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REVIEW

Fluoroscopy versus ultrasound for image guidance during percutaneous nephrolithotomy: a systematic review and meta-analysis

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Abstract This meta-analysis aims to compare the safety and efficacy of fluoroscopy versus ultrasound guidance during the access to the renal collecting system. A systematic literature review was performed in September 2016. Outcomes were explored using review manager v5.0. 18 studies with 2919 patients were included in the final analysis. There was no significant difference in stone-free rate (RR: 1.0; 95% CI, 0.98 to 1.05; $p = 0.41$), operation time (MD: 1.75; 95% CI, −9.15 to 12.65; $p = 0.75$), hospital stay (MD: −1.02; 95% CI, −3.08 to 1.05; $p = 0.34$), and success rate of tract creation (RR: 1.00; 95% CI, 0.98–1.02; $p = 0.88$) between ultrasonography and fluoroscopy. Compared to fluoroscopy, ultrasonography had shorter puncture time (MD: −4.71; 95% CI, −6.43 to −3.0; $p < 0.0001$), higher success rate of fist puncture (RR: 1.16; 95% CI, 1.04 to 1.3; $p = 0.01$), less blood loss (MD: −0.42, 95% CI −0.81 to −0.02; $p = 0.04$), and less transfusion requirement (RR: 0.73; 95% CI, 0.33–1.6; $p = 0.44$). Two patients in each group experienced perforation of the renal pelvis. Five patients in fluoroscopy and two in ultrasonography group had pneumothorax. One patient in fluoroscopy group had intestinal injury. Both fluoroscopy and ultrasound guidance can aid to obtain successful percutaneous renal access. The advantages of ultrasonography over fluoroscopy include shorter puncture time, higher success rate of fist puncture, less blood loss, and less complications.

Keywords Fluoroscopy · Ultrasound · Percutaneous nephrolithotomy · Image guidance

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Introduction

Renal access is a major step for percutaneous nephrolithotomy (PCNL). It can be obtained either with fluoroscopy or ultrasound guidance. Fluoroscopy was the most commonly used image modality. However, fluoroscopic use can result in radiation exposure to the patient and the staff in the operating theatre. Ultrasound is another useful interventional tool which has the advantages of reduced radiation exposure, lower cost, and portability [1, 2]. And it is the choice for pregnant or transplanted patients [3–5].

To date, the choice of the imaging modality is mainly based on the preference of the surgeon. The ideal modality of image guidance for PCNL has not reached a consensus. Therefore, we perform the meta-analysis of available studies comparing the safety and efficacy between ultrasonography and fluoroscopy during PCNL.

Literature search and article selection

We carried out an electronic search of PubMed, Embase, Cochrane Library, Chinese Biomedical Literature databases, and Chinese National Knowledge Infrastructure to find relevant studies in September 2016. The search terms included: "Percutaneous Nephrostomy", "Percutaneous nephrolithotomy", "PCNL", "minimally invasive percutaneous nephrolithotomy", "MPCNL", "fluoroscopy", "X-ray", "ultrasound", "ultrasonography", "US", and their synonyms. References of searched papers were also checked manually to identify relevant articles.

Two reviewers independently selected studies for inclusion. Studies were included if they met the following criteria: (1) patients who received percutaneous PCNL, (2) adult patients, (3) patients received either ultrasound or fluoroscopy guidance.

Data extraction and quality assessment

The data were independently extracted using a pre-defined data extraction form, which included study characteristics, patient characteristics, and methodological quality. The measured outcomes were stone-free rate, operation time, hospital stay, time to puncture, success rate of access creation and first puncture, hemoglobin decrease and transfusion requirement.

The methodological quality of the studies was assessed using the Newcastle-Ottawa Scale (NOS) for nonrandomized controlled trials [6] and the Jadad scale for RCTs [7].

Statistical analysis

Meta-analysis was performed by Review Manager 5.3. For dichotomous variables, results were expressed as risk ratios (RR) with 95% confidence intervals (CI). For continuous outcomes, the mean difference (MD) was used with 95% CI. Heterogeneity between the included studies was analyzed using a Chi^2 test and the I^2 test, with p value of 0.05 used for statistical significance. The data were analyzed using the random-effects model when *I*-square >25%. Forest plots were used for graphical displays of results from the meta-analysis.

