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ORIGINAL ARTICLE

Ultrasound-guided versus fluoroscopy-guided percutaneous nephrolithotomy: a systematic review and meta-analysis

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Abstract

Purpose To evaluate the efficacy and safety of ultrasound-guided (UG) versus fluoroscopy-guided (FG) percutaneous nephrolithotomy (PCNL).

Methods A systematic search of PubMed (MEDLINE), Embase, and the Cochrane Library was conducted to identify randomized controlled trials that compared UG-PCNL with FG-PCNL, and a meta-analysis of those studies was completed. The primary outcomes assessed were stone-free rate (SFR) and complication rate. Secondary outcomes assessed were the successful access-creation rate, time necessary for entrance into the target calyx, auxiliary procedure rate, transfusion rate, hemoglobin decrease after surgery, surgery duration, and hospital stay.

Results Eight studies comprising 966 patients were included in the meta-analysis. Compared with FG-PCNL, UG-PCNL had comparable stone-free rates [odds ratio (OR) 0.95; 95% confidence interval (CI) 0.67–1.35; $p = 0.79$] irrespective of the patient's position, and a favorable safety profile resulting in a lower complication rate (OR 0.56; 95% CI 0.36–0.86; $p = 0.009$). No statistical difference was found between UG and FG groups in secondary outcomes.

Conclusions UG-PCNL is as effective as FG-PCNL and has the advantage of lower complication rates. In addition, UG-PCNL could be performed with patients in the supine position without compromising its efficacy.

Keywords Fluoroscopy · Ultrasonography · Nephrolithotomy · Percutaneous · Urinary calculi · Meta-analysis

Introduction

Nephrolithiasis is one of the most common of all urological conditions, and recent studies have demonstrated an increasing prevalence of the disease over the last several decades [1]. The current widely accepted management options for most patients with staghorn stones and large renal stones (i.e., > 20 mm) is percutaneous nephrolithotomy (PCNL) [2,

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3], and creating exact access to the renal collecting system is an essential step for success of PCNL [4]. This step can be performed using different imaging modalities, including fluoroscopy, ultrasound, or a combination of both, or by applying new technologies, such as robotics, augmented reality, and electromagnetic navigation [5]. Fluoroscopy-guided PCNL (FG-PCNL) with the patient in the prone position has been the preferred and well-established modality for localizing renal stones and creating percutaneous access [6] however, fluoroscopy is associated with exposure to radiation and could pose a health risk to both the patients and staff [7]. Moreover, the prone position is not ideal for obese patients or those with cardiopulmonary disorders or skeletal deformities [8, 9]. Thus, ultrasound-guided (UG)-PCNL was introduced with the aim of lowering radiological hazards while enabling real-time guidance. In addition, it has proved to be safe for pregnant women, is less costly [10–12], and can be performed with patients in positions other than prone, such as supine or flank, for less risk during anesthesia [13]. For these reasons, clinicians are highly interested in comparing the outcomes between UG-PCNL and FG-PCNL with patients in different positions.

Although several meta-analyses have compared the efficacy and safety between UG-PCNL and FG-PCNL, those studies contained only five randomized trials [14, 15]. In addition, the studies did not compare the two image modalities with patients in different positions and provided no data on the auxiliary procedure rate or complication rate. Several other relevant randomized studies comparing UG-PCNL and FG-PCNL have recently been published [10, 16, 17] therefore, we conducted this meta-analysis to systematically describe the newest available data on adults who had either UG-PCNL or FG-PCNL. This study is the first to compare these two image modalities with the patients in various positions.

Materials and methods

Our systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [18].

Search strategy and study selection

The PubMed, Embase, and Cochrane databases were electronically searched for relevant studies published up to December 2017. The following search string was used: (ultrasound OR ultrasound-guided OR ultrasonographic) AND (fluoroscopy OR fluoroscopic) AND (percutaneous nephrolithotomy OR PCNL). Articles were selected according to the PRISMA criteria for search strategies (http://www.prisma-statement.org). The cited references from the articles retrieved in the search were also assessed to find more significant papers, and no language restriction was applied. Two weeks before submission, we conducted the search again to determine whether any new relevant trials had been published. The inclusion criteria were as follows: (1) patients with renal calculi or proximal ureteral calculi; (2) a comparison of UG-PCNL with FG-PCNL; (3) reporting of at least one of the following outcomes: surgery duration, stone-free rate (SFR), drop in hemoglobin (Hb) after surgery, hospitalization time, and complications; (4) a randomized controlled trial (RCT); and (5) details on the patient's position for creation of percutaneous access. The exclusion criteria were as follows: (1) conference abstracts that were not deemed to be methodologically appropriate, (2) non-randomized studies, and (3) review studies.

