comprising a total of 661 patients: 321 in the tubeless PCNL group and 340 in the standard PCNL group. These studies included 3 randomized controlled trials [15, 23, 24] and 10 case-control studies [11, 12, 16–22, 25]. The literature screening process is shown in Fig. 1. The basic characteristics of the included studies are summarized in Table 2.

Quality assessment of included studies

Among the three included randomized controlled trials (RCTs) [15, 23, 24], although one RCT exhibited a high risk of bias in random sequence generation and another in allocation concealment, no significant overall risk of bias was detected, reinforcing the reliability of the findings. All ten case-control studies [11, 12, 16–22, 25]were rated as high-quality studies. The detailed quality assessment of the RCTs and Newcastle-Ottawa Scale (NOS) scores for the non-RCT studies is provided in Fig. 2; Table 3.

Hospital stay

A total of 12 studies [11, 12, 15, 17–25] included in the analysis used hospital stay as the outcome measure, with 276 patients in the tubeless group and 295 patients in the standard group. There was significant heterogeneity between the studies ($P < 0.01$, $I^2 = 94\%$). Due to the high heterogeneity, a sensitivity analysis was performed using a sequential exclusion method, and no significant changes in the overall results were found, suggesting the robustness of the findings (Fig. 3). A random-effects model was used for the meta-analysis, which showed that the hospital stay was significantly shorter in the tubeless PCNL group compared to the standard PCNL group (WMD = -1.60, 95% CI: -2.27 to -0.92, $P < 0.01$)(Fig. 4).

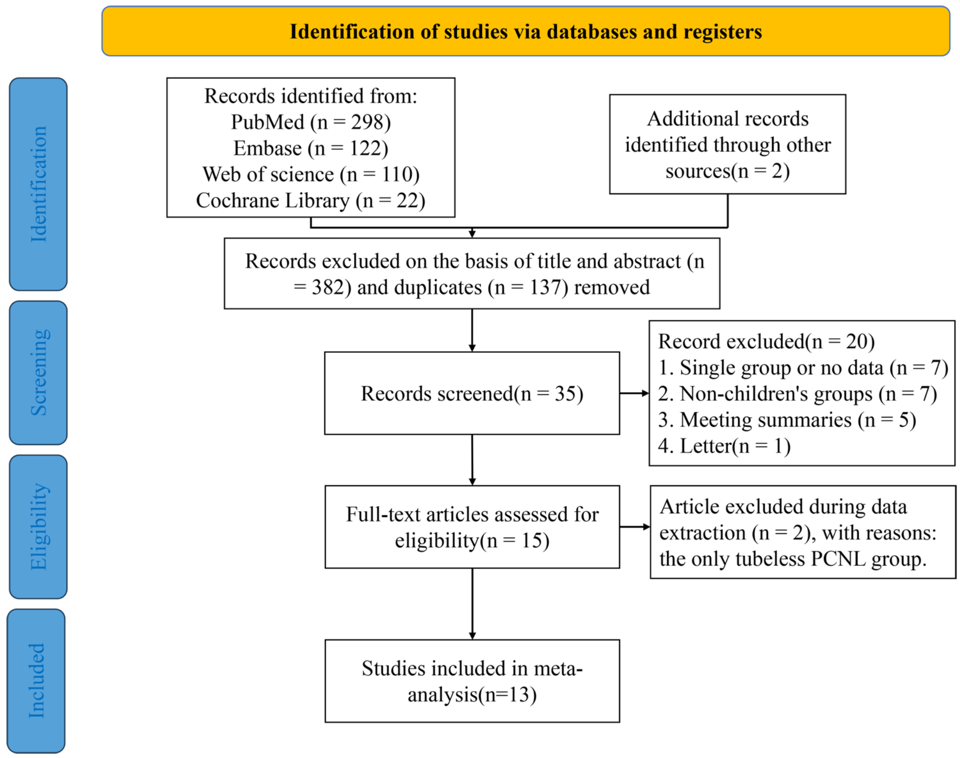

Fig. 1 Literature Screening Flowchart

Operative time

A total of 8 studies [11, 12, 15, 19, 21, 23–25] included in the analysis used operative time as the outcome measure, with 215 patients in the tubeless group and 225 patients in the standard group. There was no significant heterogeneity between the studies ($P = 0.21$, I^2 = 27%), and a fixed-effects model was used for the meta-analysis. The results showed that the operative time was significantly shorter in the tubeless PCNL group compared to the standard PCNL group (WMD = -2.06, 95% CI: -4.02 to -0.10, $P = 0.04$)(Fig. 4).

Hemoglobin drop

A total of 8 studies [11, 15, 18–21, 23, 24] included in the analysis used hemoglobin drop as the outcome measure, with 173 patients in the tubeless group and 192 patients in the standard group. There was significant heterogeneity between the studies ($P < 0.01$, I^2 = 94%). Due to the high heterogeneity, a sensitivity analysis was performed using a sequential exclusion method, and no significant changes in the overall results were found, suggesting the robustness of the findings (Fig. 3). A random-effects model was used for the meta-analysis, and the results showed that there was no statistically significant difference in hemoglobin drop between the two PCNL groups (WMD = -0.20, 95% CI: -0.54 to 0.15, $P = 0.26$)(Fig. 4).

Stone clearance rate

A total of 11 studies [11, 15–20, 22–25] included in the analysis used stone clearance rate as the outcome measure, with 263 patients in the tubeless PCNL group and 282 patients in the standard group. There was no significant heterogeneity between the studies ($P = 0.85$, I^2 = 0%), and a fixed-effects model was applied for the meta-analysis. The results demonstrated that the stone clearance rate in the tubeless PCNL group was higher than that in the standard group (OR = 2.18, 95% CI: 1.09 to 4.34, $P = 0.03$)(Fig. 4).