Results

Study characteristics

The search strategy identified 352 studies (Fig. 1). 18 studies [8–25] with 2919 patients were included in the final analysis. The literature screening process is shown in Fig. 1. Six studies were RCTs and twelve were case–control studies. Table 1 presents the study characteristics and quality assessment of the included studies.

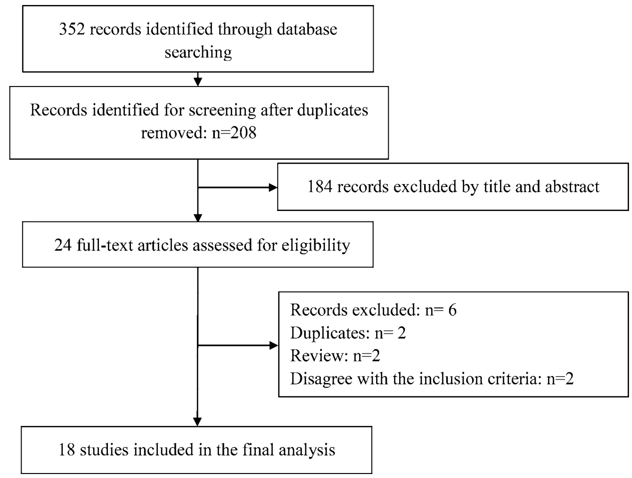


Fig. 1 Study flow chart outlining the systematic search strategy and study selection process

Stone-free rate

Thirteen studies reported the stone-free rate. No statistical significant difference was found when ultrasonography was compared with fluoroscopy for stone-free rate (RR: 1.0; 95% CI, 0.98–1.05; $p = 0.41$, Fig. 2a).

Operation time

The data of operation time was available in 4 studies. The pooled data showed no significant difference between ultrasonography and fluoroscopy (MD: 1.75; 95% CI, −9.15 to 12.65; $p = 0.75$, Fig. 2b).

Hospital stay

A forest plot for the difference in hospital stay of the two methods is presented in Fig. 2c. There was no significant difference in hospital stay group between the two groups (MD: −1.02; 95% CI, −3.08 to 1.05; $p = 0.34$).

Success rate of access creation and first puncture

Meta-analysis of eleven studies showed no significant difference in success rate of access creation between ultrasonography and fluoroscopy (RR: 1.00; 95% CI, 0.98–1.02; $p = 0.88$, Fig. 3a). Five studies reported the success rate of first puncture. Meta-analysis of these studies indicated that the ultrasonography had a higher success rate than fluoroscopy (RR: 1.16; 95% CI, 1.04–1.3; $p = 0.01$, Fig. 3b).

Table 1 Characteristics and quality assessment of the included studies

Study	Study design	Cases US vs X-ray	Age US vs X-ray	Stone size (cm/mm^2) US vs X-ray	Study quality
Jagtap et al. [8]	RCT	32 vs 32	40.7 vs 44.5	2.1 vs 2.2	3[a]
Basiri et al. [9]	RCT	43 vs 46	45.7 vs 44.8	352 vs 345	3[a]
Agarwal et al. [10]	RCT	112 vs 112	31 vs 35	280 vs 230	3[a]
Karami et al. [11]	RCT	30 vs 30	40.8 vs 39.4	2.87 vs 2.74	3[a]
Falahatkar et al. [12]	Case control	14 vs 14	46.5 vs 45.2	5.1 vs 4.9	6[b]
Basiri et al. [13]	RCT	50 vs 50	40.7 vs 41.6	2.4 vs 2.7	3[a]
Liu lan [14]	Case control	60 vs 60	46.3 vs 46.8	NS	5[b]
Chen mingxi et al. [15]	Case control	198 vs 259	44.7 vs 42.1	3.6 vs 3.4	4[b]
Liang xiaodong et al. [16]	Case control	40 vs 35	38.6 vs 36.9	3.4 vs 3.2	5[b]
Liu yinlong et al. [17]	RCT	60 vs 60	48.53 vs 49.26	5.1 vs 4.9	3[a]
Xing rui et al. [18]	Case control	38 vs 30	41 vs 38	2.5 vs 2.4	5[b]
Wu xinhui et al. [19]	Case control	52 vs 62	42 vs 42	2.54 vs 2.52	5[b]
Sun xinhui et al. [20]	Case control	65 vs 38	NS	NS	5[b]
Dong guoqiang et al. [21]	Case control	76 vs 71	47.6 vs 45.3	4.2 vs 3.9	5[b]
Wu jianping et al. [22]	Case control	74 vs 58	51.2 vs 49.6	4.4 vs 4.2	5[b]
Zhu zhenping et al. [23]	Case control	230 vs 256	43.1 vs 42.1	3.0 vs 2.9	6[b]
Yang xiaoming et al. [24]	Case control	30 vs 30	45 vs 44	NS	5[b]
Chen huiming et al. [25]	Case control	323 vs 209	NS	NS	6[b]

