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INVITED REVIEW

Miniaturised percutaneous nephrolithotomy versus flexible ureteropyeloscopy: a systematic review and meta-analysis comparing clinical efficacy and safety profile

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Abstract

Purpose This study aims to comparatively evaluate clinical outcomes of mini-PCNL and FURS for treating urinary tract calculi in a single session.

Methods A systematic search using electronic databases was performed for studies comparing mini-PCNL and FURS for the treatment of urinary tract calculi. The primary outcome measurements were stone-free rates (SFRs) and complication rates for both techniques. Secondary outcome measurements were to compare patient demographics, operative duration, and inpatient stay. Meta-analysis was performed with Review Manager version 5.3 software.

Results Sixteen studies on 1598 patients ($n = 877$ for mini-PCNL and $n = 721$ for FURS) met inclusion criteria. Demographics including age ($p = 0.26$), body mass index (BMI) ($p = 0.51$), and gender ratio ($p = 0.6$), were similar in both groups. Overall, SFR was significantly greater in the mini-PCNL group compared to the FURS group ($n = 763/877$, 89.3 ± 8.4% versus $n = 559/721$, 80.1 ± 13.3% [OR 2.01; 95% CI 1.53–2.64; $p < 0.01$]). Duration of inpatient stay was significantly greater in the mini-PCNL group compared to the FURS group ($n = 877$, 4 ± 1.6 days versus $n = 721$, 2.5 ± 2.2 days, respectively [WMD: 1.77; 95% CI 1.16–2.38, $p < 0.01$]. Overall complication rates were not significantly different between mini-PCNL and FURS ($n = 171/877$, 19.5 ± 19.1% versus $n = 112/721$, 15.5 ± 18.9%, respectively [OR 1.43; 95% CI 0.85–2.4, $p = 0.18$]).

Conclusions Mini-PCNL is associated with greater SFRs and longer inpatient stay compared to FURS. Complication rates were similar for both techniques. The advantages and disadvantages of both technologies should be familiar to urologists and conveyed to patients prior to urological intervention for nephrolithiasis.

Keywords Flexible ureteroscopy · Flexible pyeloscopy · Flexible ureteropyeloscopy · Percutaneous nephrolithotomy · Miniaturised percutaneous nephrolithotomy

Abbreviations

FURS	Flexible ureteropyeloscopy
PCNL	Percutaneous nephrolithotomy
Mini PCNL	Miniaturised percutaneous nephrolithotomy

Introduction

The management of nephrolithiasis is evolving rapidly, and a variety of urological technologies are currently available for treating patients with symptomatic stone disease. According to EAU and AUA guidelines, the available treatment options for renal and proximal ureteric calculi are extracorporeal shockwave lithotripsy (ESWL), flexible ureteropyeloscopy (FURS), miniaturised percutaneous nephrolithotomy (mini-PCNL), and conventional percutaneous nephrolithotomy (PCNL) [1, 2].

Percutaneous nephrolithotomy (PCNL) was initially introduced in 1976 and remains the recommended treatment option for removing large renal calculi due its high rate of stone clearance [3]. Morbidities associated with PCNL are bleeding, transfusion, pain, and urine leakage [4, 5]. Mini-PCNL involves a miniaturised nephroscope and offers a nephrostomy tract size < 20Fr [6]. It was initially introduced to decrease complications associated with tract size during conventional PCNL while providing comparable stone-free rates (SFR) [7]. One early meta-analysis of mini-PCNL and

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conventional PCNL demonstrated that mini-PCNL had a greater safety profile with similar SFRs [8].

Similarly, significant improvements in endoscopic technologies such as advancements in fibre optics, ureteroscope design, and laser therapies have led to increasing use of FURS for primary treatment of intra-renal and proximal ureteric calculi [9]. The advantages of FURS in this setting are preservation of renal parenchyma and less bleeding; however, FURS may be less effective for clearing larger calculi [9]. Therefore, selecting the optimal modality for treating renal calculi is challenging, as both techniques may be associated with different patient benefits and risk profiles. Despite the evolution of mini-PCNL and FURS techniques into clinical practice, there is a lack of comparative clinical data assessing SFRs and complication rates. The aim of this systematic review and meta-analysis is to comparatively evaluate the outcomes of mini-PCNL and FURS for treating urinary tract calculi in a single session.

Methods

Overview of literature search

A systematic literature search was performed using the Pubmed and Embase databases and the Cochrane Central Register of Controlled Trials to identify original peer-reviewed articles that compared outcomes of mini-PCNL and FURS for the treatment of urinary tract calculi. The search was performed based on the PRISMA statement [10]. The search was conducted using the following search algorithm: 'PCNL' or 'miniaturised PCNL', 'micro-invasive PCNL' or 'mini-PCNL' or 'mini-perc' and 'flexible pyeloscopy' or 'flexible ureteropyeloscopy' or 'flexible ureterosocopy' or 'FURS' or 'retrograde intra-renal surgery' or 'RIRS'.

Level of evidence (LE) of every included trial was graded according to the European Association of Urology (EAU) Guidelines criteria [1]. Quality assessment of non-randomised controlled trials (non-RCTs) was performed according to Newcastle–Ottawa Scale (NOS), and RCTs qualities were graded according to the Jadad scale [11, 12]. Two authors (NFD and MQ) independently examined the title and abstract of citations and the full texts of potentially eligible trials were obtained; disagreements were resolved by discussion. The reference lists of retrieved papers were further screened for additional eligible publications. If a patient group was reported twice, the most recent paper was chosen. If data were unclear or incomplete, the corresponding author was contacted to clarify data extraction. Institutional review board was not sought as this study was a systematic review and meta-analysis. There were no language or age restrictions and the literature search was performed in November 2017.

Eligibility criteria

Inclusion criteria were comparative data on patients with ≥ 1 intra-renal and/or ≥ 1 proximal ureteric calculus, nephrostomy tract size ≤ 20Fr for mini-PCNL and reporting on ≥ 1 of the following outcomes (stone-free rate after 1 treatment, operative duration, duration of inpatient stay, complication rate, and/or Clavien–Dindo grading of complications). Exclusion criteria were nephrostomy tract size > 20Fr in mini-PCNL, non-comparative studies, review articles, case reports, commentaries, letters, conference abstracts and failure to meet inclusion criteria. The primary end-point was to comparatively evaluate the efficacy of mini-PCNL and FURS. Clinical effectiveness was defined as the percentage of patients that were stone free on imaging at follow-up.

Data extraction and outcomes

The following information regarding each eligible study was recorded: author's name, journal of publication, year of publication, country of origin, study type, total number of patients, and patient demographics. Recorded data relating to mini-PCNL and FURS included surgical technique, definition of SFR, overall SFR, SFR according to anatomical location, SFR according to calculus size, and imaging modality used to determine SFR. In addition, operative duration, duration of inpatient stay, overall complication rate, and complication rate according to Clavien–Dindo grade were recorded. Results for variables are reported as percentages based on the number of cases that had relevant data available.