Incidence of complications

Overall complication rate

A total of 11 studies [11, 12, 15–17, 19–24] assessed the overall complication rate as an outcome, including 288 patients in the tubeless group and 298 patients in the standard group. Significant heterogeneity was observed between studies ($P = 0.01$, I^2 = 57%). Given the high heterogeneity, sensitivity analysis was performed by sequentially excluding studies, but no significant changes in the overall results were found, indicating that the final results are robust (Fig. 3). Subgroup analysis by study design (RCT vs. non-RCT) reduced heterogeneity in both groups, suggesting that study design may be a key source of variability ($P = 0.01$, I^2 = 84.2%)(Fig. 5). A random-effects model was used for the meta-analysis. While no statistically significant differences were observed in

Table 2 Basic information of the included studies

Author	Study period	Region	Study design	Number of kidneys		Sex(Male)		Age(years)	
				TL	T	TL	T	TL	T
Aghamir2012	2010–2011	Iran	Prospective	13	10	10	6	10.31 ± 2.68	11.10 ± 1.72
Al-Zobaie2022	2019–2021	Ukraine	Retrospective	45	45	27	28	-	-
Bilen2010	2010	Turkey	Retrospective	12	16	10	6	3.3 ± 1.13	3 ± 1.36
Goktug2013	2009–2011	Turkey	Retrospective	12	15	4	11	5.25 ± 2	9.4 ± 2.5
Iqbal2018	2010–2016	Pakistan	Retrospective	17	18	9	10	7.5 ± 5.9	9 ± 5.2
Keshavamurthy2018	2012–2015	India	Retrospective	17	29	9	16	12 ± 4.04	14.0 ± 4.29
Kiani2024	2011–2018	Iran	Retrospective	41	47	15	27	7.12 ± 5.75	7.17 ± 5.19
Ozturk2010	2006	Turkey	Retrospective	8	8	-	-	4.72 ± 2.25	4.67 ± 2.24
Salem2006	2003–2005	Egypt	Retrospective	20	10	-	-	-	-
Samad2012	2004	India	Prospective	30	30	16	15	6.3 ± 3.6	7.2 ± 3.2
Shan2022	2021–2022	Pakistan	Prospective	50	50	20	24	8.68 ± 2.07	9.12 ± 1.82
Song2014	2009–2012	China	Prospective	35	35	-	-	1.69 ± 0.53	1.68 ± 0.6
Yildizhan2021	2010–2018	Turkey	Retrospective	21	27	10	18	12.48 ± 3.41	11.19 ± 3.75

Author	Stone location(Lower calyx)		Side(Right)		Stone burden (mm)		Nephroscope diameter(Fr)	Fistula tube diameter(Fr)	Definition of stone-free
	TL	T	TL	T	TL	T			
Aghamir2012	5	2	-	-	29.23 ± 4.85	31.40 ± 5.19	26Fr,28Fr	-	≤ 4 mm
Al-Zobaie2022	1	3	27	26	31.5 ± 14.9	28.6 ± 14.5	12 Fr	-	-
Bilen2010	1	3	5	6	192(100–400)*	416 (775-1,380)*	14 Fr	10-14Fr	-
Goktug2013	-	-	9	9	199(100–320)*	402.67(95-1550)*	20Fr	14Fr	≤ 4 mm
Iqbal2018	-	-	-	-	16 ± 6	19 ± 7	20 Fr	12Fr	<4 mm
Keshavamurthy2018	2	3	7	15	13 ± 5.66	18 ± 4.68	18Fr,24 Fr	SB:16Fr/LB:22Fr	0 mm
Kiani2024	-	-	16	22	-	-	-	-	-
Ozturk2010	2	2	-	-	17.6 ± 3.5	19.1 ± 4.45	20 Fr	12 Fr	< 4 mm
Salem2006	-	-	-	-	-	-	24Fr	-	0 mm
Samad2012	-	-	-	-	20.4 ± 9.3	28.6 ± 16.7	17Fr	16 Fr	-
Shan2022	-	-	25	30	22.5 ± 3.3	21.3 ± 3.8	-	-	-
Song2014	8	9	-	-	23.2 ± 10.7	24.0 ± 13.9	14Fr,16Fr	-	< 4 mm
Yildizhan2021	-	-	8	14	21.62 ± 2.13	22 ± 1.71	18 Fr/28Fr,30 Fr	14 Fr	< 5 mm

Note: TL: Tubeless PCNL group, T: Tubed PCNL group,*Unit in mm^2

overall complication rates (OR = 0.50; 95% CI: 0.24–1.06; $P = 0.07$), the data suggest a trend toward a lower incidence in the tubeless PCNL group(Fig. 5).

Postoperative fever

A total of 10 studies [11, 12, 15, 18–24] assessed postoperative fever as an outcome, including 243 patients in the tubeless PCNL group and 252 patients in the standard PCNL group. A fixed-effects model was used for the meta-analysis, revealing that tubeless PCNL was significantly associated with a lower rate of postoperative fever compared to standard PCNL (OR = 0.46; 95% CI: 0.27–0.78; $P < 0.01$), with low heterogeneity ($P = 0.77$, $I^2 = 0\%$). This finding underscores the potential benefit of the tubeless approach in reducing infectious complications(Fig. 5).

Postoperative urinary leak

A total of 10 studies [11, 12, 15, 17–23] included postoperative urinary leak as an outcome, with 220 patients in the tubeless PCNL group and 233 patients in the standard PCNL group. There was no significant heterogeneity between studies ($P = 0.83$, $I^2 = 0\%$), and a fixed-effects model was used for the meta-analysis. The results demonstrated that the rate of postoperative urinary leak in the tubeless PCNL group was significantly lower than that in the standard PCNL group (OR = 0.20, 95% CI: 0.08–0.50, $P < 0.01$)(Fig. 6).

