Comparison of the stone-free rates of mini-percutaneous nephrolithotomy, standard percutaneous nephrolithotomy, and retrograde intrarenal surgery for renal stones: A systematic review and network meta-analysis

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Abstract

Background: Retrograde intrarenal surgery (RIRS) and percutaneous nephrolithotomy (PCNL) are performed to treat renal stones. PCNL is effective for kidney stones >2 cm but is invasive compared with RIRS. Miniature PCNL (mPCNL) has been used as an alternative treatment for conventional PCNL, and employs a miniature endoscope of 11–18 Fr. We conducted a systematic review of published studies regarding the RIRS, PCNL, and mPCNL treatment modalities, and performed a network meta-analysis of the success or stone-free rates.

Methods: The data collected up to January 2016 were searched using PubMed and EMBASE, and references were searched electronically. Two researchers used data extraction formats to extract data on the stone-free or success rates, study design, number of subjects and characteristics, and treatments for renal stones (i.e., RIRS, PCNL, and mPCNL). To evaluate the quality of the studies, the Downs and Black checklist, which is an observational research quality evaluation tool, was used and analyzed by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.

Results: Twenty-five studies were used to compare the stone-free or success rates of RIRS, PCNL, and mPCNL for renal stones. Six comparisons of PCNL and mPCNL, seven of mPCNL and RIRS, and 12 of RIRS and PCNL were analyzed. No difference in the stone-free rate was found between PCNL and mPCNL (OR: 0.95; 95% CI: 0.51–1.9) in network mata-analysis. Between RIRS and mPCNL, the stone-free rate of RIRS was lower than mPCNL (OR: 0.41; 95% CI: 0.021–0.82). Comparison of RIRS and PCNL revealed that RIRS was also lower than PCNL in terms of stone-free rate (OR: 0.43; 95% CI: 0.22–0.82). In the ranking analysis, rankogram showed that mPCNL was ranked as No. 1 and PCNL was ranked as No. 2. The P-score was 0.820 for mPCNL, 0.680 for PCNL and 0 for RIRS.

Conclusions: PCNL and mPCNL showed higher success or stone-free rates than RIRS for the treatment of renal stones. However, PCNL and mPCNL showed no difference in the treatment outcome.

Background

Mini-percutaneous nephrolithotomy (mPCNL) was developed for the treatment of pediatric patients with renal stones [1]. In 1997, Helal et al. performed mPCNL for the first time in a 2-year-old pediatric patient using a 15-Fr Hickman peel-away sheath [2]. The current definition of mPCNL implies PCNL performed using access sheaths with a diameter of 14–20 Fr [3]. mPCNL has advantages over standard PCNL in terms of blood loss, postoperative pain, and renal parenchymal damage, which are complications that occur due to the use of larger instruments in standard PCNL [4]. Despite these advantages, however, mPCNL is not considered a preferred technique [5, 6]. Additionally, the European Association of Urology (EAU) Urolithiasis Guidelines reports that mPCNL requires a longer operating time and states that additional studies should be conducted on the treatment outcomes [7].

The EAU guidelines recommend extracorporeal shock wave lithotripsy (ESWL) and retrograde intrarenal surgery (RIRS) as first-line treatments for kidney stones < 2 cm in diameter, and PCNL is recommended as the first-line treatment for stones > 2 cm [7]. In the case of a lower pole stone of 1–2 cm, endourologic procedures, including RIRS and PCNL, are recommended for patients with unfavorable factors for use of ESWL. Compared with PCNL and RIRS, ESWL is the only interventional treatment with non-invasive properties and plays a pivotal role in the treatment of urinary stones [8, 9]. Compared with PCNL and mPCNL, RIRS has the advantage of being less invasive due to the use of a natural orifice [10]. PCNL is a standard treatment for renal stones >2 cm and can be considered a treatment option for large stones with resistance to shock waves [11]. mPCNL shows reduced complications compared with PCNL when performed in selective patients [12]. Prospective studies and meta-analyses comparing the three surgical treatments (PCNL, mPCNL, and RIRS) and discussing their advantages and disadvantages have been reported, but no network meta-analysis has been conducted to simultaneously compare the three treatments. Network meta-analysis is a research method that can compare multiple treatments using direct and indirect comparisons [13–15]. We performed a systematic review and network meta-analysis comparing the success and stone-free rates of PCNL, mPCNL, and RIRS.

Methods

Inclusion Criteria

Publicly available RCTs were included according to the following criteria: (1) The study design evaluated 2 or 3 arms, including PCNL, mPCNL, and RIRS for the treatment of kidney stones. (2) Baseline data of the 2 or 3 groups of patients were matched, including the entire number of patients and the value of each index. (3) The results of each treatment were analyzed in stone-free (or success) rate. (4) Standard surgical indications of each treatment for kidney stones were applied. (5) Endpoint outcomes included complication rates. (6) Only English-language articles were allowed. This study has been performed based on the Preferred Reporting Item for System Review and Meta-Analysis (PRISMA) guidelines (S1 Table) [16].