Data extraction and study quality assessment

Two reviewers (YY and CC) independently assessed whether the studies met the inclusion criteria and then extracted the data from the selected studies. Any discrepancies were documented, discussed, and resolved by consensus. The information compiled comprised the name of the first author, publication year, study period, design, number of patients in the two imaging modality groups, and patient demographics. In addition, patient position for access creation, stone burden, stone location, SFR, drop in Hb after surgery, transfusion rate, surgery duration, hospital stay, time spent to enter the target calyx, complication rate, and auxiliary procedure rate were recorded. To assess the methodological quality of the included studies, we used the risk-of-bias (ROB) method recommended by The Cochrane Collaboration [19]. Domains comprising the adequacy of randomization, allocation concealment, patient and outcome assessor blinding, selective outcome reporting, incomplete outcome data, and freedom from other biases were assessed.

Outcomes

SFR was the primary efficacy outcome considered in the studies. SFR was defined as fragments of < 4 mm or no residual stone and was measured immediately after treatment. The complication rate was the primary safety outcome. The transfusion rate, hospital stay, drop in Hb after surgery, time spent to enter the target calyx, auxiliary procedure rate, and successful access-creation rate were assessed as secondary outcomes.

Statistical analyses

Efficacy and safety comparisons between UG-PCNL and FG-PCNL were conducted by calculating the mean difference (MD) for continuous outcomes and the odds ratios

(ORs) with a 95% confidence interval (CI) for dichotomous outcomes. Random effects models were applied to pool the data. Statistical heterogeneity among the studies was assessed using the Chi-square test with significance set at $p < 0.10$, and heterogeneity was quantified using the I^2 statistic. We performed our meta-analysis with Review Manager v 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014. The results of the meta-analysis are presented as forest graphs. In addition, a subgroup analysis was performed by pooling available estimates of different patient positions related to surgical access across trials.

Results

Studies identified in the literature search

Eight randomized clinical trials were identified that compared UG-PCNL with FG-PCNL in the meta-analysis [10, 16, 17, 20–24] (Fig. 1).

Study characteristics and quality evaluation

The characteristics of the eight studies and their patients are presented in Table 1. Among the studies of 966 patients, 481

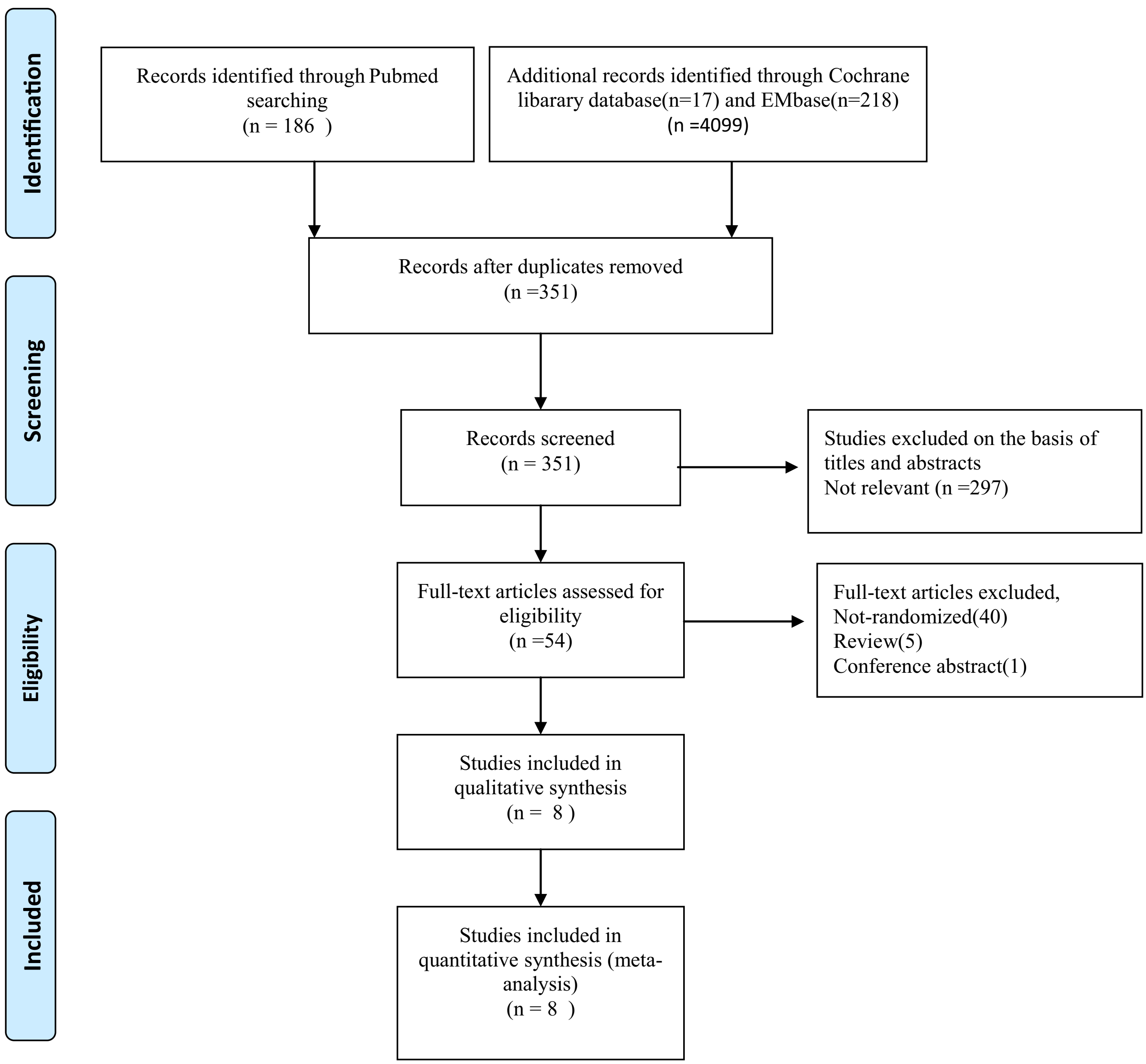

Fig. 1 Study flow chart outlining the systematic search strategy and study selection process