[a] Jadad scale for RCTs; [b] Newcastle-Ottawa Scale (NOS) for nonrandomized controlled trials (RCTs)

NS not significant, *US* ultrasonography, *X-ray* fluoroscopy

Time to puncture

Twelve studies reported the time to puncture. The data were heterogeneous ($I^2 = 99\%$), and the random-effect model showed less time in ultrasonography group as compared with fluoroscopy group (MD: −4.71; 95% CI, −6.43 to 3.0; $p < 0.0001$, Fig. 3c).

Hemoglobin decrease and transfusion requirement

Five studies reported hemoglobin decrease. The data were heterogeneous ($I^2 = 91\%$), and the random-effect model showed that the hemoglobin decrease was less in the ultrasonography group (MD: −0.42, 95% CI −0.81 to −0.02; $p = 0.04$, Fig. 4a). Meta-analysis of four studies by the fixed-effects model ($I^2 = 0\%$) demonstrated less blood transfusion in the ultrasonography group. There was no significant difference between the two groups (RR: 0.73; 95% CI, 0.33–1.6; $p = 0.44$, Fig. 4b).

Complications

Meta-analysis of three studies showed no significant difference in fever (RR: 0.37; 95% CI, 0.08–1.76; $p = 0.21$, Fig. 4c).Two patients in each group experienced perforation of the renal pelvis during the attempt to gain access [8, 13]. Five patients in fluoroscopy and two in ultrasonography group had pneumothorax [16, 20, 22]. One patient in fluoroscopy group had intestinal injury [20].

Discussion

The access to the renal collecting system is the first process in PCNL, and this procedure is usually performed under fluoroscopy. Ultrasound is another image modality for obtaining access and the number of studies demonstrating the success of ultrasound-guided PCNL is increasing. Our meta-analysis compared the safety and efficacy of the two imaging methods and demonstrated that there was no significant difference in stone-free rate, operation time, hospital stay and success rate of tract creation. Compared to fluoroscopy, ultrasonography had shorter puncture time, higher success rate of fist puncture, less blood loss and less postoperative complication.

Fluoroscopy is an important tool for the performance of PCNL. It is useful during puncture on the kidney, insertion of guidewires, tract dilatation and removal of stones [26]. However, fluoroscopy-guided PCNL exposes both patients and operators to a significant amount of ionizing radiation which may cause genetic mutation and cancer, and the severity of the effect increases with dose [27, 28]. As the number of PCNL procedures performed is increasing, the cumulative dose of radiation may be substantial especially