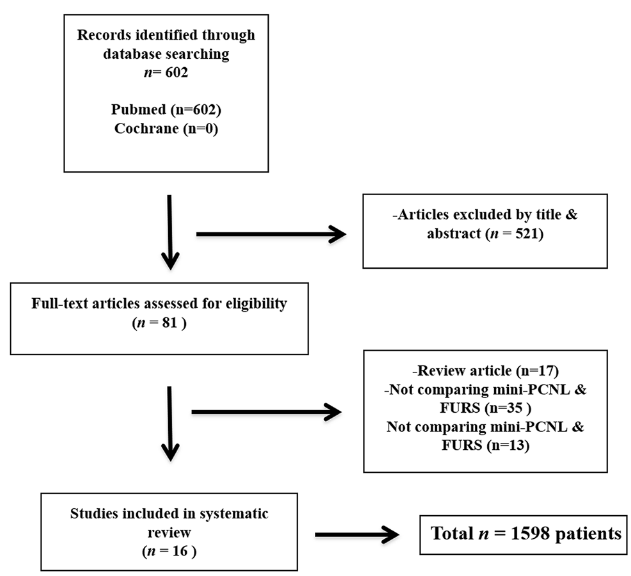


Fig. 1 Preferred reporting items in systematic reviews and meta-analyses (PRISMA) diagram

Table 1 Summary of studies included in the comparative analysis for miniaturised percutaneous nephrolithotomy and flexible ureteropyeloscopy

Author (year)	Origin	Journal	Type of study	Inclusion criteria (stone characteristics)	Level of evidence	Study quality	mini-PCNL (N)	FURS (N)
Ferroud (2011) [20]	France	Progrès en urologie	Retrospective case control	Any calculus ≤ 2 cm	2b	7^B	101	43
Gu (2013) [13]	China	World J Urol	RCT	≥ 1.5 cm calculus in proximal ureter	1b	3^A	30	29
Hu (2016) [31]	China	Urolithiasis	Retrospective case control	1–2 cm	2b	6^B	104	80
Kirac (2013) [25]	Turkey	Urolithiasis	Retrospective case control	< 1.5 cm calculus lower pole	2b	6^B	37	36
Knoll (2011) [16]	Germany	World J Urol	Prospective case control	1–3 cm calculus	2a	6^B	25	21
Kruck (2013) [22]	Germany	World JUrol	Retrospective case control	No size restrictions	2b	4^B	172	108
Kumar (2015) [14]	India	J Urol	RCT	1–2 cm single calculus in lower pole	1b	3^A	41	43
Lee (2015) [15]	South Korea	Urology	RCT	Single or multiple calculi > 1 cm	1b	3^A	35	33
Ozgor (2016) [23]	Turkey	World J Urol	Retrospective case control	1–2 cm calculus any location	2b	7^B	56	56
Pan (2013) [17]	China	Urolithiasis	Prospective case control	2–3 cm calculus any location	2a	6^B	59	56
Pelit (2017) [26]	Turkey	Urology	Retrospective case control	No size restrictions	2b	7^B	45	32
Sabnis (2013) [32]	India	BJU International	Prospective case control	1–2 cm calculus/calculi	2a	6^B	32	32
Schoenthaler (2015) [21]	Germany	World J Urol	Retrospective case control	1–2 cm calculus/calculi	2b	7^A	30	30
Wilhelm (2015) [18]	Germany	World J Urol	Prospective matched paired analysis	1–3.5 cm calculi	2b	8^B	25	25
Zeng (2015) [19]	China	World J Urol	Prospective matched paired analysis	> 2 cm any location	2b	7^B	53	53
Zhang (2014) [24]	China	Urology	Prospective case control	1–2 cm calculus in proximal ureter	2a	6^B	32	44

RCT randomised controlled trial

^{A}Corresponds to Jadad scale (1–5)

^{B}Corresponds to Newcastle–Ottawa scale (0–9)

Statistical analysis

Data are presented as a mean ± standard deviation. Student's *t* tests with unequal variances were performed for pairwise comparisons of patient demographics. Differences were considered significant at $p < 0.05$ (SPSS 16.0 for Windows). Meta-analysis was performed with Review Manager Version 5.3 software (RevMan v.5.3, Cochrane Collaboration, Oxford, UK). The odds ratio (OR) and 95% confidence interval (CI) were used for the dichotomous variables. Weighted mean difference (WMD) or standardized mean difference was used for continuous parameters. The *p* value was calculated by the *Z* test, and $p < 0.05$ was considered statistically significant. We assessed the heterogeneity of the included studies by Q and I^2 statistics. If the $p > 0.1$, $I^2 < 50\%$, the fixed-effects model was used for low heterogeneity among studies. Alternatively, the random-effects model was performed for high heterogeneity among studies.

Table 2 Comparing demographics of patients undergoing miniaturised percutaneous nephrolithotomy and flexible ureteropyeloscopy

Author (year)	Age mini-PCNL (Years)	Age FURS (years)	Male/female mini-PCNL	Male/female FURS	BMI mini-PCNL (kg/m^2)	BMI FURS (kg/m^2)	Stone size mini-PCNL (mm)	Stone size FURS (mm)
Ferroud (2011) [20]	51.7 ± 16	49.2 ± 14	80/21	28/15	NA	NA	8.9 ± 2.7	8.3 ± 3.2
Gu (2013) [13]	42.5 ± 10.1	44.2 ± 13	N/A	N/A	NA	NA	17.27	16.23
Hu (2016) [31]	65.5 ± 4.9	65.1 ± 5.2	56/48	45/35	23.7 ± 3.5	23 ± 3.1	15.8 ± 3.4	15.8 ± 3.4
Kirac (2013) [25]	41 ± 10.3	37.8 ± 8.7	25/12	22/14	18.5 ± 4.9	18.3 ± 5	10.5 ± 2.2	10.2 ± 2.9
Knoll (2011) [16]	56 ± 13	53 ± 11	15/10	9/12	27 ± 5	31 ± 7	18 ± 5	19 ± 4
Kruck (2013) [22]	53.3 ± 14.8	50 ± 16.7	109/63	69/39	NA	NA	12.6 ± 9.5	6.8 ± 6.9
Kumar (2015) [14]	33.7 ± 1.5	33.4 ± 1.4	20/21	20/23	23.5 ± 1.2	23.6 ± 1.1	13.3 ± 1.3	13.1 ± 1.1
Lee (2015) [15]	59.3 ± 13.3	55.8 ± 11.2	28/7	28/5	26.3 ± 3.9	25.6 ± 5.1	39.1 ± 30.7	28.9 ± 17.5
Ozgor (2016) [23]	51.4 ± 14.3	54.2 ± 10.6	25/31	22/34	34 ± 3.3	34.4 ± 5	19.5 ± 3.9	18.3 ± 3.2
Pan (2013) [17]	49.4 ± 14.2	49.3 ± 13.7	37/22	36/20	23.5 ± 3.7	23.7 ± 3.6	22.4 ± 2.7	22.3 ± 2.6
Pelit (2017) [26]	3.71 ± 1.9	3.65 ± 1.95	24/21	17/15	NA	NA	21 ± 5.6	19.3 ± 4.21
Sabnis (2013) [32]	44.5 ± 12.4	49.3 ± 12.2	19/13	25/7	NA	NA	15.2 ± 3.3	14.2 ± 3.4
Schoenthaler (2015) [21]	54.3	56.3	17/13	17/13	29.9	28.7	15.1	14.4
Wilhelm (2015) [18]	51.6	51.3	15/10	19/6	29.5	28.4	19.3	19.2
Zeng (2015) [19]	53 ± 14	48.5 ± 12	37/17	39/14	23.3 ± 3.4	23.6 ± 3.8	18.1 ± 13.5	18.2 ± 13.5
Zhang (2014) [24]	42.7 ± 13.6	43.3 ± 11	24/8	29/15	N/A	N/A	15.6 ± 2.5	14.9 ± 2.3
Mean	47 ± 11	46.5 ± 10.2	35/21	28/18	25.9 ± 3.6	26 ± 4.2	17.7 ± 6.6	16.2 ± 5.2

