REVIEW PAPER

UROLITHIASIS

Comparison between single-shot and gradual dilation technique in percutaneous nephrolithotomy: A systematic review and meta-analysis

Kharisma Prasetya Adhyatma[1], Muhammad Ainul Mahfuz[2], Dianita Halimah Harahap[1], Muhammad Haritsyah Warli[1], Fauriski Febrian Prapiska[1]

[1]*Division of Urology, Department of Surgery, Faculty of Medicine, Universitas Sumatera Utara – Adam Malik Hospital, Medan, Indonesia*
[2]*Department of Urology, Faculty of Medicine, Universitas Indonesia – Adam Malik Hospital, Medan, Indonesia*

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Corresponding author
Kharisma Prasetya Adhyatma
Division of Urology, Department of Surgery, Faculty of Medicine, Universitas Sumatera Utara – Adam Malik Hospital, Jl. Bunga Lau No.17, Kemenangan Tani, Kec. Medan Tuntungan, Medan, Sumatera Utara 20136, Indonesia
uro.kharis@gmail.com

Introduction Percutaneous nephrolithotomy (PCNL) is efficacious for the management of bigger or complex renal calculi. This study assesses the safety and efficacy of single-shot dilation (one-shot – OD) against gradual dilation (multiple – MD) in fluoroscopy-guided PCNL, with the objective of enhancing stone management techniques.

Material and methods A comprehensive study adhering to PRISMA criteria concentrated on adult patients receiving conventional percutaneous nephrolithotomy for nephrolithiasis. Included were clinical trials and cohort studies comparing OD and MD approaches, but omitting ultrasound-guided, mini, and micro-PCNL methods. Investigations were performed in PubMed, Scopus, EMBASE, Cochrane Library, and Medline from 2008 onwards. Two reviewers independently evaluated and extracted data, employing the Cochrane ROB2 and ROBINS-I instruments for quality evaluation. Statistical analyses utilizing Review Manager 5.4 employed fixed and random-effects models contingent upon heterogeneity (I^2).

Results Sixteen studies (14 randomized controlled trials and 2 cohort studies) including 572 individuals with OD and 581 patients with MD were examined. The meta-analysis indicated a markedly reduced complication rate in the OD group (RR = 0.77; 95% CI: 0.63–0.94; p = 0.01), with no statistically significant difference in stone-free rates (RR = 1.02; 95% CI: 0.97–1.08; p = 0.49). Variations in hemoglobin reduction, duration of hospitalization, fluoroscopy exposure, and surgical time were noted. However, the significant variability requires cautious interpretation.

Conclusions The single-shot dilation approach showed a markedly reduced complication rate, indicating it as a safer option for adult patients having conventional PCNL. Additional research is required to corroborate these results across various clinical environments.

Key Words: one-shot ‹› single-step ‹› multiple ‹› sequential ‹› dilation ‹› PCNL

INTRODUCTION

Nephrolithiasis, affecting 1–15% of people worldwide, is a significant contributor to global morbidity rates [1]. Removing kidney stones is crucial for improving the patient's condition and reducing the risk of long-term complications, such as chronic kidney disease and recurrent urinary tract infections [2]. Percutaneous nephrolithotomy (PCNL) is the preferred method for treating renal stones larger than 20 mm due to its high success rate, shorter hospital stays, rapid postoperative recovery, and minimal renal parenchyma damage compared to open surgery [3]. Nephrostomy access is a vital component of PCNL, as the selected entrance and dilation method substantially affects the likelihood

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of complications. Both single-shot and progressive dilation techniques are employed, frequently contingent upon the surgeon's training and the availability of equipment. Notwithstanding the prolonged application of PCNL, the safety and efficacy of these dilation techniques are still subject to ongoing scrutiny [3, 4, 5].

Tract size is another key factor influencing PCNL outcomes. Studies have shown that smaller tracts (15–20 Fr) can reduce hemoglobin drop and transfusion rates compared to larger tracts (24–30 Fr) [6]. Gao et al. [7] reported that mini-PCNL with smaller tracts yields higher stone-free rates for lower pole stones, while Sharma et al. [8] and Gupta et al. [9] emphasized that appropriate tract sizing minimizes renal trauma and shortens operative time and radiation exposure. We conducted a systematic review and meta-analysis to compare intraoperative and postoperative outcomes of single-shot versus gradual dilation techniques in adult PCNL patients with nephrolithiasis.

MATERIAL AND METHODS

We conducted a systematic review that included clinical trials and cohort studies involving adult patients (18 years and older) who underwent PCNL for kidney stones. This review excludes ultrasound-guided, mini-, and micro-percutaneous nephrolithotomy operations. Nevertheless, certain included studies indicated access sheath diameters ranging from 14 to 20 Fr, which may be classified as mini-PCNL in different settings. These studies were included due to their surgical techniques and outcome measurements aligning with standard PCNL practices. The aim was to evaluate the outcomes of single-shot (one-shot – OD) vs gradual (multiple – MD) dilation procedures.

Single-shot dilation method employs a singular, substantial dilator such as a balloon and metallic dilator to establish the tract in one operation. Gradual dilation, on the other hand, involves sequential expansion using gradually larger dilators, including telescopic metal dilators and Amplatz dilators.

Our search was limited to studies published from 2008 onwards, without imposing any language restrictions. Primary outcomes measured include postoperative outcomes such as stone-free rate, hemoglobin reduction, complication rates (infection, fever, surgical site infection, pain, bleeding requiring transfusion, urinary leakage, hematuria, hematoma, and other complications classified according to the Clavien-Dindo system), and hospital stay duration. Secondary outcomes covered intraoperative parameters like surgical duration and fluoroscopy time. Ethical committee approval was not required for this systematic review.

We conducted a comprehensive search on June 21, 2023, across five databases: Cochrane Library, EMBASE, Medline, PubMed, and Scopus, including papers in all languages. A 'snowball' search was also performed to identify additional studies by examining reference lists of eligible publications and screening studies that cited them. The search strategy used was: (one-shot OR single-step OR single OR one-stage) AND (multiple OR sequential OR serial OR gradual OR metal* OR stepwise) AND (dilat*) AND (percutaneous nephrolithotomy OR PCNL).