Perinephric fluid collection

A total of 8 studies [12, 15, 18, 19, 21–24] included postoperative perinephric fluid collection as an outcome, with 185 patients in the tubeless PCNL group and 176 patients in the standard PCNL group. There was no

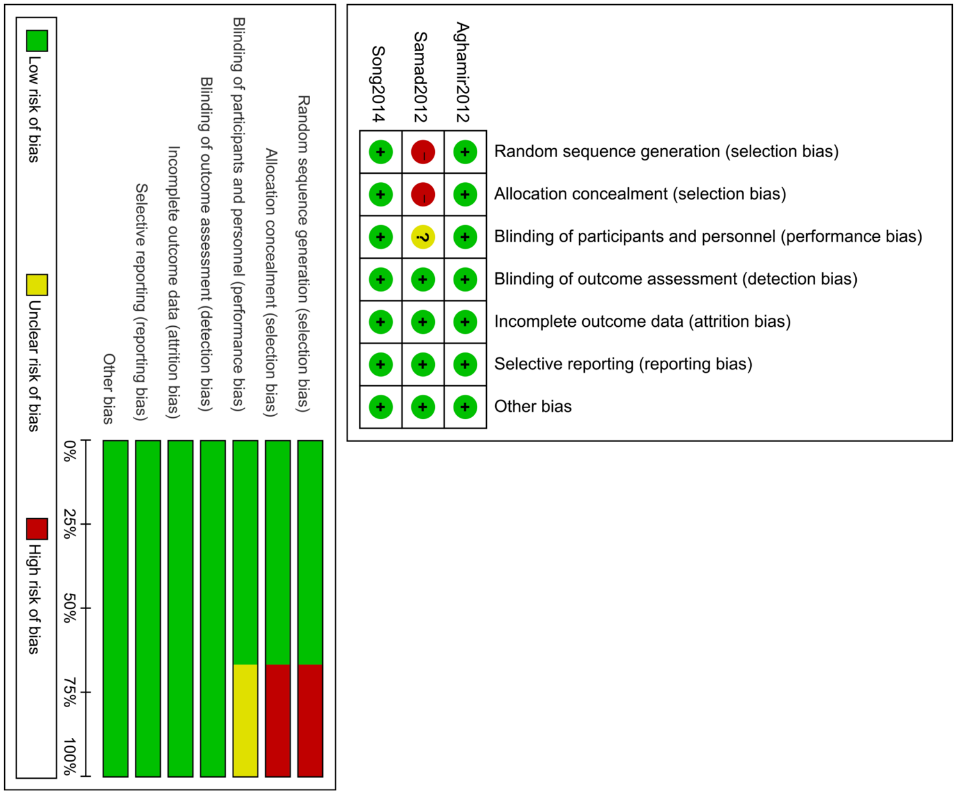

Fig. 2 Quality Assessment of RCT Studies

significant heterogeneity between studies ($P=0.77$, $I^2=0\%$), and a fixed-effects model was used for the meta-analysis. The results showed that the incidence of perinephric fluid collection between the two PCNL groups did not differ significantly (OR = 2.65, 95% CI: 0.71–9.97, $P=0.15$)(Fig. 6).

Urinary tract infection

A total of 3 studies [12, 19, 23] included postoperative urinary tract infection as an outcome, with 97 patients in the tubeless PCNL group and 98 patients in the standard PCNL group. There was no significant heterogeneity between studies ($P=0.52$, $I^2=0\%$), and a fixed-effects model was used for the meta-analysis. The results showed no statistically significant difference in the incidence of urinary tract infection between the two PCNL groups (OR = 1.38, 95% CI: 0.46–4.13, $P=0.57$)(Fig. 6).

Blood transfusion requirement

A total of 7 studies [11, 15, 17–19, 21, 24]assessed blood transfusion requirements as an outcome, with 138 patients in the tubeless PCNL group and 149 patients in the standard PCNL group. There was no significant heterogeneity between the studies ($P=0.49$, $I^2 = 0\%$), and a fixed-effect model was used for the meta-analysis. The results indicated no statistically significant difference in blood transfusion requirements between the two groups (OR = 0.46, 95% CI: 0.13–1.68, $P=0.24$)(Fig. 6).

Reoperation

A total of 9 studies [11, 15, 17, 20–25]assessed reoperation as an outcome, with 197 patients in the tubeless PCNL group and 212 patients in the standard PCNL group. There was no significant heterogeneity between the studies ($P=0.42$, $I^2 = 0\%$), and a fixed-effect model was used for the meta-analysis. The results showed no statistically significant difference in the reoperation rates between the two groups (OR = 0.50, 95% CI: 0.21–1.19, $P=0.12$)(Fig. 7).

Pain assessment

Analgesic time

Two studies [17, 20]evaluated analgesic time as an outcome, with 29 patients in the tubeless group and 45 patients in the standard group. There was no significant heterogeneity between the studies ($P=0.97$, $I^2 = 0\%$), and a fixed-effect model was used for the meta-analysis. The results showed that the analgesic time was shorter in the tubeless PCNL group compared to the standard PCNL group (WMD = -2.00, 95% CI: -2.44 to -1.56, $P<0.01$)(Fig. 7).

Table 3 NOS scores of Non-RCT studies

Newcastle-Ottawa Quality Assessment Scale: Cohort Studies									
Study	Selection				Comparability	Outcome			Total Score
	Representa-tiveness of the exposed cohort	Selection of the non-ex-posed cohort	Ascertainment of exposure to implants	Demonstration that outcome of interest was not presentat start of study	Comparability of cohortson the basis of the design or analysis	Assessment of outcome	Was follow up long enough for outcomes to occur	Adequacy of follow up of cohorts	
Al-Zobaie2022	☆	☆	☆	☆	☆	☆	☆	☆	8
Bilen2010	☆	☆	☆	☆	☆	☆	☆	☆	8
Goktug2013	☆	☆	☆	☆	☆	☆	☆	☆	8
Iqbal2018	☆	☆	☆	☆	☆☆	☆	☆	☆	9
Keshavamurthy2018	☆	☆	☆	☆	☆☆	☆	☆	☆	9
Kiani2024	☆	☆	☆	☆	☆☆	☆	☆	☆	9
Ozturk2010	☆	☆	☆	☆	☆☆	☆	☆	☆	9
Salem2006	☆	-	☆	☆	☆	☆	☆	☆	7
Shan2022	☆	☆	☆	☆	☆	☆	☆	☆	8
Yildizhan2021	☆	☆	☆	☆	☆☆	☆	☆	☆	9

Postoperative pain score

Two studies [12, 22]evaluated postoperative pain using the Visual Analog Scale (VAS) (0–10 points) as an outcome, with 70 patients in the tubeless group and 60 patients in the standard group. There was no significant heterogeneity between the studies ($P=0.36$, $I^2 = 0\%$), and a fixed-effect model was used for the meta-analysis. The results showed that the pain score was lower in the tubeless PCNL group compared to the standard PCNL group (WMD = -2.52, 95% CI: -2.81 to -2.22, $P<0.01$)(Fig. 7).