BMI Body mass index, *NA* Not available

Results

Eligible studies

Sixteen studies published between 2011 and 2017 that met inclusion criteria were retrieved and analysed. The initial search identified 602 articles and 81 full-text studies were assessed for eligibility; of which 65 were excluded (Fig. 1). These studies were excluded as they did not have comparative data on mini-PCNL and FURS. Included studies were reflective of modern clinical practice and data was available for analysis on 1598 patients ($n = 877$ for mini-PCNL and $n = 721$ for FURS). Study characteristics are summarised in Table 1 and consisted of three randomised controlled trials (RCTs) [13–15], four prospective case–control studies [16, 17, 24, 32], two prospective matched paired analysis studies [18, 19], six retrospective case–control studies [20, 21, 23, 25, 26, 31], and one multi-institutional retrospective case–control study [22].

Demographics including age 47 ± 11 years versus 46.5 ± 10 years [95% confidence interval (CI) − 0.44 to 1.64; $p = 0.26$], body mass index (BMI) 25.9 ± 3.6 kg/m^2 versus 26 ± 4.2 kg/m^2 (95% CI − 0.514 to 0.254; $p = 0.51$), and gender ratio (3.5:2.1, male:female versus 2.8:1.8 male:female, $p = 0.6$) were similar in mini-PCNL and FURS groups, respectively (Table 2). Stone size was significantly greater in the mini-PCNL group compared to the FURS group (17.6 ± 6.6 mm versus 16.2 ± 5.2 mm, respectively (95% CI 0.98–2.09; $p < 0.01$) (Table 2). Data on stone location within the urinary tract are reported in 12 studies and are summarised in Table 3.

In three studies, mini-PCNL and FURS were compared in adults with one calculus [16, 17, 23], two studies compared both techniques for proximal ureteral calculi [13, 24], two studies compared both techniques for lower pole stones [14, 25], and the remainder were compared for ureteral and/or intra-renal calculi (Table 2). One study was performed in paediatric patients with intra-renal calculi [26] and one study was performed in patients with a solitary kidney [19].

Table 3 Stone locations for studies comparing miniaturised percutaneous nephrolithotomy and flexible ureteropyeloscopy

Author (year)	Upper pole mini-PCNL	Upper pole FURS	Interpolar mini-PCNL	Interpolar FURS	Lower pole mini-PCNL	Lower pole FURS	Pelvis mini-PCNL	Pelvis FURS	Proximal ureter mini-PCNL	Proximal ureter FURS	> 1 location mini-PCNL	> 1 location FURS
Ferroud (2011) [20]	1	2	2	5	12	44	32	37	45	0	8	12
Gu (2013) [13]	–	–	–	–	–	–	–	–	100	100	–	–
Hu (2016) [31]	1.9	3.8	7.7	12.5	13.5	17.5	40.4	37.5	36.5	28.8	59.6	57.5
Kirac (2013) [25]	–	–	–	–	100	100	–	–	–	–	–	–
Knoll (2011) [16]	4	9.5	68	66.7	12	4.8	56	38.1	–	–	–	–
Kruck (2013) [22]	–	–	–	–	42.7	76.8	–	–	–	–	–	–
Lee (2015) [15]	2.9	3	–	–	40	17.1	–	–	–	–	40	39.4
Ozgor (2016) [23]	8.9	7.1	1.8	1.8	26.8	26.8	25	39.3	–	–	37.5	25
Pan (2013) [17]	8.5	12.5	18.6	12.5	52.5	51.8	20.3	23.2	–	–	–	–
Sabnis (2013) [32]	3.1	9.4	0	3.1	31.3	28.1	43.8	25	–	–	21.9	34.4
Zeng (2015) [19]	3.8	5.7	3.8	3.8	22.6	18.9	22.6	26.4	–	–	47.2	45.3
Zhang (2014) [24]	–	–	–	–	–	–	–	–	100	100	–	–

Stone locations are reported as percentages in the kidney and ureter

Surgical approaches for mini-PCNL and FURS differed in each study and techniques are summarised in Table 4.

Overall stone-free rate

All studies reported on postoperative stone-free rate (SFR) and stone clearance was significantly greater in the mini-PCNL group compared to the FURS group [n = 763/877, 89.3 ± 8.4% versus n = 559/721, 80.1 ± 13.3% (OR 2.01; 95% CI 1.53–2.64; p < 0.01)] (Fig. 2). Imaging modality for determining SFR and definition of SFR differed for each study and are summarised in Table 5.

Stone-free rate according to location

Eight studies reported SFR in calculi that were in > 1 location and the SFR was significantly greater in the mini-PCNL group compared to the FURS group [n = 515/602, 85.5 ± 10.7% versus n = 330/449, 73.5 ± 16.3%, respectively, 9 OR 2.25; 95% CI 1.35–3.78; p = 0.002)] (Fig. 3a). Two studies compared SFRs among lower pole calculi and the SFR was similar to mini-PCNL and FURS (n = 72/78, 92.3 ± 4.2% versus n = 69/79, 87 ± 2%, respectively [OR 1.74; 95% CI 0.6–5.06, p = 0.31]) (Fig. 3b). Two studies compared SFR for proximal ureteral calculi and the SFR was similar to mini-PCNL and FURS [n = 60/62, 96.8 ± 4.4% versus n = 63/73, 86.3 ± 3.9%, respectively (OR: 3.79; 95% CI 0.91–15.71, p = 0.07)] (Fig. 3c).