Searches

All literature searches before January 1, 2017 were conducted at PubMed and EMBASE. In addition, cross-reference searches of available studies were carried out to recognize articles that were not searched during the computerized literature search. The progress of the relevant meeting was also retrieved. Percutaneous nephrolithotomy, nephrolithotomy, percutaneous, flexible ureteroscopy, flexible, ureterorenoscopy, retrograde intrarenal surgery, renal stone, urolithiasis, success rate, miniature, mini, and stone-free of Medical Subject Headings (MeSH) and keywords were applied.

Data Extraction and Quality Assessment

An author (JYL) screened all titles and abstracts found by the search strategy. 2 other authors (DHK and HDJ) independently analyzed the all details of each article to ensure that they met the inclusion criteria. If there is any inconsistency between the two researchers, it was resolved through discussion until consensus was reached, or via third party adjudication performed by another author (WSJ). Once the final article group was agreed, 2 authors independently

investigated the quality of each study in accordance with the Downs and Black checklist [17]. High scores were considered an indicator of a fine-quality research.

Heterogeneity Investigation

We derived the heterogeneity of the enrolled studies using the Q statistic and Higgins' I^2 statistic [18]. Higgins' I^2 represents the percentage of the variability in effect estimates that is due to heterogeneity rather than chance. Higgins' I^2 = 100% x (Q-df)/Q in which 'Q' is the Cochran's heterogeneity statistic, and 'df' is the degrees of freedom. An $I^2 \geq 50\%$ means that it exhibits substantial heterogeneity [19]. Heterogeneity of the Q statistic was considered significant if $p < .10$ [20]. If evidence of heterogeneity is determined, we analyzed the data using a random-effects model. We also created L 'Abbe plots and Galbraith's radial plots to assess heterogeneity [21, 22].

Statistical Analysis

We compared the outcome variables by odd ratios (ORs) and their 95% confidence intervals (CIs). The analysis was performed based on non-informative priors for effect sizes and precision. Convergence and lack of autocorrelation were identified after 4 chains and a 50,000 samples burn-in steps; At last, direct probability was derived from an additional 100,000 samples stage. We evaluated the probability of the lowest incidence of clinical events in each group using Bayesian Markov chain Monte Carlo methods. Sensitivity analysis was conducted by repeating the main calculation using fixed-effects models. We calculated and compared estimates for the deviation and deviation information criteria to assess model's goodness of fit. R (R Foundation for Statistical Computing, Vienna, Austria), version 3.3.2, was used for all statistical analyses and network plots were created by netmeta, pcnetmeta, and gemtc packages.

Results

Literature Search

A total of 259 studies were identified. After screening, 41 articles were assessed for eligibility. 16 of these studies were excluded for the following reasons: 3 articles did not have any data on stone-free rates, 10 articles were review articles, and 3 articles were case report series. Finally, the remaining 25 studies were included in the meta-analysis. (Fig. 1).

Table 1 summarized the data derived from each study. 8 studies compared PCNL versus mPCNL treatments [5, 23–29]. 10 studies compared PCNL versus RIRS treatments [30–39]. 7 studies compared mPCNL versus RIRS treatments [40–46] (Fig. 2). We summarized the detailed data including stone-free rates of the enrolled studies for this meta-analysis in Table 1.

Table 1
Enrolled studies for this meta-analysis

Category	Study	Year	Design	Methods	Inclusion criteria	No. of points	Follow-up	Definition of stone free	No. of stone-free patients	Stone-free rate	Quality assessment
PCNL vs. mPCNL	Giusti et al [5].	2006	Retrospective	PCNL	Renal stone < 2 cm	67	1 month	Not stated	63	94.0	13
				mPCNL		40			31	77.5	
	Cheng et al [23].	2010	RCT	PCNL	Renal stone	115	1 week	< 4 mm	92	80.0	14
				mPCNL		72			61	84.7	
	Knoll et al [24].	2010	Prospective, case control	PCNL	Solitary calculi (lower pole or pelvis)	25	1 day	Not stated	23	92.0	13
				mPCNL		25			24	96.0	
	Li et al [25].	2010	Prospective, case control	PCNL	Renal stone	72	Not stated	Not stated	63	87.5	13
				mPCNL		93			78	83.9	
	Mishra et al [26].	2011	Prospective, case control	PCNL	Renal stone 1 to 2 cm	26	1 month	Radiologic absence of stone	26	100.0	14
				mPCNL		26			25	96.2	
	Song et al [27].	2011	RCT	PCNL	Renal stone ≥ 2 cm	30	3–5 days	Not stated	22	73.3	17
				mPCNL		30			27	90.0	
	Zhong et al [28].	2011	RCT	PCNL	Staghorn calculi	25	1 day	Radiologic absence of stone	14	56.0	18
				mPCNL		29			24	82.8	
	Xu et al [29].	2014	Prospective, case control	PCNL	Renal stone	34	Not stated	Not stated	27	79.4	17
				mPCNL		37			29	78.4	
mPCNL vs. RIRS	Resorlu et al [40].	2012	Retrospective	mPCNL	1- to 3-cm, renal stone, children	106	1 month	Not stated	100	94.3	14
				RIRS		95			88	92.6	
	Kirac et al [41].	2013	Retrospective	mPCNL	< 1.5-cm, lower pole renal stone	37	3 months	No fragments	33	89.2	14
				RIRS		36			32	88.9	
	Pan et al [42].	2013	Retrospective	mPCNL	2- to 3-cm, solitary renal calculi	59	1 month	< 2 mm	57	96.6	15
				RIRS		56			40	71.4	
	Sabnis et al [43].	2013	Prospective, case control	mPCNL	1- to 2-cm renal stone	32	1 month	No fragments	32	100.0	14
				RIRS		32			31	96.9	
	Kumar et al [44].	2015	RCT	mPCNL	Lower calyceal radiolucent, 1 to 2 cm	41	3 months	Not stated	39	95.1	17
				RIRS		43			37	86.0	
	Lee et al [45].	2015	RCT	mPCNL	> 1-cm renal stone	35	3 months	< 2 mm	30	85.7	19
				RIRS		33			32	97.0	
	Zeng et al [46].	2015	Retrospective	mPCNL	> 2 cm, solitary renal stone	53	3 weeks	< 4 mm	38	71.7	14
				RIRS		53			23	43.4	
PCNL vs. RIRS	Hyams et al [30].	2009	Retrospective	PCNL	2- to 3-cm renal stone	20	3 months	< 4 mm	20	100.0	13
				RIRS		19			18	94.7	
	Akman et al [31].	2011	Retrospective	PCNL	2- to 4-cm renal stone	34	3 months	Not stated	33	97.1	14
				RIRS		34			32	94.1	
	Bozkurt et al [32].	2011	Retrospective	PCNL	1.5- to 2-cm renal stone	42	After two procedures	Not stated	41	97.6	13
				RIRS		37			35	94.6	