Publication Bias

We assessed potential publication bias for outcomes with 10 or more studies by generating funnel plots. The results indicated that there was no significant publication bias for any of the outcomes. Below are the funnel plots for the primary outcome measures(Fig. 8).

Discussion

Similar to adults, a longstanding debate in pediatric PCNL concerns the necessity of nephrostomy tubes and their impact on surgical outcomes and complications. To mitigate complications and discomfort associated with nephrostomy tubes, various drainage techniques have been employed postoperatively, including tubeless (i.e., placement of only a double-J stent), completely tube-less (i.e., no nephrostomy or double-J stent), and nephrostomy-only approaches [7]. Currently, tube-less PCNL remains a relatively rare practice [26], despite evidence suggesting it may shorten operative and hospital stay times, reduce complications such as urinoma, and decrease postoperative pain scores and analgesic requirements [9]. However, the postoperative effects of tube-less techniques in pediatric PCNL remain controversial, primarily due to the lack of large-scale studies.

Since Fernström and Johansson first described PCNL in 1976, the technique has evolved into one of the primary approaches for the treatment of renal stones [27]. In 1986, Dickinson et al. introduced the concept of tubeless PCNL, aiming to reduce postoperative complications associated with nephrostomy tubes, such as bleeding, tract infection, extravasation of urine, and catheter pain, thereby shortening hospital stays [28]. In 1997, Bellman et al. published the first study on tube-less PCNL, reporting no major complications in any of the 50 patients, all of whom were discharged early [29]. In 1998, Jackman performed the first pediatric tube-less PCNL and proposed the feasibility of outpatient tube-less PCNL for children [30]. In 2006, Salem et al. conducted 20 pediatric tube-less PCNL cases and compared them with 10 standard PCNL cases, concluding that tube-less PCNL in children offered advantages such as less pain, fewer complications, and shorter hospital stays [31]. More recently,

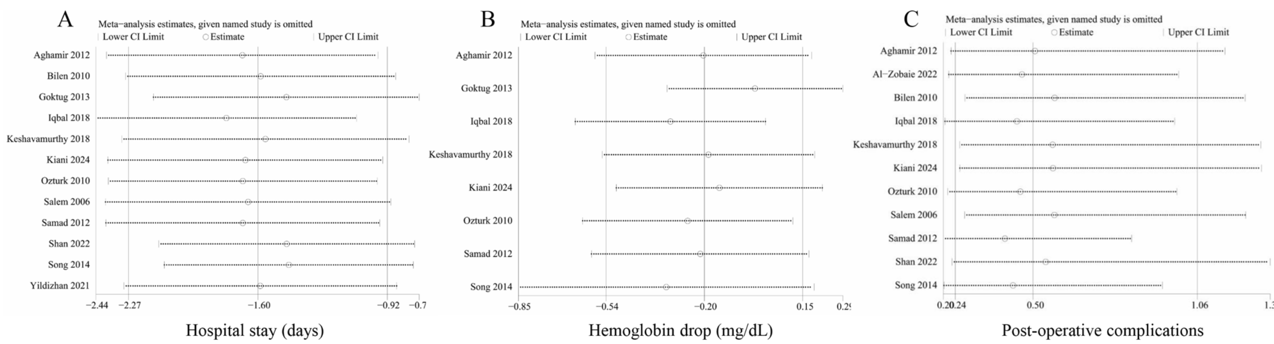

Fig. 3 Sensitivity Analysis of Hospital Stay, Hemoglobin Decrease, and Postoperative Complications

pediatric tube-less PCNL continues to be a prominent research focus in pediatric urology [32, 33].

We found that, in the pediatric population, tube-less PCNL is associated with shorter operative and hospital stay times, which is consistent with recent meta-analytic findings in adults undergoing tube-less PCNL [9]. Compared to standard PCNL, tube-less PCNL simplifies the placement and adjustment of nephrostomy tubes, which not only avoids the additional steps associated with tube placement but also reduces the need for postoperative monitoring and care, thereby shortening overall surgical duration [34]. Our study suggests that tube-less PCNL can reduce complications associated with nephrostomy tubes, such as urine leakage and fever, promote faster recovery in children, and decrease the need for prolonged hospitalization and treatment. Furthermore, as nephrostomy tubes are not required, tube-less PCNL reduces postoperative pain and discomfort, eliminates the need for nephrostomy tube care and removal, and enables patients to resume daily activities more quickly, thus further reducing the length of hospitalization [35]. Although the high heterogeneity observed among studies may be attributed to differences in surgical protocols, study populations, or outcome definitions, sensitivity analysis through sequential exclusion of studies confirmed the stability of the final results.

Postoperative bleeding or hemoglobin reduction following PCNL is closely associated with the diameter of the puncture sheath [36]. In this study, all PCNL procedures were either Mini PCNL or Ultra-Mini PCNL, where smaller instruments and more refined techniques reduced intraoperative blood loss. Consequently, no significant differences were observed between the two groups in terms of postoperative hemoglobin drop and transfusion requirements.