Stone-free rate according to size

Two studies compared SFRs for calculi > 2 cm and the SFR was significantly greater in the mini-PCNL group compared to the FURS group [n = 95/112, 84.8 ± 17.6% versus n = 63/109, respectively, 57.8 ± 19.8% (OR 5.17; 95% CI 1.58–16.89, p = 0.006)] (Fig. 4a). Eight studies compared SFR for calculi < 2 cm and the SFR was significantly greater in the mini-PCNL group compared to the FURS group [n = 385/433, 88.9 ± 6.8% versus n = 297/364, 81.6 ± 9.2%, respectively (OR 1.81; 95% CI 1.19–2.75, p = 0.005)] (Fig. 4b).

Operative duration

Fifteen studies reported on the operative duration and there was no significant difference between both groups (n = 705, 72.6. ± 23.5 min for mini-PCNL versus n = 613, 72.1 ± 24.4 min for FURS; weighted mean difference [WMD]: 0.32; 95% CI − 9.54–10.17, p = 0.95) (Fig. 5a). As overall baseline stone size was significantly greater in the mini-PCNL group, a subgroup analysis was performed on

Table 4 Summary of surgical technique and treatment modality deployed for miniaturised percutaneous nephrolithotomy and flexible ureteropyeloscopy

Author (year)	Access sheath mini-PCNL (Fr)	Access sheath FURS (Fr)	Scope size mini-PCNL (Fr)	Scope size FURS (Fr)	Lithotripsy mini-PCNL	Lithotripsy FURS
Ferroud (2011) [20]	18–20	12–14	13	NA	Laser	Laser
Gu (2013) [13]	12–18	N/A	8.5–9.8	7.4	Laser	Laser
Hu (2016) [31]	16–20	12–14	8–9.8	7.5	Laser	Laser
Kirac (2013) [25]	20	9.5–11.5; 12–14	15–16.5	8 and 9.5	Pneumatic + US	Laser
Knoll (2011) [16]	18	12–14	14	7.5	Laser	Laser
Kruck (2013) [22]	16–18	N/A	12	7.5	US	Laser
Kumar (2015) [14]	18	12	15	8 and 9.5	Pneumatic	Laser
Lee (2015) [15]	18	14–16	15	7.5	Laser	Laser
Ozgor (2016) [23]	18–20	9.5–11.5	17	7.5	Laser + US	Laser
Pan (2013) [17]	18	12	14	5.3	Laser	Laser
Pelit (2017) [26]	20	9.5	17	7.5	Pneumatic	Laser
Sabnis (2013) [32]	16–19	14	15–18; 16.5–19.5	7.5	Laser	Laser
Schoenthaler (2015) [21]	10–14	14–16	NA	N/A	Laser	Laser
Wilhelm (2015) [18]	10–13/14	14–16	13	N/A	Laser	Laser
Zeng (2015) [19]	18	12–14	NA	7.5	Laser + pneumatic	Laser
Zhang (2014) [24]	18–20	12–14	8.6–9.8	5.3–8.4	Laser + pneumatic	Laser

NA Not available

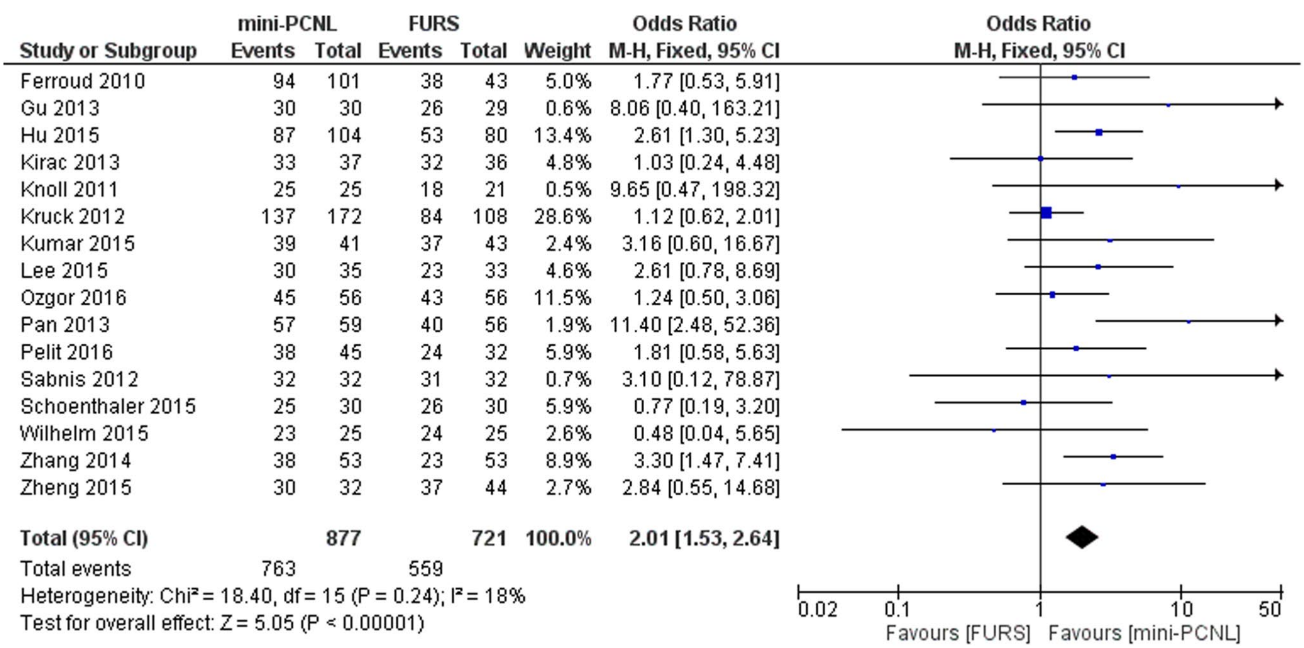


Fig. 2 Forest plot and meta-analysis of overall stone-free rate for miniaturised nephrolithotomy and flexible ureteropyeloscopy

11 studies with non-significant differences in baseline stone size for both techniques. In this subgroup analysis, there was no significant difference in operative duration between both groups [(WMD: − 3.4; 95% CI − 14.31–7.52, $p = 0.54$]) (Fig. 5b).

Duration of inpatient stay

All studies reported on the duration of inpatient stay and the inpatient stay was significantly greater in the mini-PCNL group compared to the FURS group [$n = 877$, 4 ± 1.6 days

Table 5 Summary of imaging modality utilised to determine stone-free rate and definition of stone-free rate for miniaturised percutaneous nephrolithotomy and flexible ureteropyeloscopy

Author (year)	Modality to determine SFR	Definition of SFR (mm)
Ferroud (2011) [20]	KUB	< 4
Gu (2013) [13]	KUB, US, IVU	< 4
Hu (2016) [31]	KUB, US, CT	< 4
Kirac (2013) [25]	KUB, US, CT	< 3
Knoll (2011) [16]	KUB, US	0
Kruck (2013) [22]	N/A	0
Kumar (2015) [14]	CT	0
Lee (2015) [15]	CT	< 2
Ozgor (2016) [23]	KUB, CT	< 2
Pan (2013) [17]	CT	≤ 2
Pelit (2017) [26]	US	< 4
Sabnis (2013) [32]	KUB, US	< 4
Schoenthaler (2015) [21]	NA	< 4
Wilhelm (2015) [18]	US or CT	< 4
Zeng (2015) [19]	KUB	< 4
Zhang (2014) [24]	KUB + US	< 3

SFR Stone-free rate; *KUB* plain-film X-ray of kidneys, ureters and bladder; *US* renal ultrasonography; *CT* non-contrast computed tomography of kidneys, ureters, and bladder; *NA* not available

versus $n = 721$, 2.5 ± 2.2 days, respectively (WMD: 1.77; 95% CI 1.16–2.38, $p < 0.01$)] (Fig. 5c).