Table 1 Characteristics of the included studies

First author (year of publication)	Inclusion criteria	Cases (UG/FG)	Age (mean)/(UG/FG) (years)	Sex Male (*n*) (UG/FG)	BMI, kg/m^2 (mean) (UG/FG)	Stone burden (mean) (UG/FG)	Multiple stones (UG/FG)	PCNL technique (UG/FG)
Agarwal 2011 [22]	Normal renal function; absence of congenital abnormalities	112/112	31/35	N/A	–	280[a]/230 mm^2	N/A	Prone/prone
Basiri2008 [20]	Renal or upper ureteral stones and no abnormalities of the upper urinary tract	50/50	40.7/41.6	34/31	25/24.6	24/27 mm	0/0	Flank/flank
Basiri 2013 [23]	Kidney stones > 2 cm; proximal ureteral stones > 1.5 cm; stones refractory to extracorporeal shockwave lithotripsy; stones with at least mild hydronephrosis	43/46	45.7/44.8	30/31	25.29/24.86	N/A	13/20	Supine/prone
Falahatkar 2016 [10]	Single large pelvic stone, lower caliceal stone, stones in the pelvis and lower calyx, middle caliceal stones, and non-opaque stones (staghorn stones) with hydronephrosis	26/25	48.41/51.17	17/15	28.14/26.31	26.48/30.44 mm	N/A	Supine/supine
Jagtap 2014 [24]	<3 cm renal calculi undergoing single-tract PCNL	32/32	40.7/44.5	25/20	N/A	21/22 mm	3/2	Prone/prone
Karami 2010 [21]	Pelvic or caliceal stones > 2.5 cm in diameter	30/30	40.9/39.4	18/19	27.8/26	28.7/27.4 mm	0/0	Flank/prone
Sun 2017 [17]	>2 cm kidney stones with hydronephrosis	43/43	42.9/45.1	29/32	24.2/24.5	29.4/30.1 mm	N/A	Supine/supine
Zhu 2017 [16]	Normal renal function; absence of congenital abnormalities kidney stones diameter of > 2 cm	145/147	49.9)/49.6	86/77	23.7/23.5	838.3[a] (± 578.1)/834.8 (± 730.1) (mm^2)	130[b]/124	Prone/prone

N/A not available, *UG* ultrasound-guided, *FG* fluoroscopy-guided, *BMI* body-mass index, *PCNL* percutaneous nephrolithotomy

[a]Stone burden expressed as a volume (mm^2)

[b]Multiple or staghorn stones

(49.8%) patients had undergone UG-PCNL and 485 (50.2%) had undergone FG-PCNL. There were no differences between UG-PCNL and FG-PCNL populations in mean ages (42.3 vs. 41.7 years, respectively, $p=0.59$), body mass index (BMI; 24.8 vs. 24.4 kg/m^2, respectively, $p = 0.59$), or stone sizes (24.8 and 26.5 mm, respectively, $p=0.52$). Six trials comprised only patients with renal stones [10, 16, 17, 21, 22, 24], and two trials also enrolled patients with upper ureteral stones [20, 23]. Data on stone location within the urinary tract were reported in six trials and are summarized in Table 2. All trials excluded cases with congenital urinary tract anomalies. The PCNL sheath size as reported in the eight studies was 28–30 F, with the exception of Zhu et al. (18 F). The sheath size, medical specialty and experience of PCNL performers, and other detailed PCNL techniques are summarized in Table 3. UG-PCNL was performed in the prone position in three studies, in the supine position in three studies, and in the flank position in two studies (Table 1). The final results of quality using the ROB tool are shown in Supplement 1, and the potential bias of included RCTs are categorized into high risk, low risk, and unclear.

Stone-free rate

Among the 966 patients, 799 patients (seven trials) were included in the SFR comparison [10, 16, 17, 21–24]. Figure 2 shows SFRs among the trials from which a random effects analysis yielded an OR of 0.95 (95% CI 0.67–1.35; $p=0.79$; $I^2=0\%$) for UG-PCNL versus FG-PCNL. The pooled results indicated no statistically significant difference between the two groups. A summary of the definition, technique, and timing of SFR assessment is provided in Supplement 2. Allowances for SFR assessment were made for three studies. In two of the trials, the outcome was measured 1 day after surgery rather than immediately after surgery [16, 24] and was measured 1 month after surgery in the third trial [17].