Two authors independently reviewed the full-text articles and extracted relevant data, including demographics, quality assessment, and results. Data were included only from studies meeting the inclusion criteria. In cases of duplicate reports, the most recent full report was used. Discrepancies in data extraction were resolved through discussion and consultation with senior authors. The methodological quality of the included studies was independently assessed by two reviewers using the Risk of Bias 2 (ROB2) tool for randomized controlled trials (RCTs) and the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool for cohort studies.

Statistical analysis was performed using RevMan V.5.4 software developed by the Cochrane Collaboration. For dichotomous data, risk ratios (RRs) with 95% confidence intervals (CIs) were calculated. Continuous data were analyzed using mean differences (MDs) with 95% CIs. Heterogeneity among the studies was assessed using Cochrane's Q test and the I^2 statistic were calculated to assess the included studies' heterogeneity. Heterogeneity was categorized as low if $I^2 <40\%$, moderate if $40\% \leq I^2 <75\%$, and high if $I^2 \geq 75\%$ [6]. Fixed-effect meta-analysis was used for low heterogeneity, while random-effects meta-analysis was conducted for moderate to high heterogeneity. Sensitivity and subgroup analyses were performed to identify the sources of significant heterogeneity. A p-value less than 0.05 was considered statistically significant. In cases where the standard deviation was missing, it was estimated using formulas from the Cochrane Handbook [11].

RESULTS

Our investigation included a total of sixteen studies [5, 12–26], including fourteen RCTs [12–22, 24–26] and two retrospective cohorts [5, 23], to compare single step dilation with multiple stages dilation

PCNL in 1,734 eligible patients. Figure 1 depicts the search flow diagram illustrating the selection procedure. Tables 1–3 provide detailed characteristics of the included investigations. All eligible studies with a low risk of bias were declared eligible for inclusion in the meta-analysis.

Stone-free rate

The analysis encompassed a collection of eleven studies [5, 13–15, 17, 19, 21–24, 26], comprising a combined sample size of 1,153 patients. Among these patients, 572 individuals underwent single-shot dilation. The stone-free rate, which refers to the absence of any remaining stones as observed in subsequent imaging, was evaluated. While the methodology for evaluating the stone-free rate varied, common methods included KUB (kidney, ureter, bladder) X-rays or ultrasound (USG). However, our study did not specify the methods used to evaluate the stone-free rate.

Our results indicate no statistically significant differences in the stone-free rate between the group treated with OD and the group treated with MD (RR = 1.02; 95% CI: 0.97–1.08; p = 0.49; I^2 = 0%). Most studies assessed the stone-free rate within one day following the surgical procedure, though some measured it at varying intervals [14, 23, 24], and a few did not define their criteria for stone-free status [5, 19, 21]. Despite these variations, our analysis revealed no heterogeneity among the studies (I^2 = 0%). Additionally, upon visual examination of the funnel plot, no apparent indications of small study effects or publication bias were observed (Figures 2, 3).

Complication rate

The included studies reported several complications among patients, such as infection, fever, surgical site infection, pain, bleeding requiring transfusion, urinary leakage, hematuria, hematoma, kidney-pelvis injury, and other complications categorized using the Clavien-Dindo system. Seven out of eleven studies employed this classification system to document complications [5, 19, 21–25].

The study involved 714 patients who underwent single-dilation PCNL and 712 patients who underwent multiple dilation PCNL. Our meta-analysis revealed a significant overall effect (RR = 0.77; 95% CI: 0.63–0.94; p = 0.01, I2 = 16%), indicating that single-shot dilation PCNL is associated with