PCNL, percutaneous nephrolithotomy; mPCNL, miniature percutaneous nephrolithotomy; RIRS, retrograde intrarenal surgery.

Category	Study	Year	Design	Methods	Inclusion criteria	No. of points	Follow-up	Definition of stone free	No. of stone-free patients	Stone-free rate	Quality assessment
	Aboutaleb et al [33].	2012	Retrospective	PCNL	1- to 2-cm lower caliceal stone	19	2 days	< 3 mm	17	89.5	15
				RIRS		13			11	84.6	
	Bryniarski et al [34].	2012	RCT	PCNL	Renal pelvis stone ≥ 2 cm	32	3 weeks	Not stated	30	93.8	14
				RIRS		32			24	75.0	
	Ozturk et al [35].	2013	Retrospective	PCNL	1- to 2-cm lower renal stone	144	Not stated	< 3 mm	135	93.8	16
				RIRS		38			28	73.7	
	Resorlu et al [36].	2013	Retrospective	PCNL	1- to 2-cm radiolucent renal calculi	140	After one procedure	Not stated	128	91.4	17
				RIRS		46			40	87.0	
	Bas et al [37].	2014	Retrospective	PCNL	1- to 2-cm renal pelvis stone	50	1 month	Not stated	49	98.0	17
				RIRS		47			43	91.5	
	Jung et al [38].	2015	Retrospective	PCNL	15- to 30-mm lower pole stone	44	1 month	< 3 mm	37	84.1	16
				RIRS		44			41	93.2	
	Karakoyunlu et al [39].	2015	RCT	PCNL	Renal pelvis stone > 2 cm	30	Final procedures	Complete removal	26	86.7	17
				RIRS		30			20	66.7	

PCNL, percutaneous nephrolithotomy; mPCNL, miniature percutaneous nephrolithotomy; RIRS, retrograde intrarenal surgery.

Table 2

Subgroup network meta-analysis for the length of stay and operation time (OR and 95% credible interval).

Length of stay		mPCNL	PCNL	RIRS
	mPCNL		-1.668 (-2.311 – -1.320)	-0.413 (-1.188 – 0.386)
	PCNL	1.668 (1.3200 – 2.3110)		1.281 (0.812 – 1.930)
	RIRS	0.413 (-0.386 – 1.188)	-1.281 (-1.930 – -0.812)	
Operation time		mPCNL	PCNL	RIRS
	mPCNL		11.360 (7.455 – 14.290)	3.519 (2.175 – 5.442)
	PCNL	-11.360 (-14.290 – -7.455)		-7.224 (-11.320 – -4.382)
	RIRS	-3.519 (-5.442 – -2.175)	7.224 (4.382 – 11.320)	

PCNL, percutaneous nephrolithotomy; mPCNL, miniature percutaneous nephrolithotomy; RIRS, retrograde intrarenal surgery.

Quality, Heterogeneity and Inconsistency

The mean of the quality scores was 15.12 (Table 1). Briefly, the result of quality assessment shows the quality scores within subscales were relatively low-moderate. In particular, the external validity was not satisfactory for both significant and non-significant groups in most studies.