Unlike most studies [9, 37, 38], we observed a higher stone clearance rate with tubeless PCNL in pediatric patients. Aslan et al. [39] reported that stone treatment history, stone load, and stone-to-kidney size (SKS) score affect stone-free rates, while nephroscope sheath size does not. In Mini or Ultra-Mini PCNL—commonly used in children—the small puncture tract limits the clearance of residual stones via nephrostomy tubes. Instead, the absence of a tube enhances surgical precision, facilitates earlier mobilization, and promotes natural renal drainage. Another possible explanation is the lack of blinding in the surgical intervention—surgeons aware of nephrostomy tube placement may be more likely to leave behind fragments [7]. Ultimately, surgeon experience and operative techniques play a critical role in stone clearance rates. Experienced surgeons determine catheter placement at the end of the procedure based on patient-specific and intraoperative factors, such as residual stone burden [5]. The use of advanced surgical techniques enhances the likelihood of achieving optimal outcomes, making tube-less PCNL more feasible. Conversely, in complex cases requiring a second-look PCNL, surgeons are more likely to place a nephrostomy tube [40].

In a retrospective analysis of 438 renal stone patients, Hill et al. [40] found that the decision to retain a nephrostomy tube in PCNL did not seem to affect the overall complication rate. Recently, Bildirici et al. [41]compared the efficacy of completely tube-less PCNL with standard-prone PCNL in 87 stone patients, with results also indicating that tube-less PCNL did not significantly impact the overall complication rate. Tube-less PCNL and traditional PCNL are similar in terms of intraoperative procedures, choice of renal puncture sites, nephroscope handling, and stone fragmentation techniques [7]. Although tube-less PCNL reduces the use of drainage tubes, it does not alter the technical difficulty of the procedure or the likelihood of renal injury. Therefore, the major intraoperative complications, such as bleeding, renal injury, and ureteral injury, show little difference between the two approaches. Overall, while tube-less PCNL reduces complications related to drainage tubes (e.g., tube displacement, and lumen obstruction), the incidence of other complications remains unchanged. Thus, there are no significant differences between the two methods when considering overall complications (including perinephric fluid collections, urinary tract infections,

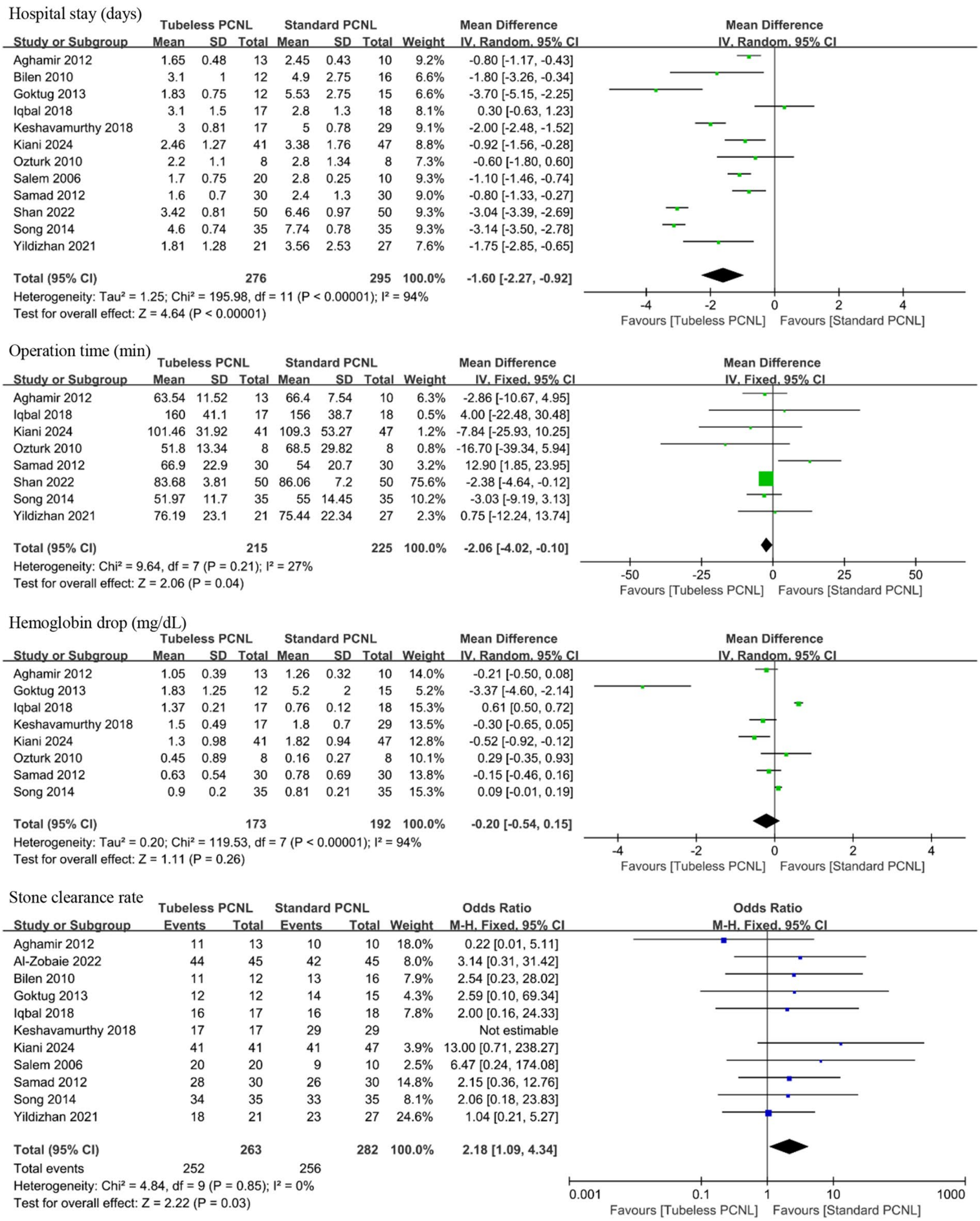

Fig. 4 Forest Plots of Hospital Stay, Operative Time, Hemoglobin Drop, and Stone Clearance Rate in Pediatric Tubeless vs. Standard PCNL