Complications

All studies reported on their complications and the overall complication rates were not significantly different between mini-PCNL and FURS [$n = 171/877$, 19.5 ± 19.1% versus $n = 112/721$, 15.5 ± 18.9%, respectively (OR 1.43; 95% CI 0.85–2.4, $p = 0.18$)] (Fig. 6a). Fifteen studies subclassified complications according to Clavien–Dindo grade (Fig. 6b–d). The incidence of Clavien–Dindo grade 1 complications was not significantly different between both groups [$n = 92/847$, 10.8 ± 16.6% versus $n = 63/691$, 9.1 ± 18.9% for mini-PCNL and FURS, respectively (OR 1.3; 95% CI 0.74–2.57); $p = 0.31$]. The incidence of Clavien–Dindo grade 2 complications was not significantly different between both groups [$n = 60/847$, 7.08 ± 12.2% versus $n = 42/691$, 6.1 ± 5.4% for mini-PCNL and FURS, respectively (OR 1.27; 95% CI 0.84–1.91); $p = 0.26$]. In addition, the incidence of Clavien–Dindo grade 3 complications was not significantly different between both groups [$n = 15/847$, 1.78 ± 3.5% versus $n = 4/691$, 0.58 ± 1.15% for mini-PCNL and FURS, respectively (OR 2.58; 95% CI 0.97–6.53); $p = 0.06$]. There were no Clavien–Dindo grade 4 or grade 5 complications reported in either group.

Discussion

Currently, a variety of minimally invasive urological techniques for treating urinary tract calculi are evolving with the aims of decreasing perioperative morbidity and providing effective stone-free rates (SFRs). Mini-PCNL and FURS have both been used effectively for treating urinary tract calculi with no definite clinical benefit of one modality over the other clearly demonstrated. In the present meta-analysis, we investigated the clinical effectiveness of mini-PCNL and FURS by comparing SFRs and complication rates between both techniques. We also compared patient demographics, operative duration, inpatient stay, and stratified complications according to Clavien–Dindo grade. Our main finding is that mini-PCNL is associated with a higher SFR compared to FURS for treating urinary tract calculi.

SFR is probably the most important clinical parameter for comparing the efficacy of both urological techniques. Our findings demonstrate that mini-PCNL has a significantly greater SFR than FURS after one treatment session. In addition, SFR with mini-PCNL was also significantly greater when stones in > 1 location and stone size were analysed separately as sub-groups. We noted a variety of definitions and imaging modalities among the 16 studies that evaluated SFR. Imaging modalities at follow-up included plain-film X-ray and/or ultrasonography and/or non-contrast computed tomography (CT). Non-contrast CT is the most accurate modality for determining SFR, but is associated with higher costs and additional radiation exposure compared to other imaging techniques. Notably, no clear definition for SFR has been unanimously agreed in endourological societies and definitions in our review were residual fragments ranging from 0 to 4 mm indicating the heterogenous nature of data available for comparative analysis. In the future, prospective randomised controlled trials comparing mini-PCNL and FURS should define complete stone clearance as the complete absence of any residual fragments after follow-up with low-dose, non-contrast CT to truly determine SFR with both techniques.

Modification of the conventional PCNL procedure by miniaturising the instruments has led to an established role for mini-PCNL in managing symptomatic nephrolithiasis. Mini-PCNL is less invasive than standard PCNL with lower perioperative haemoglobin drop, lower perioperative analgesic requirement, decreased hospital inpatient stay and comparable complete stone clearance [8, 27, 28]. Furthermore, reduced diameter of the nephrostomy tract dilation decreases the potential for injury to the renal vasculature and decreases the frequency of infundibular calyceal injuries