Figures 3–5 show forest plots of the pairwise meta-analyses of mPCNL, PCNL, and RIRS. There was no evidence of heterogeneity between PCNL and RIRS (Fig. 3); however, heterogeneity was demonstrated between mPCNL and PCNL (I^2 = 51.0%, p = .05; Fig. 4), and between mPCNL and RIRS (I^2 = 50.9%, p = .06; Fig. 5). Thus, the random-effects model was applied using the Mantel–Haenszel method to compare mPCNL with PCNL (Fig. 4) and mPCNL with RIRS (Fig. 5). After applying the effect model, very little heterogeneity was observed in L'Abbe (Fig. 6) and radial plots (Fig. 7). Node split analysis has not demonstrated inconsistencies in direct, indirect and network comparisons (Fig. 8).

Risk of Bias Assessment Results

The Begg-Mazumdar rank correlation tests revealed no evidence of publication bias between PCNL and RIRS (p = .79), between PCNL and mPCNL (p = .81), or between mPCNL and RIRS (p = .45). Egger regression tests also did not show any publication bias between PCNL and RIRS (p = .87), between PCNL and mPCNL (p = .99), or between mPCNL and RIRS (p = .56). In addition, little publication bias was detected in the funnel plots for each comparison (Fig. 9).

Pairwise Meta-analysis of the Stone-free Rate

The stone-free rate of PCNL was significantly higher compared with RIRS (OR: 2.31; 95% CI: 1.45–3.67; $p < .001$) (Fig. 3). Between PCNL and mPCNL, there was no significant difference in the stone-free rate (OR: 0.89; 95% CI: 0.46–1.71; $p = .73$) (Fig. 4). Comparison of mPCNL and RIRS revealed that the stone-free rate of mPCNL was not significantly higher than RIRS (OR: 2.12; 95% CI: 0.95–4.72; $p = .07$) (Fig. 5).

Network Meta-analysis of the Stone-free Rate

No difference in the stone-free rate was found between PCNL and mPCNL (OR: 0.95; 95% CI: 0.51–1.9) in network mata-analysis. Between RIRS and mPCNL, the stone-free rate of RIRS was lower than mPCNL (OR: 0.41; 95% CI: 0.021–0.82). Comparison of RIRS and PCNL revealed that RIRS was also lower than PCNL in terms of stone-free rate (OR: 0.43; 95% CI: 0.22–0.82) (Fig. 8). In the ranking analysis, mPCNL was ranked first and RIRS was ranked third (Fig. 10). The P-score test showed that mPCNL (P-score: 0.820) was better than PCNL (P-score: 0.680) and RIRS (P-score: 0) in terms of the stone-free rate [47].

Network Meta-analysis of the Length of Stay (LOS) and Operation Time

13 studies had data regarding LOS for two treatments. 5 studies compared PCNL and mPCNL, 7 studies compared PCNL and RIRS, and one study compared RIRS and mPCNL. In network meta-analysis, the LOS of mPCNL [mean difference (MD): -1.668; 95% CI: -2.311 to -1.320] and RIRS (MD: -1.281; 95% CI: -1.930 to -0.812) were shorter than that of PCNL. There was no difference between mPCNL and RIRS in LOS (MD: -0.413; 95% CI: -1.188 to 0.386). To compare operation times, 21 studies were enrolled. The operation time of PCNL was shorter than that of mPCNL (MD: -11.360; 95% CI: -14.290 to -7.455) and RIRS (MD: -7.224; 95% CI: -11.320 to -4.382). The operation time of RIRS was also shorter than that of mPCNL (MD: -3.519; 95% CI: -5.442 to -2.175).

Complication Rate (Clavien-Dindo Classification)

The complication rates in mPCNL, PCNL, and RIRS were 19.0%, 22.7%, and 17.4%, respectively from 23 studies data. The rates of major complications among the total complication cases were 12.5% in mPCNL, 7.4% in PCNL, and 14.4% in RIRS; however, there was no significant difference ($p = .13$) (Table 3).

Table 3
Complication rate from studies according to Clavien-Dindo classification

Methods		**Complication**					
		Total		**Clavien Grade I-II (Minor)**		**Clavien Grade III-IV (Major)**	
No. of patients		N	%	N	%	N	%
mPCNL	675	128	19.0	112	87.5	16	12.5
PCNL	830	188	22.7	174	92.6	14	7.4
RIRS	637	111	17.4	95	85.6	16	14.4

Discussion

Renal stones are one of the most common urological diseases and are characterized by high recurrence rates [48]. In the case of asymptomatic, tiny renal stones, observation can be performed without any treatment. However, if the stone causes obstruction or infection, is associated with symptoms such as pain or hematuria, or has a high possibility of size increase, treatment is recommended. Interventional treatment for renal stones may be considered if the size is greater than 1.5 cm or if removal of the stone is necessary because of the patient's social situation. The EAU guideline recommends ESWL and RIRS as first-line treatments for kidney stones < 2 cm in diameter and PCNL as the first-line treatment for stones > 2 cm [7]. As surgical procedures, PCNL and RIRS have an anesthetic burden and their invasiveness is a disadvantage, but the stone-free rates of PCNL and RIRS are higher than those of ESWL [49]. The development of surgical techniques and instruments continues to play a major role in the popularization of PCNL and RIRS [48, 50]. mPCNL is defined as PCNL performed using Amplantz sheaths with a diameter of 14–20 Fr [3, 51]. mPCNL has the advantage of reducing complications that may arise from larger instruments and sheaths [4].