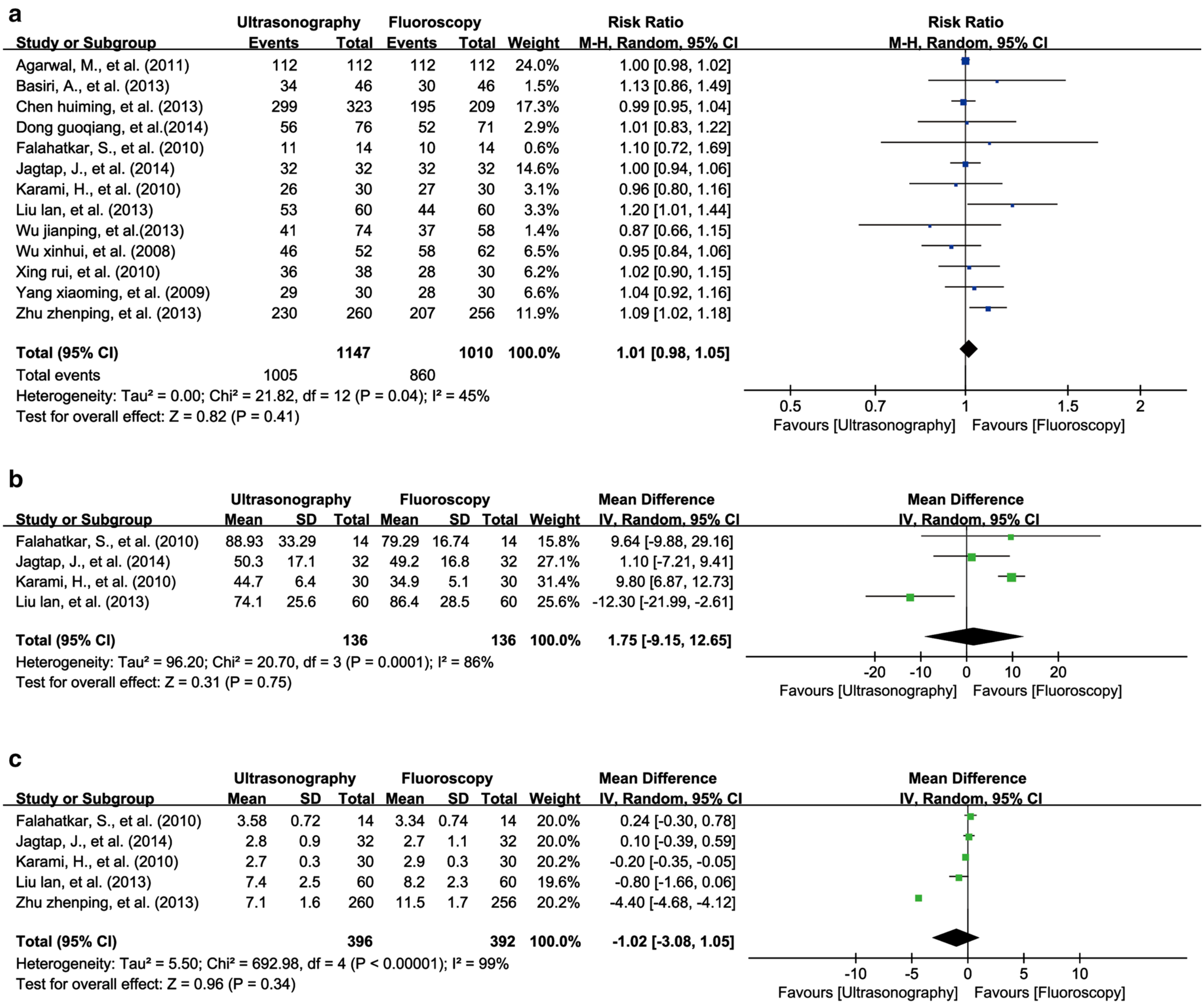


Fig. 2 Forest plot comparing stone-free rate (**a**), operation time (**b**), and hospital stay (**c**)

in high-volume centers. It is important to follow the principles of As Low As Reasonably Achievable (ALARA) in PCNL [27]. The International Commission on Radiation Protection (ICRP) recommends the annual limit for equivalent dose in the lens of the eye at 150 mSv, in the skin at 500 mSv, and in the extremities at 500 mSv [29]. For this reason, using ultrasound instead of fluoroscopy during PCNL should be popularized to reduce radiation exposure.

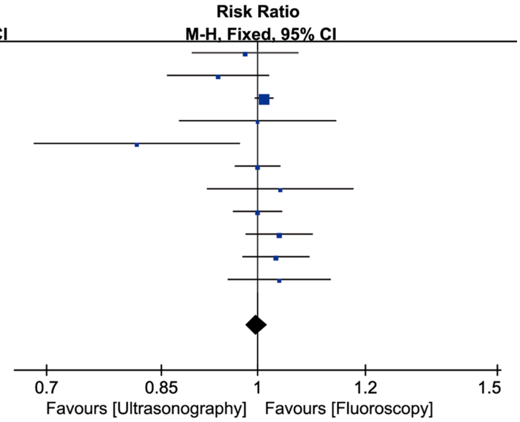
Our analyses indicated that there is no difference in the stone-free rate and hospital stay. Meanwhile, our study showed some advantages of ultrasonography guidance. First, in ultrasonography guided PCNL, the time taken to puncture was shorter and the success rate of first puncture was higher. During the access to the calyx with ultrasonography, you do not need to rotate the x-ray machine and wear a lead apron and thyroid collar to protect you from radiation. It is quick to obtain the access to the targeted calyx especially for experienced operators.