In the subgroup analysis of patient position, the FG-PCNL group had a higher SFR with patients in the prone position (OR 0.74, 95% CI 0.47–1.14; $p=0.20$;

Table 2 Stone size, multiplicity, renal location, and degree of hydronephrosis

First author (year of publication)	Multiple stones, *n* (UG/FG)	Location, *n* (UG/FG)	Side, *n* Left (UG/FG)	Degree of hydronephrosis (UG/FG)
Agarwal 2011 [22]	N/A	N/A	N/A	N/A
Basiri 2008 [20]	0/0	Inferior: 40/40 Middle: 7/9 Superior: 3/1	N/A	Mild: 14/16 Moderate: 20/21 Severe: 16/13
Basiri 2013 [23]	13/20	Renal pelvis: 16/15 Inferior calyx: 10/8 Middle calyx: 4/3 Renal pelvis + inferior calyx: 7/10 Renal pelvis + middle calyx: 1/8 Middle and inferior calices: 5/2	N/A	N/A
Falahatkar 2016 [10]	N/A	N/A	10/8	N/A
Jagtap 2014 [24]	N/A	Superior calix: 3/2 Middle calix: 3/7 Inferior calix: 10/10 Renal pelvis: 13/11	19/12	None: 6/5 Mild: 13/15 Moderate: 11/10 Severe: 2/2
Karami 2010 [21]	0/0	Superior calix: 3/2 Middle calix: 7/7 Inferior calix: 14/17 Renal pelvis: 6/4	8/14	Mild: 12/14 Moderate: 16/11 Severe: 2/5
Sun 2017 [17]	N/A	Renal pelvis: 15/17 Inferior calyx: 11/10 Middle calyx: 5/4 Renal pelvis + inferior calyx: 7/6 Renal pelvis + middle calyx: 1/3 Middle and inferior calices:4/3	12/16	N/A
Zhu 2017 [16]	130/124	Superior calyx: 44/46 Middle calyx: 92/74 Inferior calyx: 26/59	74/76	None or mild: 87/94 Moderate or severe: 60/51

N/A not available, *UG* ultrasound-guided, *FG* fluoroscopy-guided

Table 3 PCNL technique

First author (year of publication)	Performer of PCNL (category and expertise)	Saline infusion to distend the pelvicaliceal system	Ultrasound probe	Sheath size, *F*	Dilator	Lithotripsy technique	Technique used for checking for a stone-free status	Post PCNL nephrostomy tube
Agarwal 2011 [21]	N/A	Yes	3.5 MHz	26 or 28	Amplatz	Pneumatic	Nephroscope and ultrasound	Nephrostomy tube
Basiri 2008 [19]	urologists in one single center	Yes	3.5 MHz	30	Amplatz	N/A	Nephroscope and ultrasound	Nephrostomy tube
Basiri 2013 [22]	N/A	N/A	3.5 MHz	28 or 30	Amplatz	Pneumatic	KUB	Nephrostomy tube
Falahatkar 2016 [11]	N/A	Yes	N/A	N/A	Amplatz	N/A	UG, ultrasound/FG, fluoroscopy	Tubeless PCNL except with complications
Jagtap 2014 [23]	Trainee urologists[a]	Yes	3.5 MHz	28	Amplatz	Pneumatic lithotripter (Swiss Lithoclast) or (Ho:YAG) laser of 30 W	KUB plus ultrasound	Upon individual case (nephrostomy tube or ureteral stent) Double-J stent: 18/25 Ureteral catheter: 14/7
Karami 2010 [20]	One surgical team	Yes	3.5 MHz	28 or 30	Amplatz	Pneumatic	KUB plus ultrasound	Tubeless procedure
Sun 2017 [18]	One surgical team	Not mentioned	3.5 MHz	30	Amplatz	N/A	N/A	N/A
Zhu 2017 [17]	4[b] surgeon (G.Z., J.Y., Y.L. and G.L.)	Yes	N/A	18	Not mentioned	Pneumatic	UG, ultrasound FG, fluoroscopy	5-F JJ ureteric stent plus nephrostomy tube

KUB kidney, ureter, and bladder, *PCNL* percutaneous nephrolithotomy, *N/A* not available