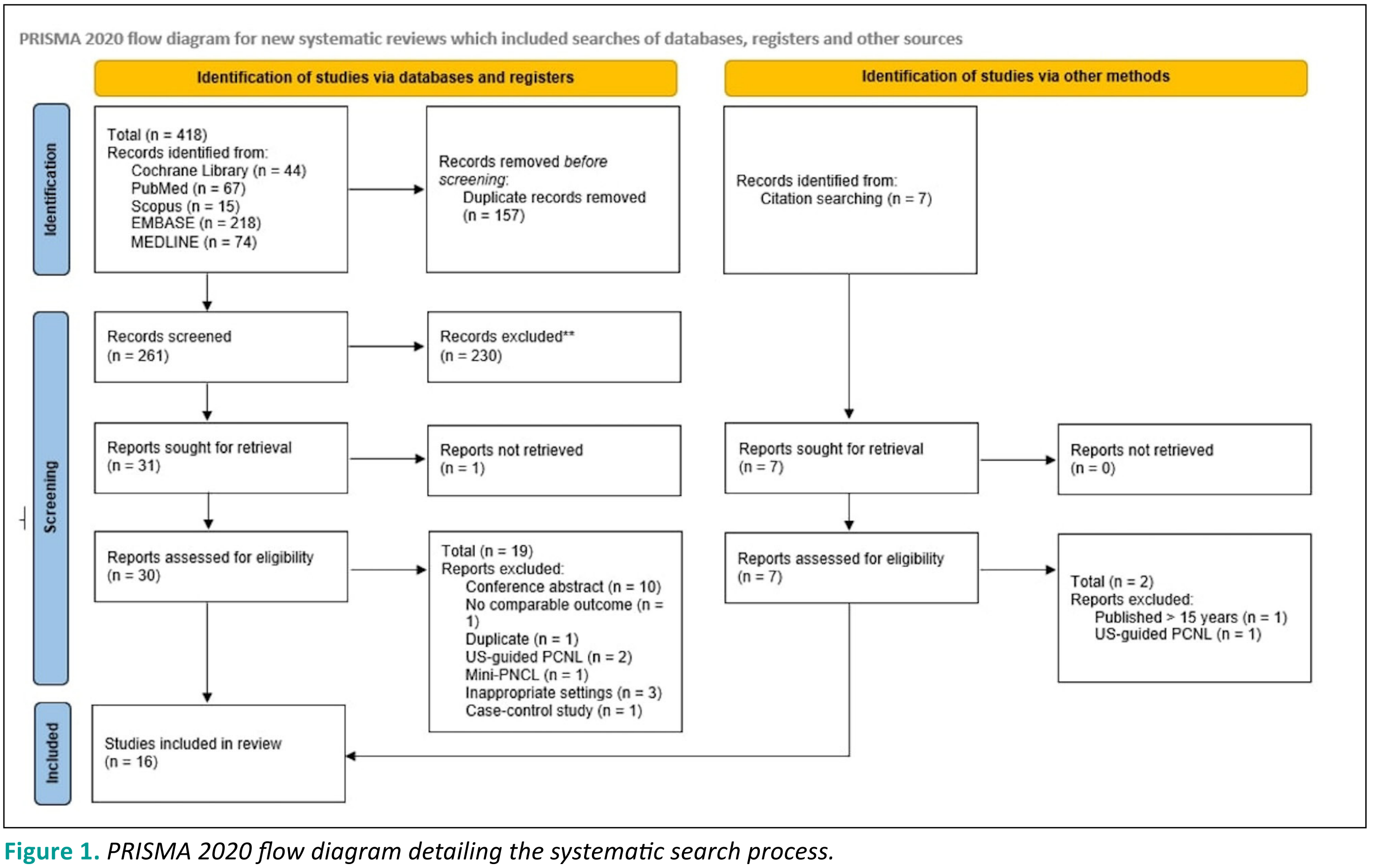

Figure 1. *PRISMA 2020 flow diagram detailing the systematic search process.*

Table 1. *Study characteristics*

Study, location, design	PCNL Position	Intervention (sample sizes)	Dilator types (size)	Male (%)	Mean age ± SD (year)	BMI ± SD (kg/m²)
Sedano-Portillo 2017 Mexico RCT	Prone	OD (n = 30)	Amplatz (30 F)	15 (50)	49.73 ±14.3	28.05 ±5.49
		MD (n = 29)	Amplatz (30 F)	15 (51.7)	45.44 ±14.4	27.45 ±4.30
Amirhassani 2014 Iran RCT	Prone	OD (n = 50)	Amplatz (28–30 F)	28 (56)	44.8 ±15	26.2 ±7.3
		MD (n = 50)	Metal telescopic Alken (28–30 F)	22 (44)	45.6 ±14	25.4 ±6.8
Khorrami 2017 Iran RCT	Prone	OD (n = 120)	Amplatz (28 F)	76 (63.3)	44.6 ±14.8	N/A
		MD (n = 120)	Metal telescopic (28 F)	74 (61.7)	44.4 ±15.3	N/A
Ghoneima 2022* Egypt RCT	Prone; supine in rare cases	OD (n = 71)	Amplatz (30 F)	49 (69)	43.24 ±13.03	32.46 ±6.27
		MD (n = 58)	Metal telescopic Alken (9–24 F)	39 (67.2)	44.60 ±11.14	31.36 ±5.98
Mohyelden 2022 Egypt RCT	Flank-Free Supine	OD (n = 75)	Amplatz (30 F)	39 (52)	37.2 ±10.5	25.2 ±3.4
		MD (n = 75)	Metal telescopic Alken (9–30 F)	44 (58.7)	34.4 ±9.8	26 ±3.2
Falahatkar 2009 Iran RCT	Prone	OD (n = 102)	Amplatz (28 F)	56 (55)	57	N/A
		MD (n = 112)	Metal telescopic Alken (10–28 F)	62 (55)	51	N/A
Amjadi 2008 Iran RCT	N/A	OD (n = 17)	Amplatz (27 F)	10 (58.8)	42	N/A
		MD (n = 14)	Metal telescopic Alken (12–27 F)	12 (85.7)	44	N/A
Aminsharifi 2011 Iran RCT	Prone	OD (n = 29)	Amplatz (30 F)	19	44.1 ±13.7	N/A
		MD (n = 19)	Metal telescopic Alken (up to 28 F)	9	42.5 ±18.2	N/A
Kalpee 2012 South Africa RCT	Prone	OD (n = 10)	Second-generation PCNL balloon dilatation device	N/A	48.8	N/A
		MD (n = 10)	Amplatz polyurethane serial dilators (30 F)	N/A	55.9	N/A
Attallah 2023 Iraq RCT	Prone	OD (n = 50)	Amplatz (26–30 F)	27 (54)	44.5 ±12.6	N/A
		MD (n = 70)	Metal telescopic Alken (24–30 F)	51 (58.6)	45.2 ±11.6	N/A
Phaijitwichian 2021 Thailand RCT	Prone	OD (n = 33)	Amplatz (30 F)	23 (69.7)	58.21 ±10.89	23.52 ±3.30
		MD (n = 32)	Metal telescopic Alken (10–30 F)	17 (53.12)	57.13 ±7.15	22.78 ±4.03
Kamal 2020 Bangladesh RCT	Prone	OD (n = 30)	Amplatz (24–28 F)	N/A	35.30 ±12.31	N/A
		MD (n = 30)	Metal telescopic Alken	N/A	35.30 ±12.31	N/A
Wifaq 2022 Afghanistan RCT	Supine	OD (n = 30)	Amplatz (28 F)	16 (53.3%)	41.96 ±11.18	N/A
		MD (n = 30)	Metal telescopic Alken	19 (63.3%)	41.16 ±11.48	N/A
Nour 2014 Egypt RCT	Prone	OD (n = 24)	Amplatz (30 F)	17	43.8	25.9
		MD (n = 25)	Metal telescopic Alken (30 F)	16	38.2	25.7
Aydmemir 2020 Turkey Cohort	Prone	OD (n = 105)	Amplatz (30 F)	57 (54%)	47.85 ±13.68	27
		MD (n = 108)	Amplatz (30 F)	70 (65%)	48.55 ±11.93	27
Ozbilen 2022 Turkey Cohort	Supine	OD (n = 87)	Amplatz (up to 30 F)	59 (67.8%)	45.6 ±11.6	27.4 ±3.8
		MD (n = 89)	Amplatz (up to 30 F)	69 (77.5%)	47.2 ±13.7	26.8 ±3.3

*All PCNL technique is fluoroscopy guided unless marked study with tubeless fluoroscopy guided
BMI – body mass index; MD – gradual dilation; OD – single-shot dilation; PCNL – percutaneous nephrolithotomy; RCT – randomized controlled trial, SD – standard deviation,

a lower risk of complications compared to multiple dilation PCNL. However, we observed asymmetry in the lower left part of the funnel plot, suggesting a possibility of publication bias (Figures 2, 3).