Another advantage of ultrasonography guidance was lower risk of complications. The analysis indicated that the hemoglobin decrease was significantly less in the ultrasonography group. And transfusion requirement reduced in the ultrasonography group. The reason for this difference may be related to the shorter access time. As Akman showed that the blood loss during PCNL was related to prolonged access time [30]. In addition, we think the high success rate of first puncture also contributed to the less blood loss. Additionally, US can help to evaluate the depth of the access needle and allow identification of the surrounding structure, thus avoiding injuries to nearby organs. The present study also showed less pneumothorax and intestinal injury in the ultrasonography guided PCNL.

a

Study or Subgroup	Ultrasonography Events	Ultrasonography Total	Fluoroscopy Events	Fluoroscopy Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Basiri, A., et al. (2008)	47	50	48	50	7.4%	0.98 [0.89, 1.07]
Basiri, A., et al. (2013)	43	46	46	46	7.2%	0.94 [0.86, 1.02]
Chen mingxi, et al. (2012)	198	198	256	259	34.3%	1.01 [1.00, 1.03]
Falahatkar, S., et al. (2010)	14	14	14	14	2.2%	1.00 [0.88, 1.14]
Jagtap, J., et al. (2014)	26	32	32	32	5.0%	0.82 [0.69, 0.97]
Karami, H., et al. (2010)	50	50	50	50	7.8%	1.00 [0.96, 1.04]
Liang xiaodong, et al. (2012).	38	40	32	35	5.3%	1.04 [0.92, 1.18]
Sun xinhui, et al.(2007)	65	65	38	38	7.5%	1.00 [0.96, 1.04]
Wu jianping, et al.(2013)	74	74	56	58	9.8%	1.04 [0.98, 1.10]
Wu xinhui, et al. (2008)	52	52	60	62	8.5%	1.03 [0.97, 1.09]
Xing rui, et al. (2010)	38	38	29	30	5.1%	1.04 [0.95, 1.13]
Total (95% CI)		**659**		**674**	**100.0%**	**1.00 [0.98, 1.02]**
Total events	645		661			

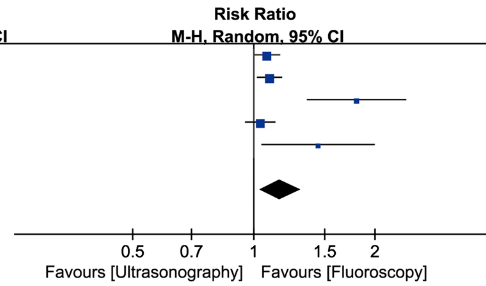
Heterogeneity: Chi² = 14.05, df = 10 (P = 0.17); I² = 29%
Test for overall effect: Z = 0.15 (P = 0.88)



b

Study or Subgroup	Ultrasonography Events	Ultrasonography Total	Fluoroscopy Events	Fluoroscopy Total	Weight	Risk Ratio M-H, Random, 95% CI
Chen huiming, et al. (2013)	283	323	170	209	26.9%	1.08 [1.00, 1.16]
Chen mingxi, et al. (2012)	179	198	214	259	27.3%	1.09 [1.02, 1.18]
Sun xinhui, et al.(2007)	65	65	21	38	10.7%	1.80 [1.36, 2.39]
Xing rui, et al. (2010)	38	38	29	30	26.1%	1.04 [0.95, 1.13]
Yang xiaoming, et al. (2009)	26	30	18	30	8.9%	1.44 [1.04, 2.00]
Total (95% CI)		**654**		**566**	**100.0%**	**1.16 [1.04, 1.30]**
Total events	591		452			