[a]Each of them had performed > 30 PCNLs

[b]Each of them had performed >500 USG and FG mini-PCNLs during their career

Study or Subgroup	Ultrasonographic access Events	Total	Fluoroscopic access Events	Total	Weight	Odds Ratio M-H, Random, 95% CI
18.1.1 prone position						
Agarwal,2011	112	112	112	112	1.6%	1.00 [0.06, 16.19]
jagtap2014	32	32	32	32	1.6%	1.00 [0.06, 16.71]
Zhu 2017	81	147	91	145	56.2%	0.73 [0.46, 1.16]
Subtotal (95% CI)		**291**		**289**	**59.3%**	**0.74 [0.47, 1.17]**
Total events	223		233			
Heterogeneity: Tau² = 0.00; Chi² = 0.09, df = 2 (P = 0.95); I² = 0%						
Test for overall effect: Z = 1.29 (P = 0.20)						
18.1.2 supine						
Basiri2013	34	46	30	46	15.3%	1.51 [0.62, 3.70]
Falahakta2016	20	26	17	25	8.0%	1.57 [0.45, 5.42]
Sun 2017	34	43	31	43	12.5%	1.46 [0.54, 3.94]
Subtotal (95% CI)		**115**		**114**	**35.8%**	**1.51 [0.84, 2.71]**
Total events	88		78			
Heterogeneity: Tau² = 0.00; Chi² = 0.01, df = 2 (P = 1.00); I² = 0%						
Test for overall effect: Z = 1.37 (P = 0.17)						
18.1.3 flank position						
Karami2010	26	30	27	30	4.9%	0.72 [0.15, 3.54]
Subtotal (95% CI)		**30**		**30**	**4.9%**	**0.72 [0.15, 3.54]**
Total events	26		27			
Heterogeneity: Not applicable						
Test for overall effect: Z = 0.40 (P = 0.69)						
Total (95% CI)		**436**		**433**	**100.0%**	**0.95 [0.67, 1.35]**
Total events	337		338			
Heterogeneity: Tau² = 0.00; Chi² = 3.74, df = 6 (P = 0.71); I² = 0%						
Test for overall effect: Z = 0.26 (P = 0.79)						
Test for subgroup differences: Chi² = 3.64, df = 2 (P = 0.16), I² = 45.1%						

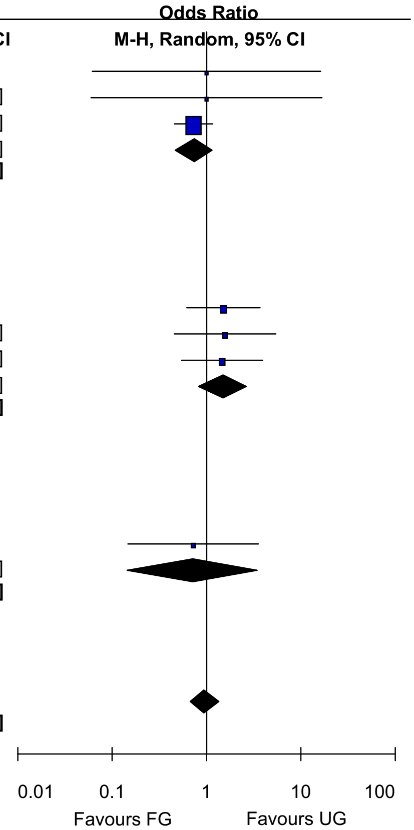

Fig. 2 Forest plot and meta-analysis of stone free rate in ultrasound-guided verses fluoroscopy-guided PCNL

$I^2=0\%$), whereas the UG-PCNL group had a higher SFR with patients in the supine position (OR 1.51, 95% CI 0.84–2.74; $p=0.17$; $I^2=0\%$). Heterogeneity assessed using I^2 statistics remained at zero after the subgroup analysis; however, no significant difference was detected between the UG-PCNL and FG-PCNL groups. In the analysis of the flank position subgroup, no significant differences were observed in SFR between the two groups (OR 0.72; 95% CI 0.15–3.54; $p=0.69$).

Complication rate

Complications of treatment were reported in all eight studies [10, 16, 17, 20–24]. A meta-analysis of the eight

Study or Subgroup	Ultrasonographic access Events	Total	Fluoroscopic access Events	Total	Weight	Odds Ratio M-H, Random, 95% CI
Agarwal 2011	2	112	2	112	4.9%	1.00 [0.14, 7.23]
Basiri2008	5	50	4	50	10.1%	1.28 [0.32, 5.07]
Basiri2013	1	46	7	46	4.2%	0.12 [0.01, 1.05]
Falahaktar 2016	2	26	6	25	6.5%	0.26 [0.05, 1.46]
jagtap2014	5	32	6	32	11.3%	0.80 [0.22, 2.95]
Karami2010	2	30	1	30	3.2%	2.07 [0.18, 24.15]
Sun 2017	5	43	9	43	13.6%	0.50 [0.15, 1.63]
Zhu 2017	17	147	31	145	46.3%	0.48 [0.25, 0.91]
Total (95% CI)		**486**		**483**	**100.0%**	**0.56 [0.36, 0.86]**
Total events	39		66			
Heterogeneity: Tau² = 0.00; Chi² = 6.02, df = 7 (P = 0.54); I² = 0%						
Test for overall effect: Z = 2.62 (P = 0.009)						

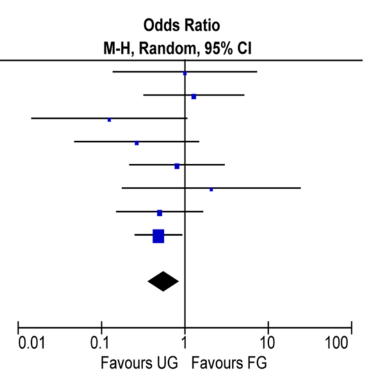

Fig. 3 Forest plot and meta-analysis of complication rate in ultrasound-guided verses fluoroscopy-guided PCNL

studies showed that UG-PCNL had a statistically lower complication rate (OR 0.56; 95% CI 0.36–0.86; $p=0.009$; $I^2=0\%$) than FG-PCNL (Fig. 3); however, the results of a study by Zhu et al. [16] were the only ones that reported significantly lower complication rates in the UG-PCNL group than in the FG-PCNL group [16]. None of the remaining seven studies showed any significant difference in complications.