The evaluation of perioperative and postoperative outcomes in the surgical treatment of renal stones is very important. The stone-free rate, operative time, and complications may be appropriate indicators for the perioperative and postoperative outcomes. Among these indicators, the stone-free rate can be one of the most important outcomes to avoid the need for auxiliary treatment as well as complications related to residual fragments. The stone-free rate is mainly correlated with the stone burden; however, most importantly, differences have been reported between different procedures [52]. The stone-free rate is the most important parameter to estimate the efficacy of all the approaches [53]. According to previous reports, PCNL and mPCNL have a higher stone-free rate than RIRS, although various imaging modalities were used.

In 2017, Kang et al. reported a systematic review and meta-analysis, in which updated evidence of stone-free rates of RIRS and PCNL in > 2-cm renal stones were compared with a previous report [54]. In their meta-analysis comparing the success (stone-free) rates between PCNL and RIRS, the forest plot using the random-effects model showed a risk ratio of 1.11 (95% CI: 1.02–1.21; $p = .01$) favoring PCNL. In 2014, Zheng et al. reported no difference between RIRS and PCNL in > 2-cm renal stones using meta-analysis [55]. Kang et al. concluded that their meta-analysis was performed using three additional articles compared with Zheng et al., and all three additional studies reported stone-free rates with RIRS that were relatively lower than those seen with PCNL [54]. Zhang et al. examined the efficacy and safety of RIRS, PCNL, and SWL in the management of lower pole renal stones [56]. They concluded that PCNL is associated with

the highest stone-free rate at the expense of the longest hospital stay. In 2015, Zhu et al. performed meta-analysis of the stone-free rate between mPCNL and PCNL [57]. They concluded that mPCNL was a safe and effective procedure with a stone-free rate comparable to that of PCNL. In addition, they found that mPCNL resulted in less bleeding, fewer transfusions, less pain, and shorter hospitalization. Another recent systematic review demonstrated that smaller tracts used in mPCNL tended to be associated with significantly lower blood loss or the need for blood transfusion, at the cost of a significantly longer procedure than standard PCNL [58]. The results of our study support these previous study findings. In network meta-analysis of the LOS, mPCNL and RIRS were superior to PCNL. However, regarding the stone-free rate, mPCNL and PCNL were superior to RIRS, and there was no difference between mPCNL and PCNL (OR: 0.95; 95% CI: 0.51–1.9).

mPCNL could be developed because of the popularization of dilating instruments, including the recently released miniature nephroscope and irrigation system. In 1998, Jackman et al. used a 6.9-Fr rigid ureteroscope, a 7.2-Flexible ureteroscope, and a 7.7-Fr rigid offset pediatric cystoscope [59]. MIP-M by Nagele et al. (Karl Storz GmbH & Co. KG, Tuttlingen, Germany) and Miniperc by Lahme et al. (Richard Wolff, Knittlingen, Germany) are miniature nephroscope instruments with a typical single-step dilating system [6, 50]. In addition, mPCNL often offers even higher stone-free rates than conventional PCNL perhaps because of the vacuum-cleaner effect [60].

The American Urological Association and EAU have not yet presented specific recommendations for the use of mPCNL to treat renal stones. However, previous reported evidence shows that mPCNL can achieve similar outcomes as standard PCNL in the treatment of renal stones > 2 cm [23]. RIRS, which uses a flexible ureteroscope through a natural orifice, can be a competitor of mPCNL for treatment of renal stones, not Staghorn stones [58]. However, it is clear the stone-free rate of mPCNL is superior to that of RIRS and that stones can be removed easily through the vacuum-cleaner effect. However, the long operation time of mPCNL can be a major disadvantage. In our network meta-analysis, the operation time of mPCNL was longer than that of PCNL and RIRS. No significant difference was seen between the complication rates of these three surgeries; however, the total number of complications of PCNL was higher than that of mPCNL and RIRS. Finally, a well-designed prospective study is needed to better understand the use of mPCNL, and to explore its potential to replace PCNL.

Conclusions

PCNL and mPCNL showed the highest success or stone-free rate in the surgical treatment of renal stones. RIRS has the lowest success or stone-free rate and the lowest rank. Patient selection should be performed based on the complexity of individual patients, and a well-designed prospective study is needed to better understand the use of mPCNL.

Abbreviations

CIs:confidence intervals; EAU:European Association of Urology; ESWL:extracorporeal shock wave lithotripsy; MeSH:Medical Subject Headings; mPCNL:Mini-PCNL; OR:odds ratios; PCNL:percutaneous nephrolithotomy; PRISMA:Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RIRS:retrograde intrarenal surgery

Declarations

Acknowledgments

Not applicable.

Authors' contributions

Study concept and design: JYL; Literature research: DHK, HDJ, WSJ and JYL; Data acquisition: DHK, HDJ, WSJ and JYL; Data analysis: DHK and JYL; Statistical analysis: DHK, DYC, DKK and JYL; Manuscript preparation: DHK; Manuscript editing: DYC, WSJ, HDJ and DKK; Manuscript review: KSC and JYL. All authors have approved the manuscript and agree with its submission.