Table 2. *Study nephrolithiasis characteristics*

Study, location, design	Intervention (sample sizes)	Stone burden ± SD (cm)	Staghorn (%)
Sedano-Portillo 2017 Mexico RCT	OD (n = 30)	2.23 ±1.15	4 (13.33)
	MD (n = 29)	2.52 ±1.14	3 (10.34)
Amirhassani 2014 Iran RCT	OD (n = 50)	N/A	31 (62)
	MD (n = 50)	N/A	33 (66)
Khorrami 2017 Iran RCT	OD (n = 120)	N/A	N/A
	MD (n = 120)	N/A	N/A
Ghoneima 2022* Egypt RCT	OD (n = 71)	2.64 ±1.15	N/A
	MD (n = 58)	2.78 ±1.09	N/A
Mohyelden 2022 Egypt RCT	OD (n = 75)	2.8 ±0.6	N/A
	MD (n = 75)	3.1 ±0.7	N/A
Falahatkar 2009 Iran RCT	OD (n = 102)	3.9 ±1.6	N/A
	MD (n = 112)	3.4 ±1.2	N/A
Amjadi 2008 Iran RCT	OD (n = 17)	3.7 ±1.1	7 (41)
	MD (n = 14)	3.2 ±1.1	4 (29)
Aminsharifi 2011 Iran RCT	OD (n = 29)	2.69 ±0.97	6 (20.7)
	MD (n = 19)	3.09 ±1.29	5 (26.3)
Kalpee 2012 South Africa RCT	OD (n = 10)	N/A	4 (40)
	MD (n = 10)	N/A	4 (40%)
Attallah 2023 Iraq RCT	OD (n = 50)	2.79 ±0.66	N/A
	MD (n = 70)	2.67 ±0.45	N/A
Phaijitwichian 2021 Thailand RCT	OD (n = 33)	4.62 ±1.72	21 (63.64)
	MD (n = 32)	4.00 ±1.44	15 (46.88)
Kamal 2020 Bangladesh RCT	OD (n = 30)	2.86 ±0.57	N/A
	MD (n = 30)	2.88 ±0.58	N/A
Wifaq 2022 Afghanistan RCT	OD (n = 30)	N/A	N/A
	MD (n = 30)	N/A	N/A
Nour 2014 Egypt RCT	OD (n = 24)	3.02	N/A
	MD (n = 25)	3.07	N/A
Aydmemir 2020 Turkey Cohort	OD (n = 105)	N/A	22 (21)
	MD (n = 108)	N/A	3 (2.8)
Ozbilen 2022 Turkey Cohort	OD (n = 87)	27.0 ±7.3	N/A
	MD (n = 89)	26.1 ±6.4	N/A

MD – gradual dilation, OD – single-shot dilation, RCT – randomized controlled trial, SD – standard deviation

Decrease in hemoglobin level

Ten randomized controlled trials observed a reduction in postoperative hemoglobin levels [13, 14, 17, 20–26]. The meta-analysis findings indicated that MD resulted in a significant decrease in hemoglobin levels compared to the OD group (MD = –0.35; 95% CI: from –0.52 to –0.18; $p < 0.00001$), however, a significant level of heterogeneity was observed ($I^2 = 81\%$). Two studies [21, 25] were identified through sensitivity analysis as substantial contributors to the observed heterogeneity. Both studies employed similar outcome measurement methods as the other studies, and we found no significant methodological diversity in our assessment. The heterogeneity observed in our study can be attributed to the clinical diversity resulting from variations in the participants' baseline health status. We observe the possibility of publication bias while assessing the funnel plot (Figures 2, 3).

Hospital length-of-stay

Our analysis included eight studies, with a total of 1,137 patients [5, 15, 17, 19–23]. Among these patients, 562 underwent single-shot dilation PCNL. Significantly shorter hospitalization durations (measured in days) were observed between patients in the OD group (MD = –0.35; 95% CI: from –0.66 to –0.04; $p = 0.03$). However, we found significant variation in the results ($I^2 = 86\%$). To explore the heterogeneity, we conducted subgroup analysis for study design (RCTs vs cohort studies), the dilator types for single shot/gradual dilation technique (Amplatz/Amplatz vs Amplatz/Alken), and PCNL position (prone vs supine), but all of them did not reveal any significant change in heterogeneity. However, our sensitivity analysis showed that the heterogeneity was possibly resourced from studies that used different techniques such as tubeless fluoroscopy-guided PCNL [17], flank-free supine position [21], and imputed standard deviation [5]. No evidence of small study effects or publication bias was found upon visual inspection of the funnel plot (Figure 4).

Surgical duration

We conducted a meta-analysis of nine studies involving a total of 1,062 patients to compare the duration of surgeries between the OD and MD groups [5, 13, 15, 17, 19, 21–24]. A statistically significant overall effect favoring the OD group was observed (MD = –6.90; 95% CI: from –12.14 to –1.67; $p = 0.010$). Given the substantial variability