Complication rate according to Clavien–Dindo score and types

Three studies classified complications according to Clavien–Dindo score [10, 16, 24], and we classified the reported complications of the other five studies [17, 20–23] according to de la Rosette et al. [25]. (Supplement 3). In the pooled analysis, the UG-PCNL group had significantly lower complication rates (Clavien grades I–II) than the FG-PCNL group (OR 0.57; 95% CI 0.34–0.96; $p=0.03$; $I^2=6\%$). No statistical difference was found when analyzing Clavien grade III (OR 0.82; 95% CI 0.22–3.12; $p=0.79$; $I^2=0\%$) and grade IV (OR 0.36; 95% CI 0.10–1.40; $p=0.77$; $I^2=0\%$) complications between the two groups (Supplement 4). No statistical difference was found in patient fever (OR 0.49; 95% CI 0.24–1.02; $p=0.06$; $I^2=0\%$), intraoperative bleeding (OR 0.70; 95% CI 0.32–1.53; $p=0.37$; $I^2=0\%$), or renal pelvis perforation (OR 1.05; 95% CI 0.15–7.40; $p=0.37$; $I^2=0\%$) between the two groups (Supplement 4). Basiri et al. [23] and Jagtap et al. [24] reported that there were four patients with renal pelvic disruption, two in each group. No pleural or visceral injuries were reported from any study (Supplement 3).

Success rate for access creation

Six studies reported the success rate for access creation [10, 16, 20, 23, 24]. The pooled analysis showed no significant difference between the two groups (OR 0.67 95% CI 0.25–1.77; $p=0.41$; $I^2=12\%$; Fig. 4a).

Time necessary for entrance into the target calyx

Six studies assessed the time necessary in seconds for entrance into the target calyx [10, 16, 20–22, 24]. The pooled results revealed no significant difference between the two groups (MD 10.10; 95% CI −61.79 to 81.99; $p=0.78$; $I^2=98\%$; Fig. 4b).

Surgery duration

Four studies assessed surgery duration in minutes [10, 16, 20, 21, 23, 24]. The pooled results revealed no significant difference between the two groups (MD 2.62; 95% CI −4.64 to 9.89; $p=0.48$; $I^2=12\%$; Fig. 4c).

Hospital stay

Four studies assessed the length of hospital stay in hours [10, 16, 17, 21, 24]. The pooled results indicated no significant difference between the two groups (MD −1.82; 95% CI −6.94 to 3.29; $p=0.48$; $I^2=32\%$; Fig. 4d).

Transfusion rate

Three studies reported the transfusion rate [10, 16, 24]. One patient in 205 in the UG-PCNL group and 5 patients in 202 in the FG-PCNL group received a blood transfusion after surgery. The pooled results indicated no significant difference in transfusion rates between the two groups (OR 0.26; 95% CI 0.04–1.60; $p=0.15$; $I^2=0\%$; Fig. 4e).

Drop in hemoglobin after surgery

Four studies assessed the drop in Hb level (g/dL) after surgery [10, 16, 21, 24]. The pooled results showed no significant difference in Hb decreases between the two groups (MD −0.08; 95% CI −0.20 to 0.03; $p=0.16$; $I^2=0\%$; Fig. 4f).

Auxiliary-procedure rate

Two studies reported the auxiliary-procedure rate [16, 24]. The pooled results showed no significant difference between the two groups (OR 1.22; 95% CI 0.69–2.16; $p=0.50$; Fig. 4g).

Discussion

To the best of our knowledge, this is the first meta-analysis of RCTs to demonstrate a comparison of the efficacy and safety of UG-PCNL and FG-PCNL with patients in different positions. This meta-analysis demonstrated that UG-PCNL had a comparable efficacy in SFR and a favorable safety profile with a significantly lower complication rate than FG-PCNL. Furthermore, an analysis of the patient position subgroup demonstrated that UG-PCNL could be performed with patients in the supine position without compromising its efficacy.