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Availability of data and materials

All relevant data are within the manuscript and its Supporting Information files.

Ethics approval and consent to participate

The study was exempt from requiring the participants' written informed consent because this is systematic review and network meta-analysis. The approval of the Institutional Review Board was also exempted.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

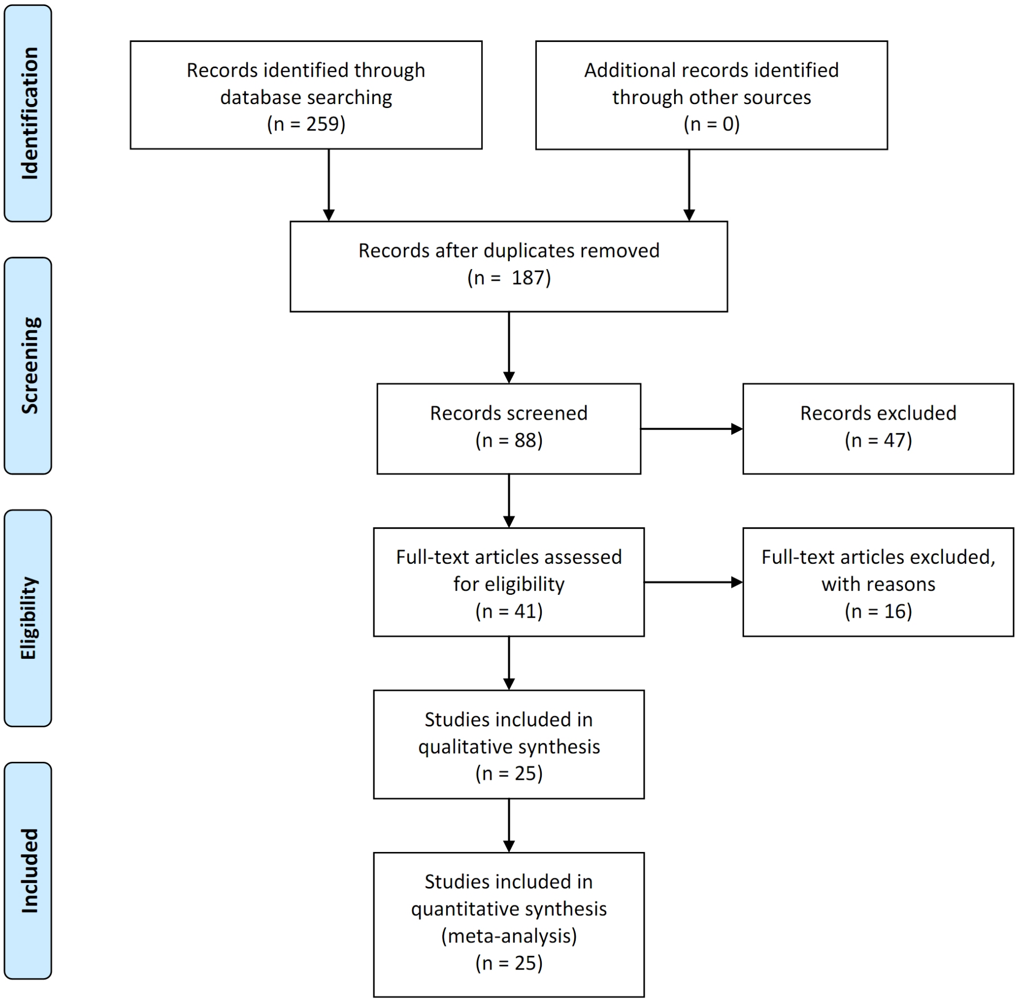

Figure 1

Flow diagram of evidence acquisition. Thirteen studies were ultimately included in the qualitative and quantitative synthesis that used pairwise and network meta-analyses.