Heterogeneity: Tau² = 0.01; Chi² = 19.38, df = 4 (P = 0.0007); I² = 79%
Test for overall effect: Z = 2.55 (P = 0.01)



c

Study or Subgroup	Ultrasonography Mean	Ultrasonography SD	Ultrasonography Total	Fluoroscopy Mean	Fluoroscopy SD	Fluoroscopy Total	Weight	Mean Difference IV, Random, 95% CI
Agarwal, M., et al. (2011)	1.8	0.7	112	3.2	1.2	112	9.8%	-1.40 [-1.66, -1.14]
Basiri, A., et al. (2008)	11	3.5	50	5.5	1.7	50	9.4%	5.50 [4.42, 6.58]
Chen huiming, et al. (2013)	4.3	0.4	323	7.9	0.6	209	9.8%	-3.60 [-3.69, -3.51]
Chen mingxi, et al. (2012)	17.6	7.9	198	25.7	11.2	259	8.9%	-8.10 [-9.85, -6.35]
Dong guoqiang, et al.(2014)	11.7	12.8	76	32.4	15.4	71	5.7%	-20.70 [-25.29, -16.11]
Jagtap, J., et al. (2014)	2.5	2.4	32	2.4	0.8	32	9.5%	0.10 [-0.78, 0.98]
Karami, H., et al. (2010)	14.5	2.6	30	9.4	2.3	30	9.3%	5.10 [3.86, 6.34]
Liang xiaodong, et al. (2012).	8.3	3.4	40	7.8	2.8	35	9.2%	0.50 [-0.90, 1.90]
Liu yinlong, et al. (2010)	15.26	4.26	60	29.84	8.43	60	8.2%	-14.58 [-16.97, -12.19]
Wu jianping, et al.(2013)	10.6	6.2	74	30.2	14.6	58	6.4%	-19.60 [-23.61, -15.59]
Wu xinhui, et al. (2008)	29.6	14.4	52	32.1	15.3	62	4.9%	-2.50 [-7.96, 2.96]
Yang xiaoming, et al. (2009)	13	3	30	22	4	30	8.8%	-9.00 [-10.79, -7.21]
Total (95% CI)			**1077**			**1008**	**100.0%**	**-4.71 [-6.43, -3.00]**

Heterogeneity: Tau² = 7.79; Chi² = 1038.40, df = 11 (P < 0.00001); I² = 99%
Test for overall effect: Z = 5.40 (P < 0.00001)

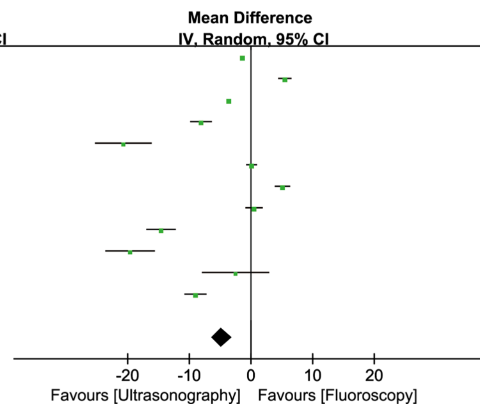


Fig. 3 Forest plot comparing success rate of access creation (**a**), success rate of first puncture (**b**), and time to puncture (**c**)

However, US guided PCNL is experience dependent and requires a certain amount of training. Yan Song indicated that the ultrasound screening time and operation time both dropped as the experience gradually increased, he concluded that the number for the competence with high stone-free rate and without major complication is 60 [31]. At present, not all the operators can perform this technique independently. In china, ultrasonography is a commonly used modality in many centers, and is familiar to most urologists. Many of them use ultrasonography guidance for all stages of PCNL without fluoroscopy, and operation time is usually shorter under ultrasonography guidance.

The choice for image guidance is mainly based on personal preference and experience. The fluoroscopy is familiar to most urologists and it is the most commonly used technique in many centers. The CROES PCNL data revealed that 86.3% of patients had fluoroscopic-guided access vs 13.7% with ultrasonography guidance [32]. One factor that limits the wide use of ultrasonography is the early learning curve. It is hard for the beginners. For example, they may misjudge the actual position of the needle tip with ultrasonography guidance, easily causing a deeper puncture than expected. Another problem of the ultrasonography is poor imaging of the renal anatomy in obese