Table 3. *Study risk factors and prognosis*

Study, location, design	Intervention (sample sizes)	Previous open renal surgery (%)	SFR (%)	Surgical duration (min)	Fluoroscopy exposure time (s)	Fluoroscopy during dilation (s)	Length-of-stay (day)	Complication rate (%)	Hb drops (mg/dl)
Sedano-Portillo 2017 Mexico RCT	OD (n = 30)	5 (16.67%)	N/A	N/A	69.60 ±21.38	N/A	N/A	1 (3.33)	0.81 ±0.78
	MD (n = 29)	6 (20.69%)	N/A	N/A	100.62 ±23.54	N/A	N/A	1 (3.45)	2.03 ±1.04
Amirhassani 2014 Iran RCT	OD (n = 50)	0 (0%)	47 (94)	51.14 ±40.85	41.2 ±17	N/A	N/A	3 (6)	1.26 ±0.09
	MD (n = 50)	0 (0%)	42 (84)	57.00 ±38.85	48.4 ±15	N/A	N/A	8 (16)	1.44 ±0.11
Khorrami 2017 Iran RCT	OD (n = 120)	N/A	N/A	N/A	7.13 ±1.36	N/A	2.36 ±0.67	3 (2.5)	1.08 ±1.23
	MD (n = 120)	N/A	N/A	N/A	35.75 ±6.71	N/A	2.28 ±0.61	4 (3.3)	1.51 ±1.08
Ghoneima 2022* Egypt RCT	OD (n = 71)	N/A	55 (77.5)	73.24 ±31.84	221.4 ±121.2	15.87 ±6.87	1.52 ±0.77	8 (11.3)	0.90 ±0.99
	MD (n = 58)	N/A	48 (82.8)	97.93 ±35.42	429.6 ±197.4	98.45 ± 39.06	2.26 ±1.40	22 (37.9)	1.34 ±1.21
Mohyelden 2022 Egypt RCT	OD (n = 75)	8 (10.7%)	65 (86.6)	71.10 ±10.00	157.7 ±16	36.3 ±10	3 ±0.6	21 (28)	0.75 ±0.29
	MD (n = 75)	10 (13.3%)	62 (82.6)	73.10 ±9.00	181 ±20	61.8 ±15	3.7 ±0.7	21 (28)	1.21 ±0.35
Falahatkar 2009 Iran RCT	OD (n = 102)	23 (22.5%)	N/A	N/A	22 ±4	N/A	N/A	8 (14.03)	N/A
	MD (n = 112)	14 (12.5%)	N/A	N/A	65 ±12	N/A	N/A	12 (23.53)	N/A
Amjadi 2008 Iran RCT	OD (n = 17)	17 (100%)	12 (71)	N/A	N/A	27 ±15	N/A	1 (5.9)	1.3 ±1.1
	MD (n = 14)	14 (100%)	10 (71)	N/A	N/A	81 ±53	N/A	2 (14.3)	1.5 ±1.1
Aminsharifi 2011 Iran RCT	OD (n = 29)	0 (0%)	N/A	N/A	N/A	46.2 ±24.6	N/A	N/A	N/A
	MD (n = 19)	0 (0%)	N/A	N/A	N/A	67.2 ±40.8	N/A	N/A	N/A
Kalpee 2012 South Africa RCT	OD (n = 10)	N/A	8 (80)	N/A	N/A	N/A	N/A	N/A	N/A
	MD (n = 10)	N/A	3 (30)	N/A	N/A	N/A	N/A	N/A	N/A
Attallah 2023 Iraq RCT	OD (n = 50)	N/A	43 (86)	88.08 ±16.93	249.18 ±82.40	N/A	2.7 ±1.38	N/A	N/A
	MD (n = 70)	N/A	59 (83.7)	95.77 ±18.67	309.17 ±108.95	N/A	2.95 ±1.52	N/A	N/A
Phaijitwichian 2021 Thailand RCT	OD (n = 33)	N/A	16 (48.48)	58.36 ±28.91	41.97 ±23.99	N/A	N/A	8 (24.2)	1.35 ± 0.87
	MD (n = 32)	N/A	18 (56.25)	59.59 ±27	48.16 ±22.16	N/A	N/A	15 (46.9)	1.45 ± 1.19
Kamal 2020 Bangladesh RCT	OD (n = 30)	N/A	28 (93.3)	91.13 ±19.08	N/A	N/A	3.40 ±0.86	N/A	N/A
	MD (n = 30)	N/A	26 (86.7)	101.67 ±15.8	N/A	N/A	3.40 ±0.72	N/A	N/A
Wifaq 2022 Afghanistan RCT	OD (n = 30)	N/A	25 (83.3)	N/A	102.16 ±32.2	N/A	N/A	N/A	1.38 ±0.36
	MD (n = 30)	N/A	26 (86.7)	N/A	124.13 ±22.40	N/A	N/A	N/A	1.62 ±0.56
Nour 2014 Egypt RCT	OD (n = 24)	N/A	22 (91)	100.9 ±29.3	10.5 ±4.7	N/A	4.3 ±1	8 (33)	1.6 ±1.63
	MD (n = 25)	N/A	24 (92)	124.9 ±29.3	11.8 ±0.42	N/A	4.6 ±1	9 (36)	2.1 ±1.88
Aydmemir 2020 Turkey Cohort	OD (n = 105)	N/A	81 (77.1)	70 ±17.91 *	120 ±51.74 *	N/A	2 ±2.19 *	34 (32.4)	N/A
	MD (n = 108)	N/A	82 (75.9)	65 ±23.88 *	130 ±62.69 *	N/A	3 ±1.59 *	34 (31.5)	N/A
Ozbilen 2022 Turkey Cohort	OD (n = 87)	N/A	75 (86.2)	75.8 ±22.1	50.7 ±20.4	N/A	1 ±0.81	13 (14.9)	2 ±1.73
	MD (n = 89)	N/A	72 (80.9)	81.0 ±23.1	62.6 ±23.8	N/A	1 ±1.21	16 (18)	1.8 ±1.87

Hb – hemoglobin, MD – gradual dilation, OD – single-shot dilation, RCT – randomized controlled trial, SFR – stone-free rate observed in the combined analysis (I^2 = 75%), a subgroup analysis was performed to examine the impact of the position of PCNL on the results. The subgroups were categorized as prone or supine. The subgroup analysis did not find a significant effect within the subgroups (p = 0.15, I^2 = 52.3%). Nevertheless, heterogeneity was still observed among the participants in the prone position subgroup. After excluding two studies, one using a tubeless, fluoroscopy-guided PCNL technique [17] and the other using an imputed standard deviation [5], significant subgroup differences, overall effect, and low heterogeneity were found. This indicates that these specific studies impacted our meta-analysis findings. Additionally, we observed the possibility of publication bias while assessing the funnel plot (Figure 4).