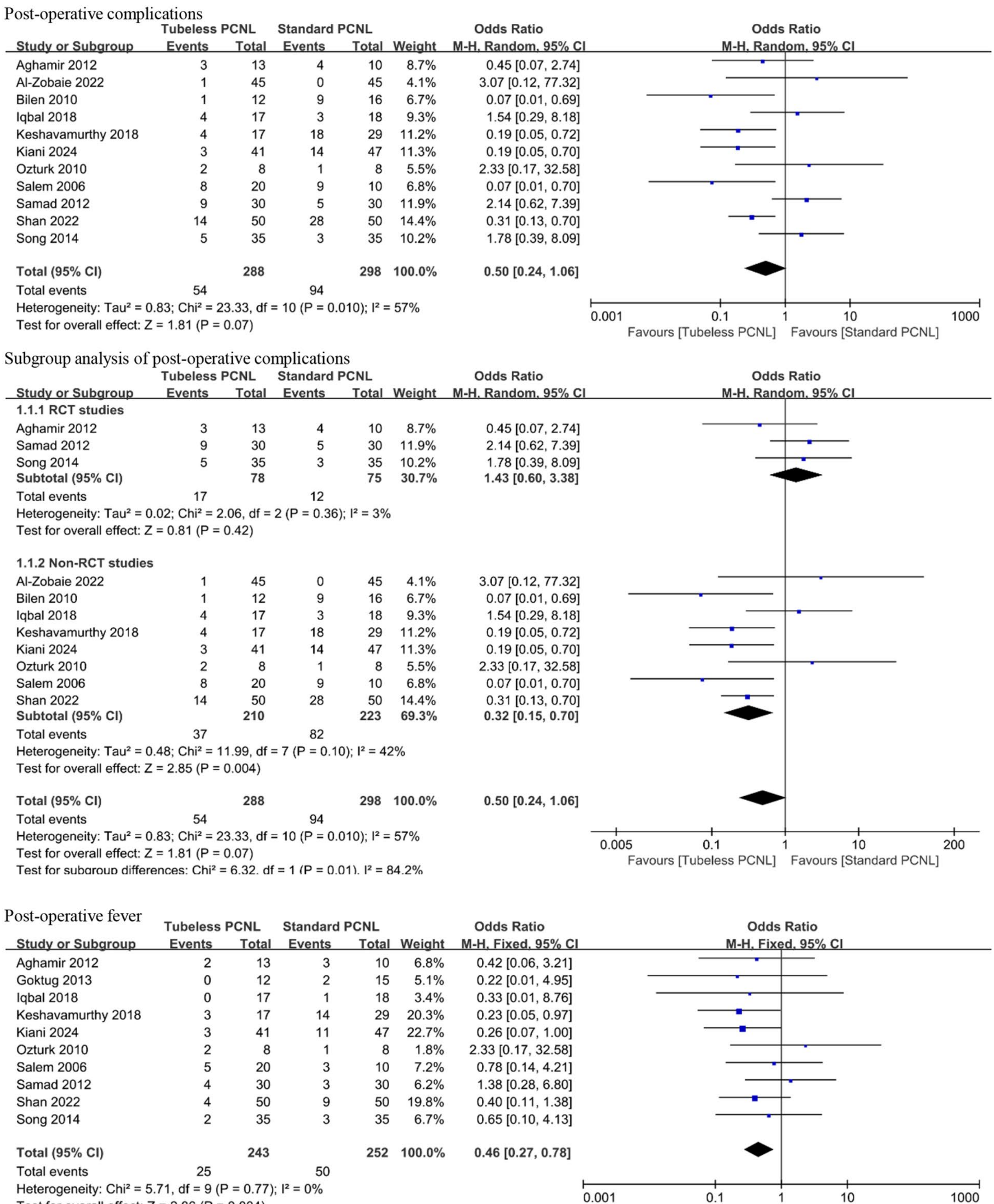

Fig. 5 Forest Plots of Complications, Subgroup Analysis of Complications, and Postoperative Fever in Pediatric Tubeless vs. Standard PCNL