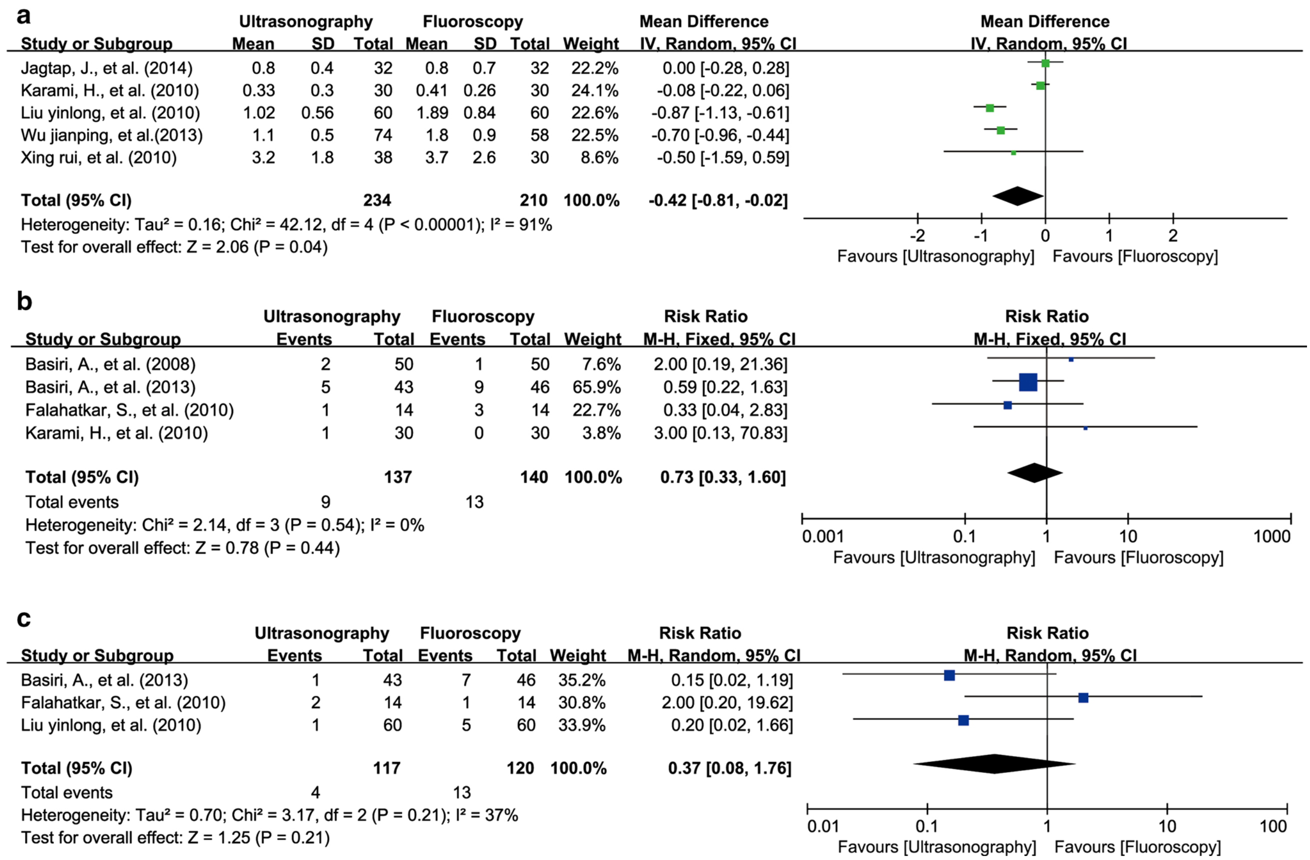


Fig. 4 Forest plot comparing hemoglobin decrease (**a**), hemoglobin decrease (**b**), and fever (**c**)

patients and in patients with nondilated collecting systems [33]. In this condition, a combined approach using ultrasound and fluoroscopy may be a good choice.

There are several limitations to our present study. First of all, most of the studies were nonrandomized comparisons. There were only six RCTs available for inclusion. In addition, heterogeneity among studies was high for several parameters. This heterogeneity could be due to difference in study design, medical settings and surgeon's experience.

Conclusion

In conclusion, current evidence from this meta-analysis indicated that both fluoroscopy and ultrasonography guidance can aid to obtain successful percutaneous renal access. In addition to radiation free, the advantages of ultrasonography over fluoroscopy include shorter puncture time, higher success rate of first puncture, less blood loss, and less complications.

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Conflict of interest The authors have declared that no conflict of interest exists.

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