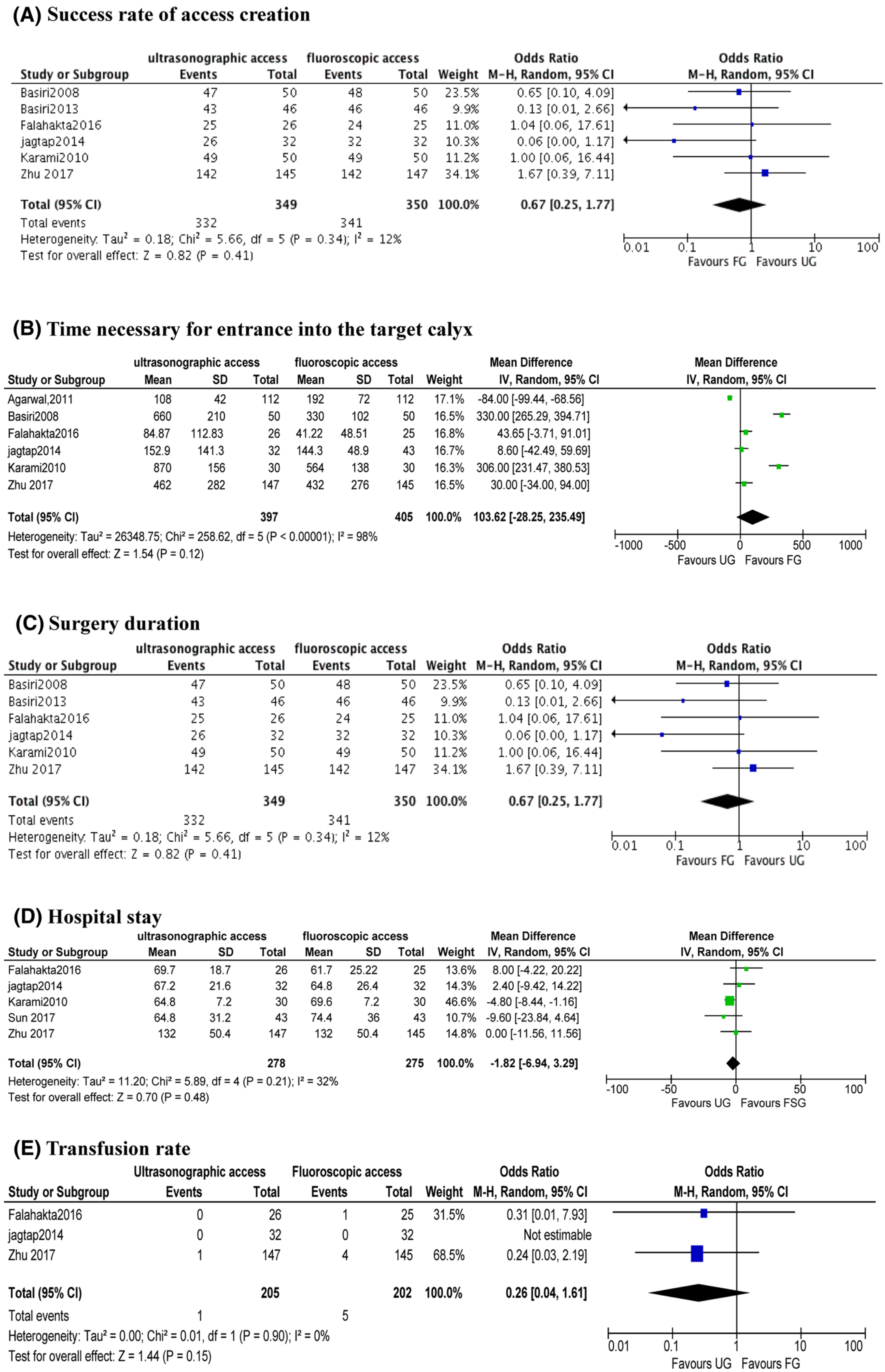

Fig. 4 Other comparison between ultrasound and fluoroscopy-guided PCNL

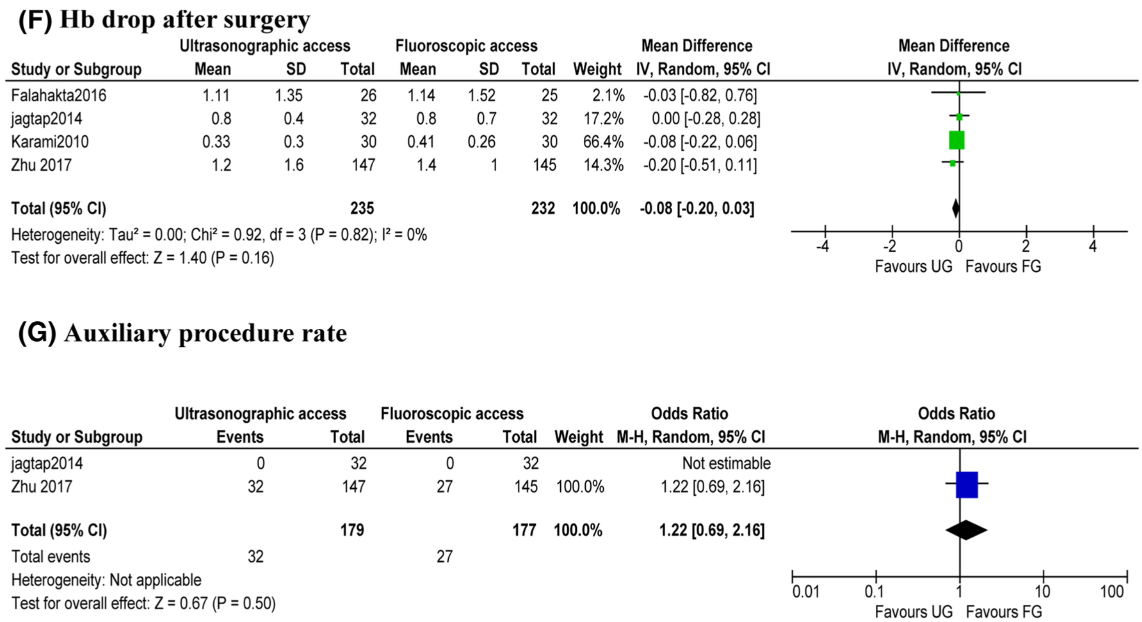

Fig. 4 (continued)