Eleven studies, comprising a total of 1,515 patients, were conducted to compare the total fluoroscopy exposure time (measured in seconds) between the OD and MD groups [5, 13, 15–17, 20–25]. The study revealed a significant overall effect in favor of OD (MD = –27.33; 95% CI: from –36.10 to –18.55; p <0.00001), although there was undeniable heterogeneity (I^2 = 96%). The subgroup analysis comparing RCTs, and cohort studies revealed a significant difference in the subgroup effect (p = 0.001, I^2 = 90.2%). However, heterogeneity was still observed within the RCT subgroup. Despite conducting a sensitivity analysis, we were unable to identify the source of heterogeneity. We hypothesize that variations in fluoroscopy operation protocols, such as the utilization of fluoroscopy and the expertise and training of operators, may contribute to the observed heterogeneity. Methodological diversity may also contribute to the heterogeneity observed in the studies, as not all of them provided a clear operational definition of total fluoroscopy time. Additionally, we note the potential presence of publication bias when evaluating the funnel plot.

DISCUSSION

The main findings of our meta-analysis suggest that the single-shot dilation technique in PCNL significantly reduces the complication rate, indicating its safety for adult patients with kidney stones. This finding contradicts a review conducted by Peng et al. [28], which found no significant difference in complication rates between the single-shot and gradual dilation groups. It should be noted that Peng et al. [28] included patients of any age and only considered English-language studies. In contrast, our study included all adult patients with no language restrictions. Other reviews that supported the safety of single-shot dilation compared to gradual

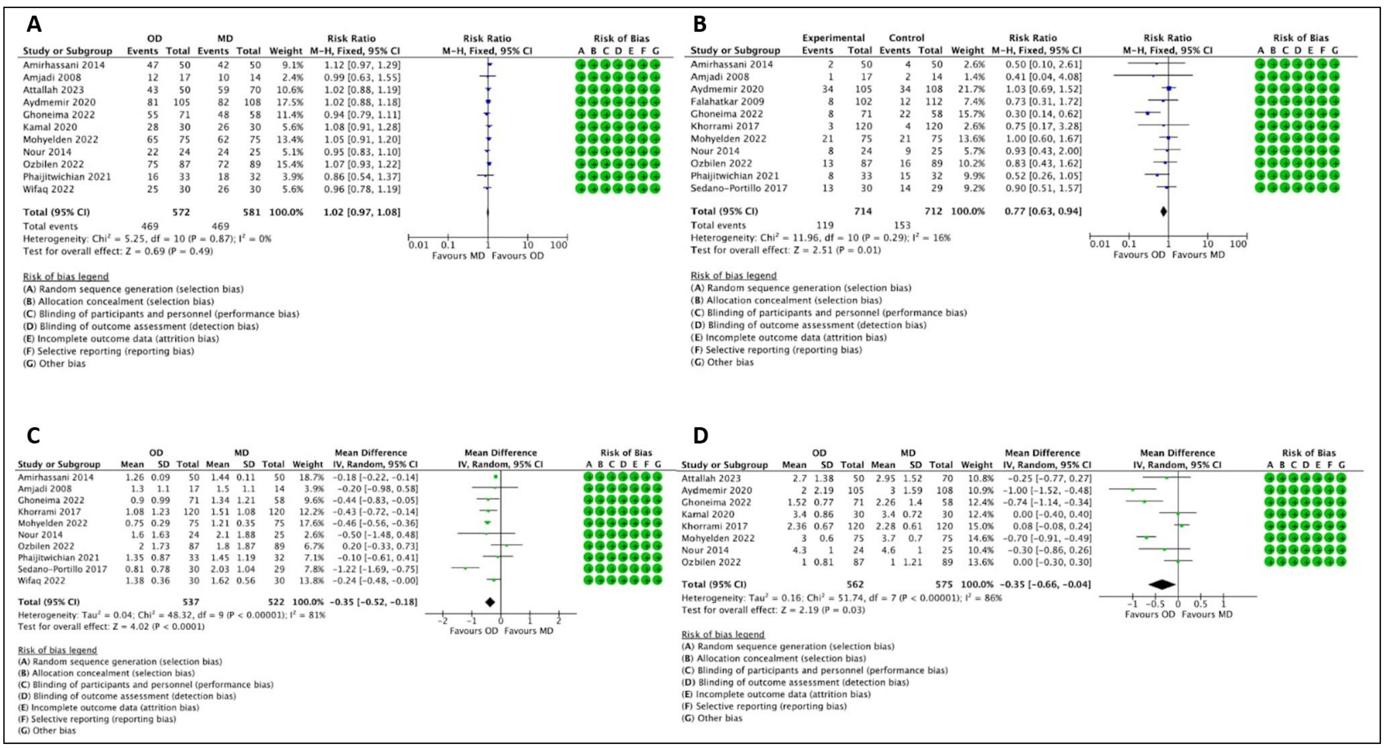

Figure 2. *Forest plots illustrating:* **A)** *stone-free rate;* **B)** *complication rate;* **C)** *decrease in hemoglobin level;* **D)** *hospital length-of-stay for those who underwent single-shot dilatation (one-shot – OD) and gradual dilatation (multiple – MD).*