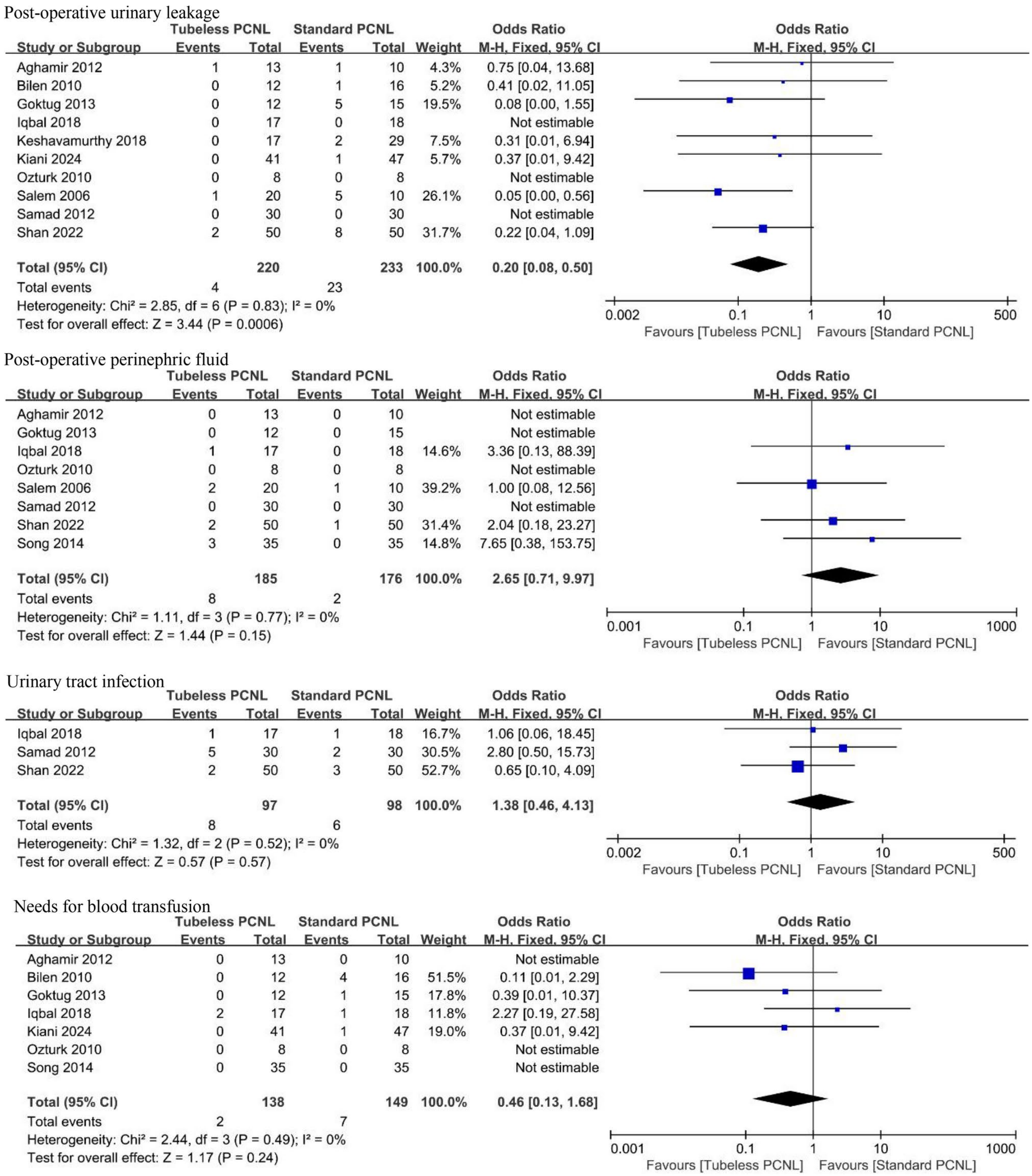

Fig. 6 Forest Plots of Postoperative Urinary Leak, Perirenal Fluid, Urinary Tract Infection, and Blood Transfusion Requirement in Pediatric Tubeless vs. Standard PCNL

and blood transfusion requirements) and reoperation rates.

However, in contrast to the findings of Akbar et al. [10] and most adult studies [9, 37, 42], we observed a lower rate of fever in pediatric tube-less PCNL. This may be attributed to the fact that the presence of a nephrostomy tube in standard PCNL can lead to urinary retention, urine leakage, and irritant responses, which in turn may cause postoperative fever.

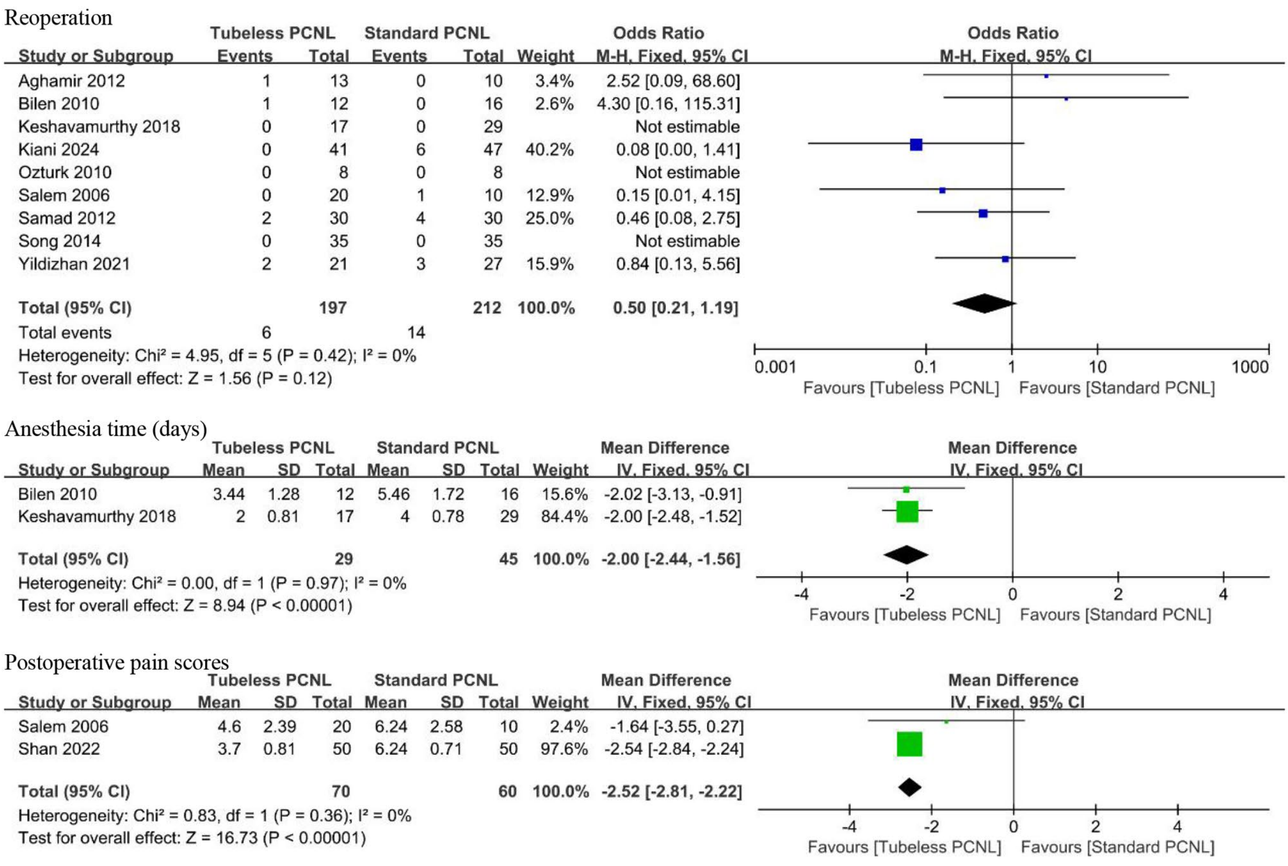

Fig. 7 Forest Plots of Reoperation, Postoperative Analgesia Time, and Visual Analog Scale (VAS) Pain Scores in Pediatric Tubeless vs. Standard PCNL