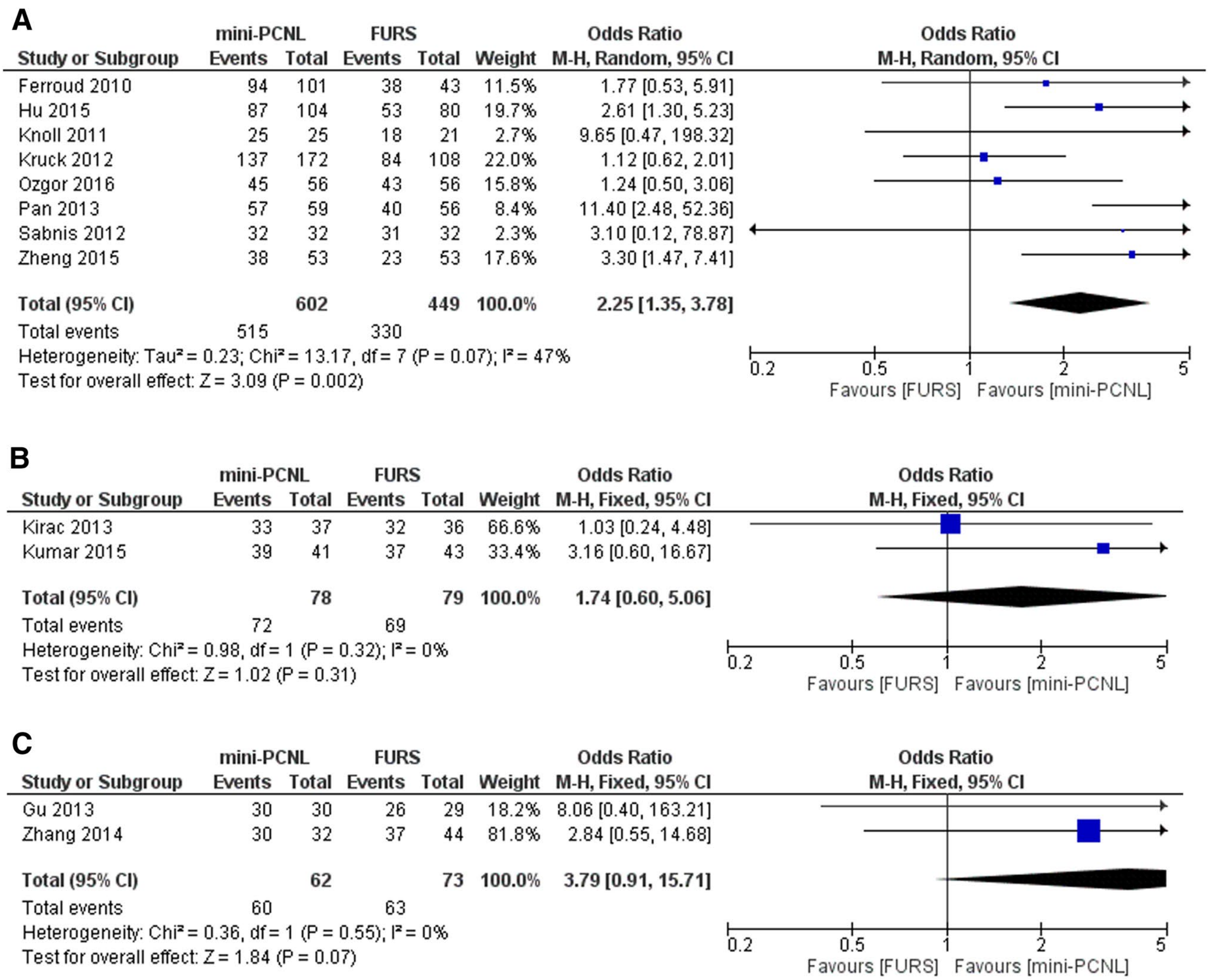


Fig. 3 Forest plot and meta-analysis of stone-free rate for stones > 1 location (**a**), lower pole stones (**b**) and proximal ureteric stones (**c**) for miniaturised percutaneous nephrolithotomy and flexible ureteropyeloscopy. *SFR* Stone-free rate

[27]. A decrease in these specific intra-operative complications may paradoxically increase visibility compared to standard PCNL [27]. Operative duration was similar to both techniques, but higher re-intervention rates associated with flexible ureterospyeloscopy are an additional limitation with FURS compared to mini-PCNL.

Currently, FURS, ESWL and PCNL are recommended as first-line treatment options for calculi for stones < 2 cm within the renal pelvis and upper or middle calyces by the EAU [1]. Recently, significant advances in FURS technology have led to its development as a feasible treatment option for larger renal calculi [28–30]. Despite the higher SFR associated with mini-PCNL, its complication rate is similar to FURS, but it is associated with a longer inpatient stay. Prolonged inpatient stay is typically caused by an indwelling nephrostomy tube for drainage purposes and/or persisting postoperative pain [27, 28]. More complications and prolonged inpatient stay will inevitably lead to higher costs of additional laboratory tests, medical investigations, and increased requirement for analgesic and antibiotic medications. Importantly, these additional burdens on hospital resources were not factored into the present meta-analysis. Moreover, an increasing number of patients cannot be treated by mini-PCNL due to widespread prescription of anticoagulants among patients with cardiovascular disease (CVD). Bleeding diathesis is a contraindication to mini-PCNL, but FURS can be used safely in such co-morbid patients [29]. These important disadvantages should be familiar to urologists and conveyed to patients that are being considered for both techniques.

The prevalence of nephrolithiasis is increasing [9, 30]. Minimally invasive techniques for treating urinary tract calculi are associated with significant costs for equipment and disposables. A cost analysis was not performed in the

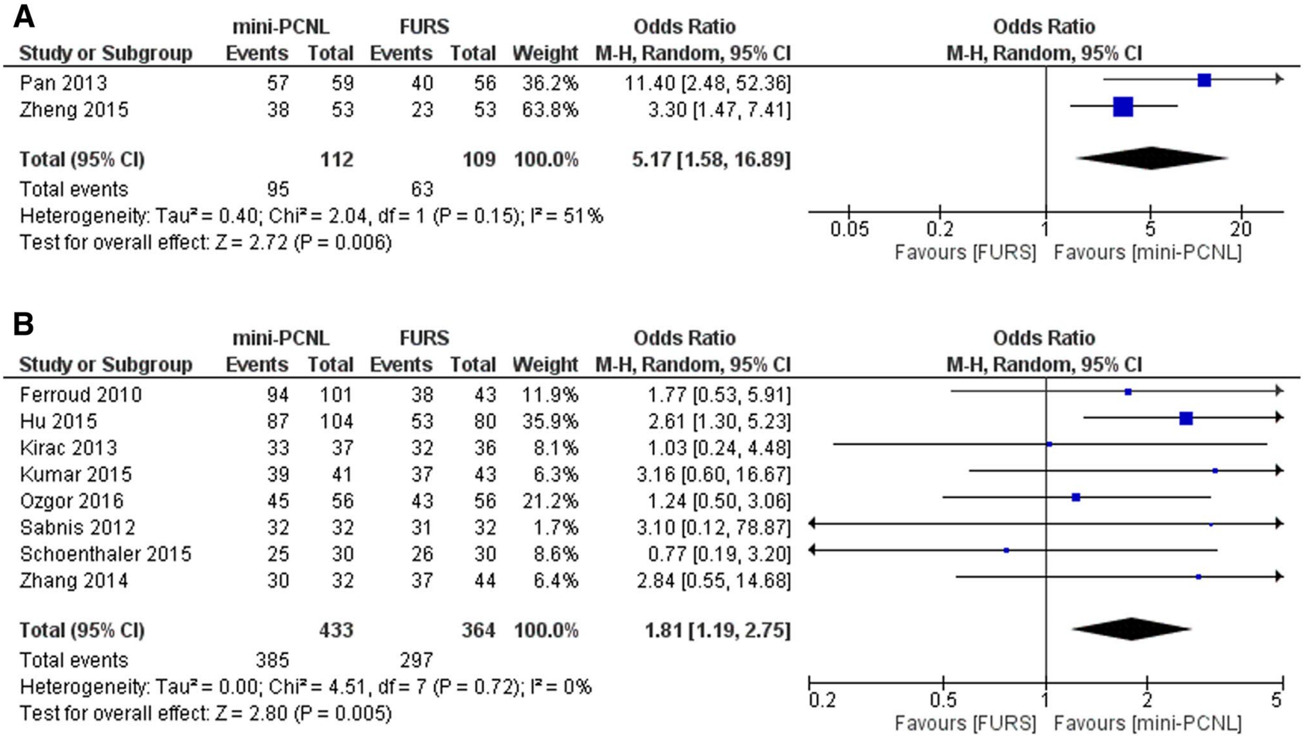


Fig. 4 Forest plot and meta-analysis of stone-free rate for stones > 2 cm (**a**) and for stones < 2 cm (**b**) for miniaturised percutaneous nephrolithotomy and flexible ureteropyeloscopy. *SFR* Stone-free rate

present meta-analysis as this data was only available in one study where clinical outcome parameters and costs of treatment (endoscopes and disposables) of both techniques were compared [21]. Findings demonstrated that the costs of disposable materials and endoscopes were €656 for mini-PCNL compared to €1160 euro for FURS indicating a significant cost–benefit with mini-PCNL [21]. The authors attribute FURS costs to additional ancillary procedures, utilisation of endoscopes with a short lifetime cycle, high-priced disposables such as stone extraction devices, ureteral access sheaths, laser fibres, and guide wires. Specifically, the authors noted that the cost of a flexible endoscope was at least double the cost of the mini-PCNL set. Potential limitations with comparative cost–benefit analyses to date include the omission of important socio-economics factors such as time to return to work and costs of long-term morbidity resulting from stone intervention.