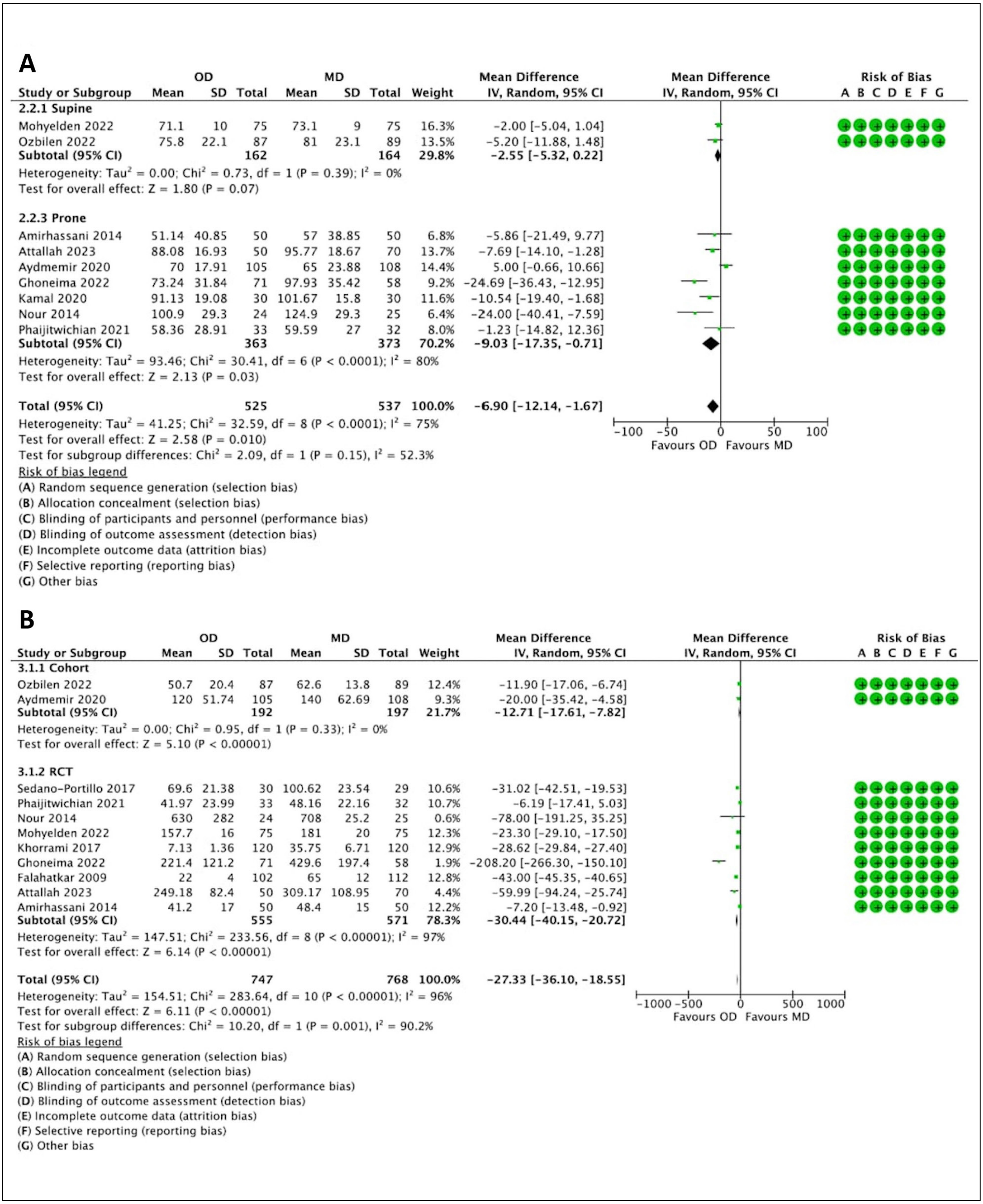

Figure 3. *Forest plots illustrating:* **A)** *surgical duration;* **B)** *total fluoroscopy exposure time for those who underwent single-shot dilatation (one-shot – OD) and gradual dilatation (multiple – MD).*

dilations focused only on specific complications such as blood transfusion rates and hemoglobin drop [29, 30], whereas our study considered all postoperative complications.

Regarding safety, the included studies reported various complications among patients, including infection, fever, surgical site infection, pain, bleeding requiring transfusion, urinary leakage, hematuria, hematoma, kidney-pelvis injury, and other complications categorized using the Clavien-Dindo system. When interpreting these results, it is important to consider that postoperative outcomes depend on multiple factors beyond the dilation technique. Stone complexity might influence outcomes such as stone-free rates. Operative time might also influence the reduction in hemoglobin levels. Patients' characteristics, such as systemic comorbidities, might also influence the incidence