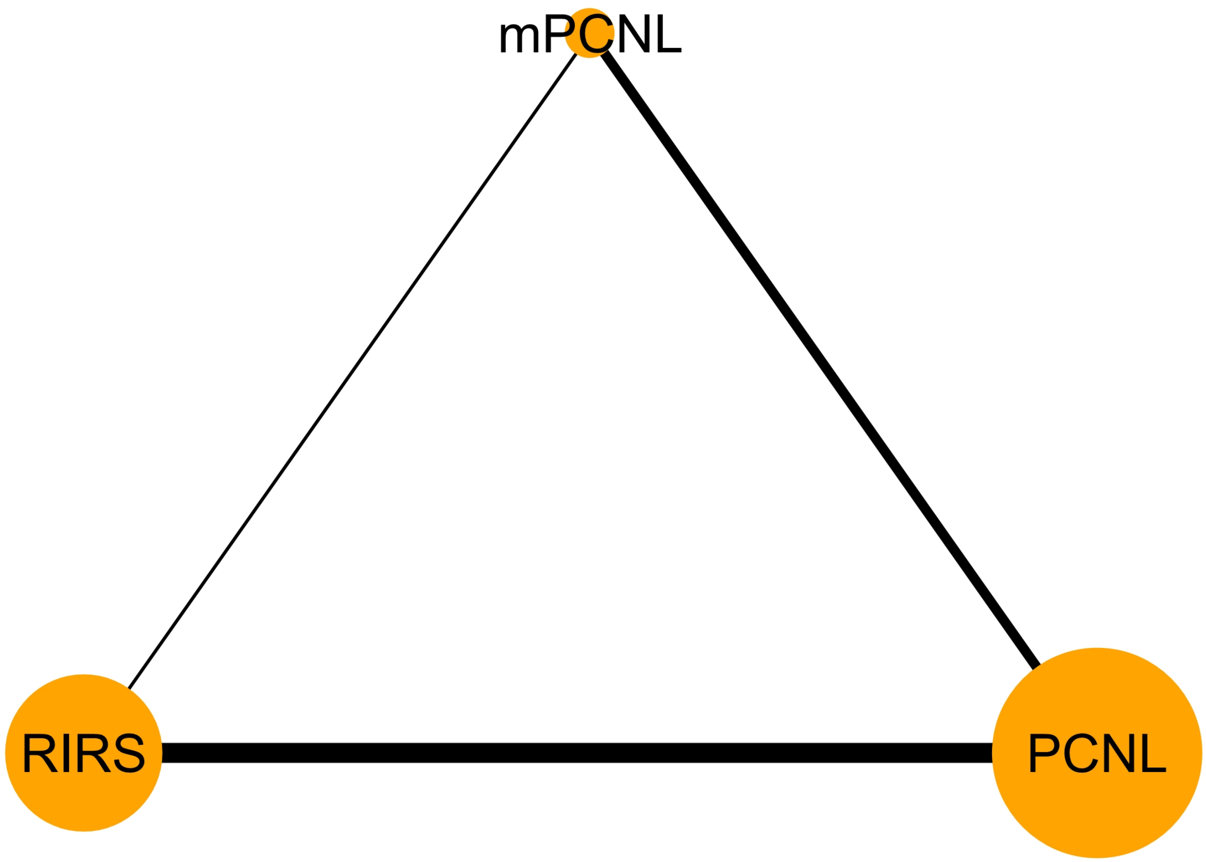

Figure 2

Network plots for the included studies. Eight studies compared PCNL versus mPCNL treatments. Seven trials reported the outcomes between mPCNL and RIRS. Ten studies compared the outcomes between PCNL and RIRS.

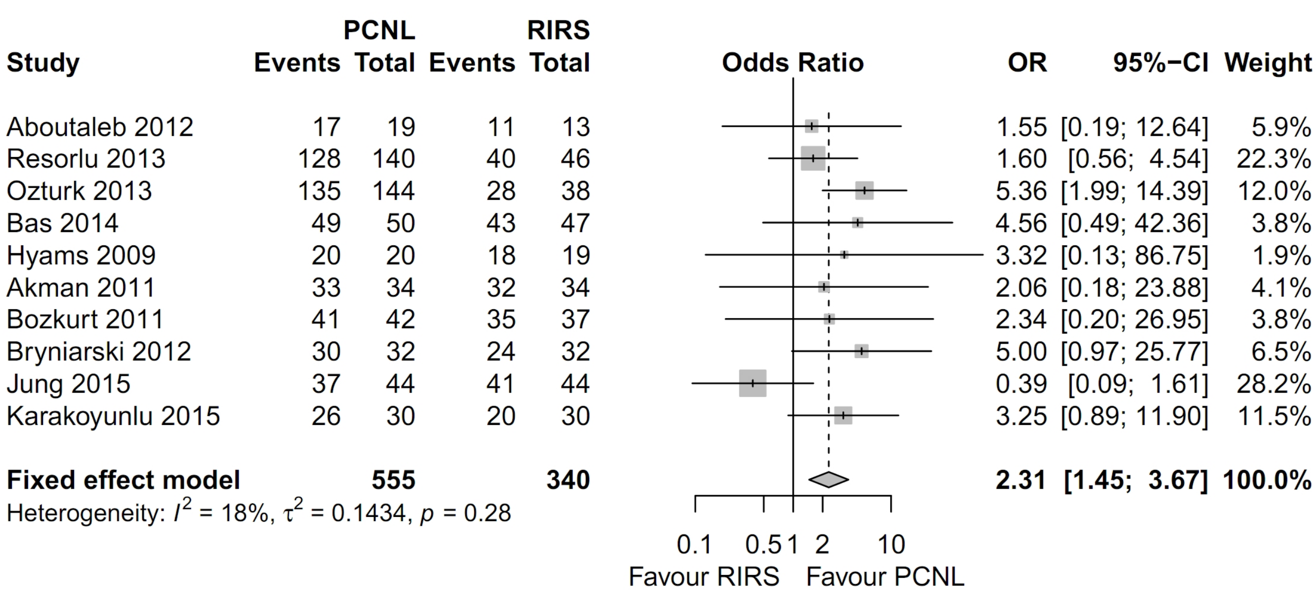

Figure 3

Pairwise meta-analysis of the success rate in PCNL and RIRS. Pooled data showed a significantly higher stone-free rate with PCNL compared with RIRS (OR: 2.31; 95% CI: 1.45–3.67; p < .001).