Limitations of the present meta-analysis are similar to previous studies and include the heterogenous nature of the available data for comparing both techniques, the small number of RCTs available, failure to describe blinding procedures in detail in RCTs and inconsistencies in classifying complications [33]. Furthermore, calculus size, calculus location and surgical equipment utilised varied in every evaluated study. Finally, availability of technical equipment and surgical experience also play a critical role in evaluating the effectiveness of both techniques and neither were assessable in the present review.

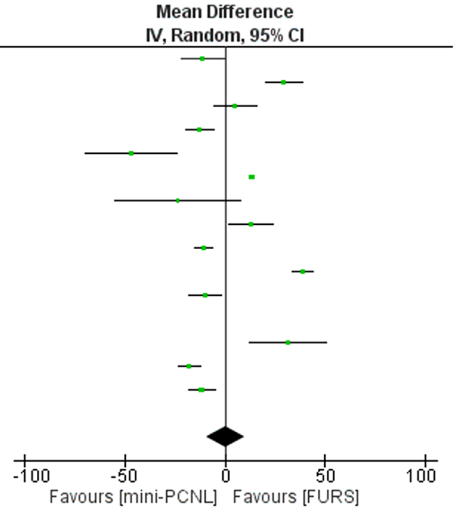
Conclusion

This systematic review and meta-analysis provides a detailed and accurate comparative analysis on mini-PCNL and FURS. Modifications and advancements in equipment design will continue to improve the performance of both techniques. The continuing evolution of both urological technologies, in conjunction with accurate cost-analysis evaluations, should facilitate high levels clinical efficacy while maintaining high safety profiles. It is clearly apparent that ongoing randomised controlled trials are necessary to accurately evaluate outcome variables for both techniques

A

Study or Subgroup	mini-PCNL Mean	mini-PCNL SD	mini-PCNL Total	FURS Mean	FURS SD	FURS Total	Weight	Mean Difference IV, Random, 95% CI
Ferroud 2010	48	28	101	59	32	43	7.3%	-11.00 [-22.01, 0.01]
Gu 2013	96.2	21.25	30	66.7	13.8	29	7.5%	29.50 [20.39, 38.61]
Hu 2015	81.1	39.9	104	75.9	34	80	7.3%	5.20 [-5.49, 15.89]
Kirac 2013	53.7	14.5	37	66.4	15.8	36	7.7%	-12.70 [-19.66, -5.74]
Knoll 2011	59	19	25	106	51	21	5.6%	-47.00 [-70.05, -23.95]
Kumar 2015	61	1.3	41	47.5	1.1	43	8.0%	13.50 [12.98, 14.02]
Lee 2015	76.1	70.6	35	99.6	60.8	33	4.4%	-23.50 [-54.76, 7.76]
Ozgor 2016	80.9	35.2	56	67.8	22.1	56	7.3%	13.10 [2.21, 23.99]
Pan 2013	62.4	10.6	59	73	13.5	56	7.9%	-10.60 [-15.05, -6.15]
Pelit 2016	85.22	12.87	45	46.3	9	32	7.8%	38.92 [34.03, 43.81]
Sabnis 2012	40.8	13.8	32	50.6	19.2	32	7.6%	-9.80 [-17.99, -1.61]
Schoenthaler 2015	121	0	30	102	0	30		Not estimable
Wilhelm 2015	130.1	39.3	25	98.5	28.8	25	6.2%	31.60 [12.50, 50.70]
Zhang 2014	49.3	11.7	32	67.2	11.7	44	7.8%	-17.90 [-23.23, -12.57]
Zheng 2015	43.8	11.63	53	55.4	22.8	53	7.7%	-11.60 [-18.49, -4.71]
Total (95% CI)			**705**			**613**	**100.0%**	**0.32 [-9.54, 10.17]**

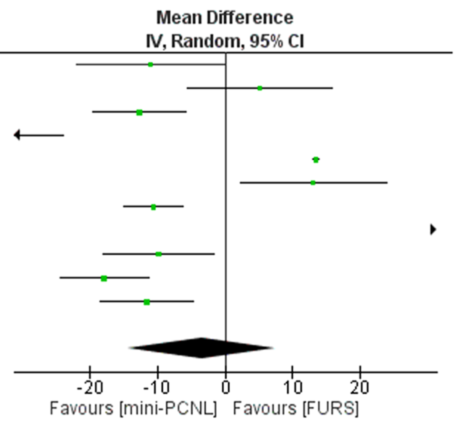
Heterogeneity: Tau² = 316.06; Chi² = 547.06, df = 13 (P < 0.00001); I² = 98%
Test for overall effect: Z = 0.06 (P = 0.95)



B

Study or Subgroup	mini-PCNL Mean	mini-PCNL SD	mini-PCNL Total	FURS Mean	FURS SD	FURS Total	Weight	Mean Difference IV, Random, 95% CI
Ferroud 2010	48	28	101	59	32	43	8.9%	-11.00 [-22.01, 0.01]
Hu 2015	81.1	39.9	104	75.9	34	80	8.9%	5.20 [-5.49, 15.89]
Kirac 2013	53.7	14.5	37	66.4	15.8	36	9.4%	-12.70 [-19.66, -5.74]
Knoll 2011	59	19	25	106	51	21	6.8%	-47.00 [-70.05, -23.95]
Kumar 2015	61	1.3	41	47.5	1.1	43	9.8%	13.50 [12.98, 14.02]
Ozgor 2016	80.9	35.2	56	67.8	22.1	56	8.9%	13.10 [2.21, 23.99]
Pan 2013	62.4	10.6	59	73	13.5	56	9.6%	-10.60 [-15.05, -6.15]
Pelit 2016	85.22	12.87	45	46.3	9	32	9.6%	38.92 [34.03, 43.81]
Sabnis 2012	40.8	13.8	32	50.6	19.2	32	9.3%	-9.80 [-17.99, -1.61]
Zhang 2014	49.3	11.7	32	67.2	17.3	44	9.4%	-17.90 [-24.42, -11.38]
Zheng 2015	43.8	11.63	53	55.4	22.8	53	9.4%	-11.60 [-18.49, -4.71]
Total (95% CI)			**585**			**496**	**100.0%**	**-3.40 [-14.31, 7.52]**

Heterogeneity: Tau² = 317.29; Chi² = 482.77, df = 10 (P < 0.00001); I² = 98%
Test for overall effect: Z = 0.61 (P = 0.54)