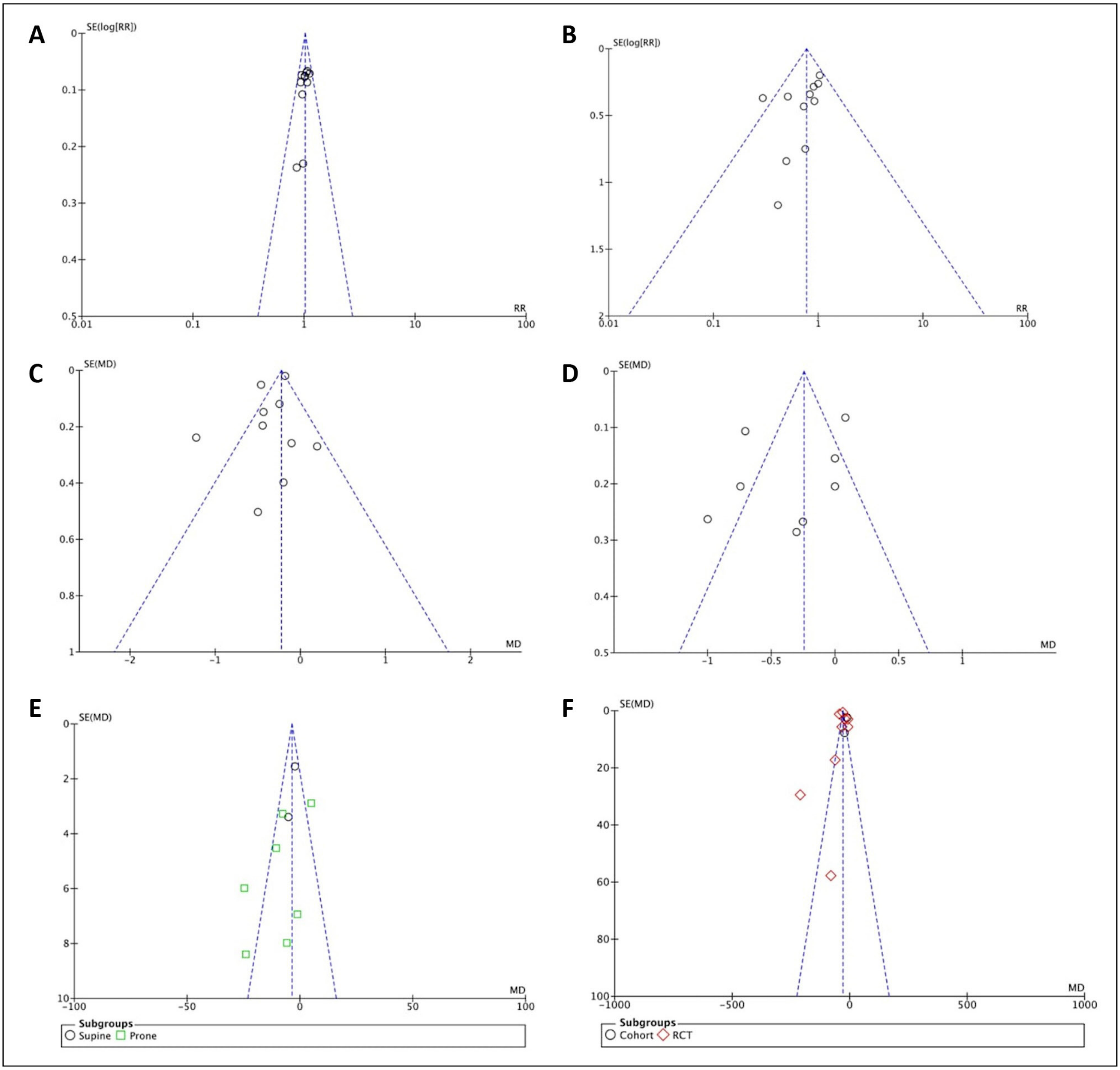

Figure 4. *Funnel plots of included studies evaluating:* **A)** *stone-free rate;* **B)** *complication rate;* **C)** *decrease in hemoglobin level;* **D)** *hospital length-of-stay;* **E)** *surgical duration;* **F)** *total fluoroscopy.*

of surgical site infections. Despite our efforts to standardize the data as much as possible, some confounders may still influence the results. These results should be interpreted with caution due to the potential influence of these confounding variables.

Regarding efficacy, our findings showed no significant difference in stone-free rates between single and multiple dilation techniques. This result aligns with previous systematic reviews conducted in 2013 [29] and 2019 [28]. We found significant results regarding the decrease in hemoglobin, hospital length-of-stay, surgical duration, and total fluoroscopy exposure time; however, there was substantial heterogeneity among the studies, which differed from previous meta-analyses [28–30]. This difference was probably due to the larger sample size in our study. Moreover, concerning the reduction in hemoglobin levels, we believe that discrepancies in the participants' initial health conditions could potentially be a source of the observed clinical variation or heterogeneity. As indicated by several studies, the existence of comorbidities (hypertension, diabetes mellitus, and preoperative urinary tract infections) heightens the risk of bleeding following PCNL [31–36].

Subgroup analyses revealed significant subgroup effects in surgical duration and total fluoroscopy exposure time. In the surgical duration analysis, we performed a subgroup analysis based on the PCNL position, as one systematic review [37] stated that the supine position had a shorter operative time compared to the prone position. However, our analysis did not find a significant effect within the subgroups. Nevertheless, after excluding a study using a tubeless, fluoroscopy-guided PCNL technique and a study with imputed standard deviation, significant subgroup differences, an overall effect, and low heterogeneity were observed. Tubeless PCNL is a technique where a nephrostomy tube is not placed at the end of the procedure, which may decrease surgery time [17]. We included this study because we considered micro- and mini-PCNL as distinct techniques from standard PCNL. Furthermore, according to the Cochrane Handbook, it is best to avoid using imputed standard deviation whenever possible [11]. Our sensitivity analysis confirmed that excluding a study with imputed standard deviation affected surgical duration results. For total fluoroscopy time, the source of heterogeneity remained unclear, though operator-dependent differences in fluoroscopy use and skill may have contributed.

Limitations of this study should be acknowledged. Firstly, the inherent heterogeneity among the included studies may limit the strength of our conclusions due to variations in study protocols, clinical practices, patient populations, and surgical techniques, which could not be entirely eliminated even with subgroup and sensitivity analyses. Secondly, there was significant variability in methodology. Thirdly, although studies in all languages were included, our search might still have missed relevant studies not indexed in the five databases or inaccessible during our search period, particularly given our focus on literature from 2008 onwards. Fourthly, many of the outcome measures, such as surgical duration and total fluoroscopy exposure time, are susceptible to confounding variables and are not direct indicators of patient outcomes. Additionally, most studies assessed stone-free rate (SFR) using KUB X-rays or ultrasound, which are less sensitive than CT scans and may fail to detect small residual fragments, potentially leading to an overestimation of the reported SFR.

Our study revealed a significant outcome in Egger's test ($p = 0.049$), suggesting possible publication bias. This indicates that smaller trials with positive MD outcomes are more likely to be published, but neutral or unfavorable research may remain unpublished. To address this, subsequent research should employ methodologies such as the trim-and-fill methodology and perform sensitivity studies to evaluate and correct for such bias.

Moreover, although we sought to examine a comprehensive range of complications, not all studies reported every outcome measure of interest, and unmeasured confounding variables cannot be discounted given the study designs. Despite these limitations, our study provides a comprehensive, up-to-date comparison of single-shot versus gradual dilation techniques in PCNL. Future prospective, randomized trials with standardized outcome measures and adequate follow-up are needed to provide more definitive evidence.

CONCLUSIONS

This systematic study and meta-analysis underscore the efficacy of single-shot dilation compared to progressive dilation in PCNL. Single-shot dilatation correlates with a reduced overall complication rate, indicating it may represent a safer alternative for adult patients with nephrolithiasis. While no significant differences in stone-free rates were observed between the two techniques, the single-shot dilation method showed notable reductions in pre- and postoperative hemoglobin levels, hospital length-of-stay, surgical duration, and total fluoroscopy exposure time.

We emphasize that these benefits outweigh the drawbacks, despite the significant heterogeneity and the presence of publication bias among the studies. However, these results should be interpreted with caution due to the inherent heterogeneity in study protocols, clinical practices, surgical techniques, and other confounding variables that may affect outcomes. Therefore, future research, ideally prospective, randomized trials with standardized outcome measures, is necessary to substantiate these findings and provide more concrete evidence supporting the implementation of single-shot dilation techniques in PCNL.

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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