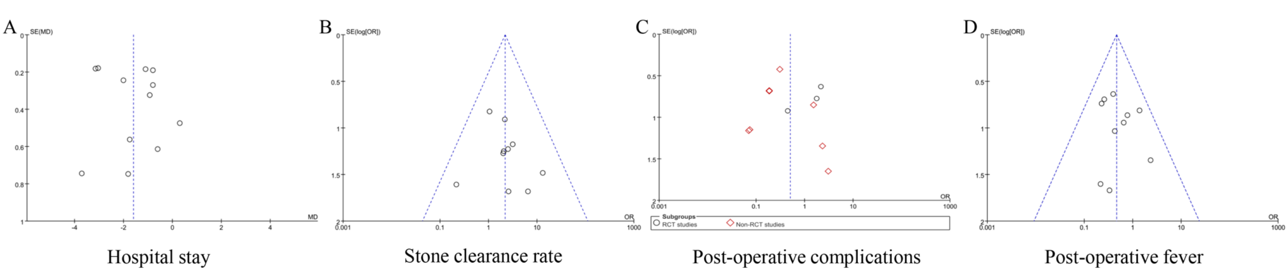

Fig. 8 Funnel Plots for Publication Bias of Hospitalization Duration, Stone Clearance Rate, Postoperative Complications, and Postoperative Fever

Although typically self-limiting, urine leakage at the percutaneous access site is a common issue that often troubles patients. Previous studies have indicated that the duration and caliber of the percutaneous nephrostomy tube typically determine the duration of the leakage [43]. Standard PCNL usually requires the placement of a nephrostomy tube, and in the early postoperative period, the drainage tube may lead to urine leakage due to pressure changes during urination, improper tube positioning, or other factors, sometimes even resulting in extravasation. The insertion of a drainage tube during or after surgery, especially if it is too long or improperly placed, can also cause urethral injury, incomplete closure of the renal pelvis, or ureteral fistulas, thus contributing to urine leakage. In contrast, tube-less PCNL eliminates the need for a drainage tube, avoiding these risks and significantly reducing the incidence of postoperative urine leakage.

Drainage tube-related pain is a major source of postoperative discomfort following standard PCNL. In traditional PCNL, the placement of a drainage tube often leads to symptoms such as discomfort and pain due to the tube [44]. The drainage tube can irritate the urinary tract, bladder, or renal pelvis, triggering bladder spasms, stent colic, and other discomforts, which in turn increases the need for analgesics [7]. In contrast, tube-less PCNL eliminates the need for a drainage tube, significantly reducing these sources of pain, and consequently decreasing both the intensity and duration of postoperative pain, as confirmed in our study.

It is noteworthy that our study demonstrates that tubeless PCNL is effective in certain pediatric patients, and age is not an absolute contraindication for this approach. Although some scholars have suggested that factors such as stone size and number, bilateral PCNL, intercostal access, and single-puncture PCNL are not absolute contraindications, the decision to perform tube-less PCNL should be made flexibly based on intraoperative conditions. However, we still recommend considering the use of a nephrostomy tube in the following situations: ureteral stricture or obstruction, complete or partial staghorn stones (with the expectation of requiring staged fragmentation), congenital urinary tract anomalies, significant intraoperative bleeding, renal abscess, solitary kidney or functionally solitary kidney, severe collecting system injury, and impaired renal function [7, 37, 38].

This study has several limitations. Firstly, variations in controlling factors such as stone burden and surgical instruments across studies, which are closely related to surgical complexity, operative time, and stone clearance rate, may have introduced potential heterogeneity, thereby affecting the generalizability of certain outcome measures. Second, the categories and dosages of postoperative analgesia were not standardized, resulting in the exclusion of certain related data (e.g., analgesic dosages, due to the inclusion of both opioid and nonsteroidal drugs) from the analysis. Finally, our study included several non-randomized controlled trials (non-RCTs), and one RCT exhibited a relatively high risk of bias due to a lack of blinding. This may contribute to higher heterogeneity in some results, potentially leading to bias and influencing the final conclusions.

To address these limitations, future research should prioritize well-designed prospective studies with standardized protocols to minimize bias and enhance comparability. In particular, multi-center, large-sample randomized controlled trials (RCTs) are needed to provide high-quality evidence on the efficacy and safety of tubeless PCNL in pediatric populations.

Conclusion

In children with kidney stones and low stone burden or an uneventful procedure, tubeless PCNL offers clear clinical advantages, including shorter hospital stays, higher stone clearance rates, and lower postoperative fever. Additionally, it improves surgical efficiency, reduces postoperative complications, and decreases the need for analgesia. These benefits suggest that tubeless PCNL can be safely applied in pediatric patients, yielding outcomes comparable to standard PCNL, provided that indications are properly managed.

Abbreviations

95% CI	95% Confidence Interval
KUB	Kidney-Ureter-Bladder plain radiography
NOS	Newcastle-Ottawa Scale Scores
OR	Odds Ratio
PCNL	Percutaneous Nephrolithotomy
RCTs	Randomized Controlled Trials
SD	Standard Deviation
VAS	Visual Analog Scale
WMD	Weighted Mean Difference

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Author contributions

Honggang Fang was responsible for the conceptualization, study design, data analysis, and manuscript writing; Zihan Wang, Kuan Wei, and Xing Liu contributed to data collection, analysis, interpretation, and manuscript revision; Shengde Wu, Yi Hua, Tao Lin, Dawei He and Guanghui Wei assisted with data analysis, result interpretation, and manuscript editing; Deying Zhang oversaw the overall project conceptualization, provided supervision, contributed to manuscript writing, and served as the corresponding author. All authors have reviewed and agreed to the final manuscript for publication.

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Data availability

All the data generated or analyzed during this study are included in the published article.

Declarations

Ethics approval and consent to participate

Since this study is a secondary study, all ethical approvals were provided by the initial study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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