C

Study or Subgroup	mini-PCNL Mean	mini-PCNL SD	mini-PCNL Total	FURS Mean	FURS SD	FURS Total	Weight	Mean Difference IV, Random, 95% CI
Ferroud 2010	4.1	2.2	101	1.49	0.8	43	8.6%	2.61 [2.12, 3.10]
Gu 2013	4.6	1.8	30	1.9	1.3	29	7.9%	2.70 [1.90, 3.50]
Hu 2015	9.1	4	104	5.6	2.4	80	7.5%	3.50 [2.57, 4.43]
Kirac 2013	1.8	0.6	37	1	0.2	36	9.1%	0.80 [0.60, 1.00]
Knoll 2011	4.6	0	25	6.3	0	21		Not estimable
Kruck 2012	7.3	3.4	172	5.1	3	108	8.0%	2.20 [1.44, 2.96]
Kumar 2015	2.2	0	41	2.1	0	43		Not estimable
Lee 2015	1.6	1.1	35	1.5	0.9	33	8.7%	0.10 [-0.38, 0.58]
Ozgor 2016	2.5	1.5	56	1.2	1.06	56	8.6%	1.30 [0.82, 1.78]
Pan 2013	4.47	1.4	59	1.95	1.3	56	8.6%	2.52 [2.03, 3.01]
Pelit 2016	3.46	1.77	45	1.2	0.52	32	8.5%	2.26 [1.71, 2.81]
Sabnis 2012	2.07	0.68	32	1.94	0.76	32	8.9%	0.13 [-0.22, 0.48]
Schoenthaler 2015	2.3	0	30	2	0	30		Not estimable
Wilhelm 2015	3.8	1	25	2.8	2.75	25	6.9%	1.00 [-0.15, 2.15]
Zhang 2014	4.2	1.1	32	1.8	0.8	44	8.7%	2.40 [1.95, 2.85]
Zheng 2015	6	0	53	2	0	53		Not estimable
Total (95% CI)			**877**			**721**	**100.0%**	**1.77 [1.16, 2.38]**

Heterogeneity: Tau² = 1.05; Chi² = 213.98, df = 11 (P < 0.00001); I² = 95%
Test for overall effect: Z = 5.72 (P < 0.00001)

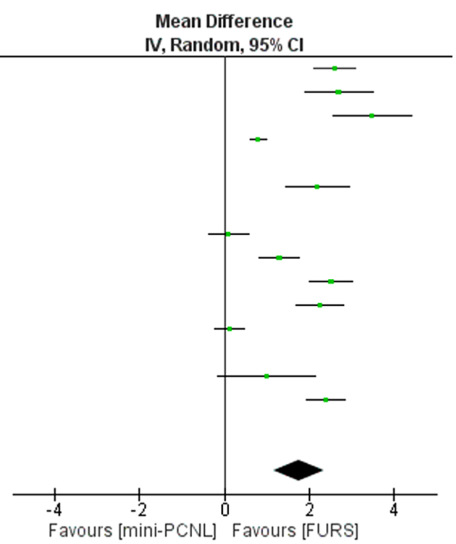


Fig. 5 Forest plot and meta-analysis of overall operative duration (**a**), operative duration in studies with similar stone size (**b**) and duration of inpatient stay (**c**) for patients undergoing miniaturised percutaneous nephrolithotomy and flexible ureteropyeloscopy. *Op. duration* Operative duration

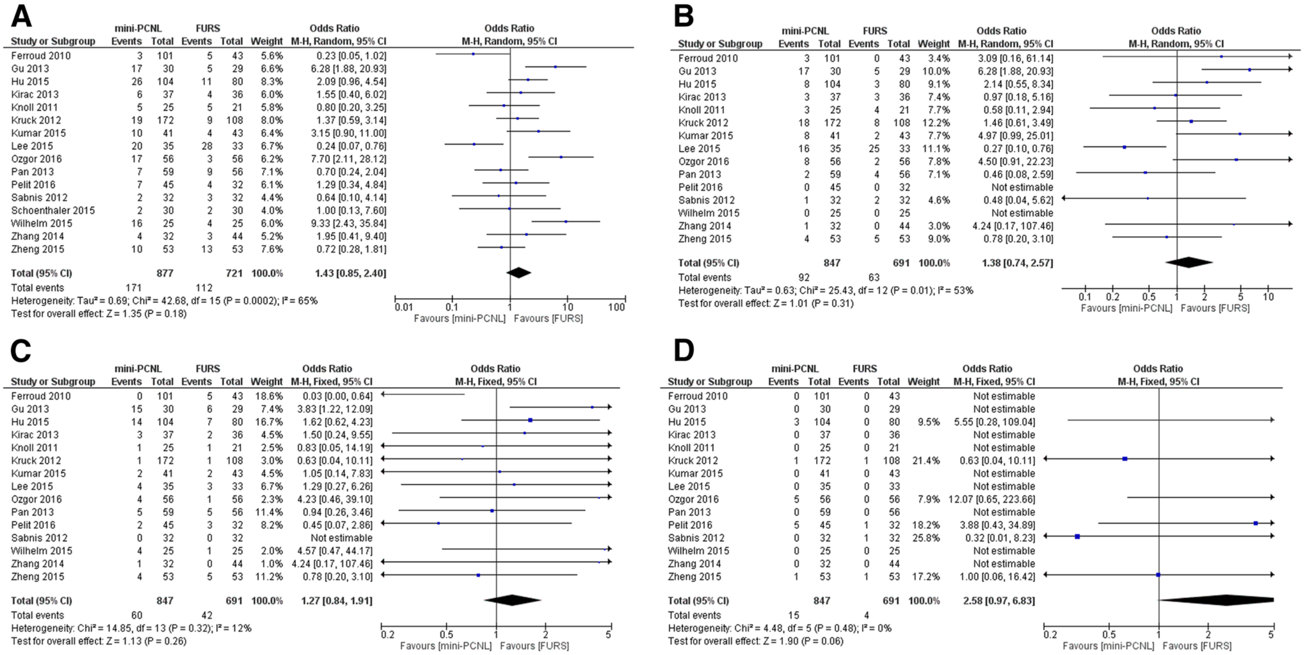


Fig. 6 Forest plot and meta-analysis of overall complication rate (**a**), Clavien–Dindo grade 1 complications (**b**), Clavien–Dindo grade 2 complications (**c**) and Clavien–Dindo grade 3 complications (**d**) for patients undergoing miniaturised percutaneous nephrolithotomy and flexible ureteropyeloscopy

and to define whether one modality demonstrates a clear overall advantage for treating symptomatic nephrolithiasis.

Author contributions ND data collection, data analysis, and manuscript writing; MQ data collection, data analysis, and manuscript writing; CP data collection; NL project development and manuscript editing; DB project development and manuscript editing; DW data analysis; and GJ data analysis, project development, and manuscript editing.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

Statement of human and animal rights This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

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