Findings within the context of existing studies

Fluoroscopy has been the standard image modality for PCNL with a high SFR. Our results showed that SFR of UG-PCNL is as high as that of FG-PCNL and that the average SFRs of the two groups are nearly identical (77.3% for UG-PCNL and 78% for FG-PCNL). In previous studies, Yan et al. [26] studied UG-PCNL on 700 patients and achieved a 91.6% SFR 4 weeks after surgery in patients with a single stone and 82.9% in patients with staghorn or multiple stones. Another comparative study reported that UG-PCNL has a significantly higher SFR (66.7%) than FG-PCNL (43.7%) [12]. These results supported our finding that UG-PCNL is as effective as or better than FG-PCNL in stone clearance; however, in the included studies, only Zhu et al. [16]. reported SFR according to different stone sizes and complexity. In that study, UG-PCNL SFR was comparable with that of FG-PCNL when treating simple kidney stones (S.T.O.N.E. scores of 5–6), but FG-PCNL was more effective when stone complexity was higher (S.T.O.N.E. scores of 7–8) (69.8% for UG-PCNL and 89.4% for FG-PCNL, $p=0.004$) [16]. Thus, additional studies are necessary to investigate the impact of stone complexity on UG-PCNL.

With respect to safety, our results indicated that UG-PCNL had lower complication rates than FG-PCNL. In previous studies, Wang et al. [15]. indicated that UG-PCNL was associated with fewer intraoperative complication. Ng et al. [12] and Lojanapiwat et al. [27] also demonstrated that UG-PCNL was associated with reduced risks of inadvertent organ injuries; therefore, it is reasonable that the difference in complication rates resulted mainly from the ability of ultrasound to provide information on surrounding viscera and the depth of puncture needle penetration and to provide distinguishing images to identify the area posterior to the anterior calyces [27].

Among the eight studies included in the meta-analysis, only Zhu et al. [16] showed significantly lower complications when comparing UG-PCNL and FG-PCNL. This finding could be explained by the use of different instrument sizes in that study. In Zhu et al. [16], with minimally invasive PCNL (mini-PCNL), a smaller percutaneous tract was established using a miniature endoscope (11–20 F). The technique was first described by Jackman et al. [28] with an 11-F endoscope on adults. Since then, several studies have investigated the efficacy and safety of this new technique and reported that mini-PCNL was associated with less bleeding and postoperative pain [29]. In addition, comparable SFRs and lower complication rates than those of standard PCNL were also reported [30]. The safety outcome of our study might, in part, be attributed to the advantages of mini-PCNL; therefore, we should regard a miniature size of the sheath as another important variance within the UG-PCNL group.

Our study indicated that the position of the patient with regard to access of the surgery site is an essential factor in PCNL outcomes. In previous clinical studies, there was no consensus on the best patient position. Yuan et al. [31] reported that PCNL with the patient in the supine position was associated with a lower rate of stone clearance than PCNL with patients in the prone position in FG-PCNL, and Falahatkar et al. [9] reported that PCNL with patients in the supine position has a SFR similar to PCNL with patients in the prone position. In our current meta-analysis, a subgroup analysis stratified by access position was performed and revealed that supine UG-PCNL had a higher SFR and significantly lower complication rate than supine FG-PCNL. Although differences in SFR were not statistically significant, which could be attributed to the small number of trials, these results imply that if a patient is a suitable case for performing supine PCNL, such as those with cardiovascular disease or spinal deformities [13], UG-PCNL might be a better choice than FG-PCNL. Our findings were supported by Manhor et al. [32] who conducted studies on supine UG-PCNL performed on 62 patients and demonstrated 95% SFR without visceral injury in 50 patients with morbid obesity or cardiopulmonary disease; however, further RCTs are necessary to better assess the real importance of patient position when performing UG-PCNL.

Limitations

This study had some limitations. First, there were several main factors, such as different stone complexity, perioperative degree of hydronephrosis, and overall BMI of patients, that were reported to have potential impacts on PCNL surgery, which consequently affected the outcomes of our study; however, because of a deficiency in eligible data, we could not conduct a subgroup analysis on these main factors. Second, heterogeneity among the studies was high for duration of access, which could be explained by the variability in the definitions of duration of access and the expertise of the end urologist. In addition, discrepancies in the assessment and definitions of SFR could also have affected the outcomes of our study. Limited to extractable data, further large-scale and well-designed clinical studies should be conducted to further explore the influence of these factors on PCNL surgery.

Conclusions

The results of our systematic review and meta-analysis suggest that UG-PCNL is an alternative to FG-PCNL with comparable efficacy and has the advantages of lower complication rates and less radiation risk for patient with urinary tract calculi. In addition, UG-PCNL could be performed with the patients in the supine position without compromising its efficacy.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies using human participants or animals conducted by any of the authors.

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