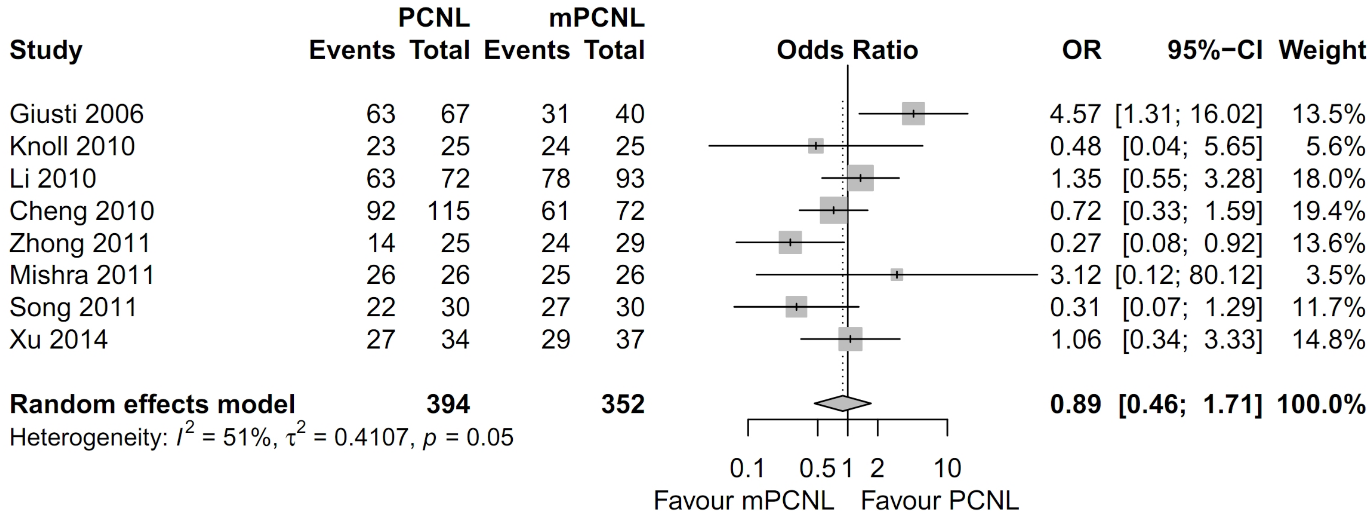

Figure 4

Pairwise meta-analysis of the success rate in PCNL and mPCNL. In PCNL and mPCNL, there was no difference in the stone-free rate (OR: 0.89; 95% CI: 0.46–1.71; p = .73).

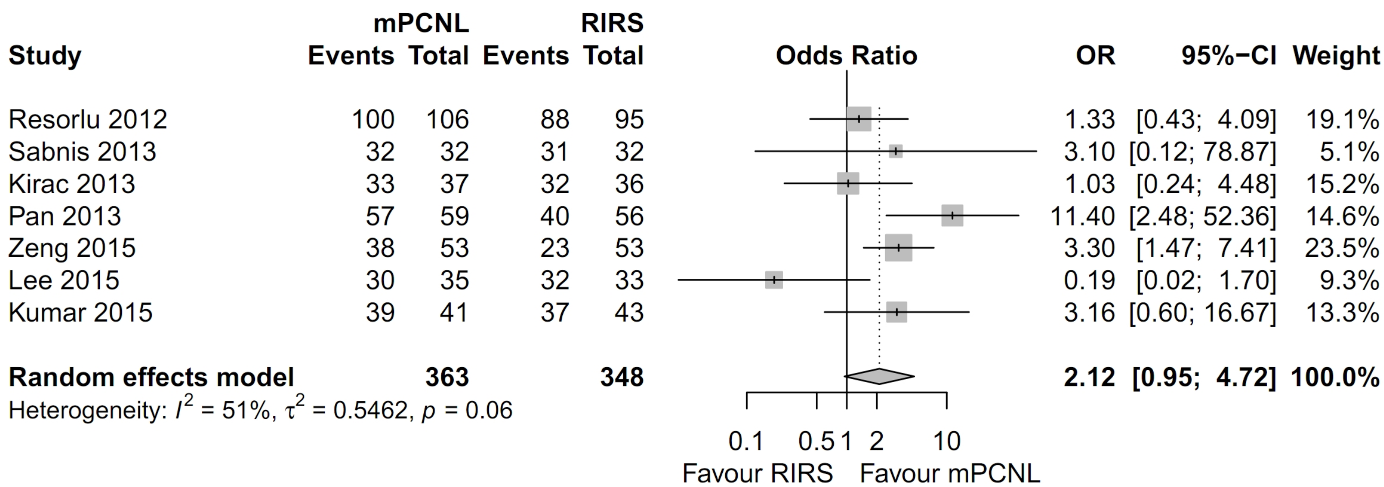

Figure 5

Pairwise meta-analysis of the success rate in mPCNL and RIRS. Comparison of mPCNL and RIRS revealed that the stone-free rate of mPCNL was not higher than that of RIRS (OR: 0.95; 95% CI: 0.95–4.72; p = .07).

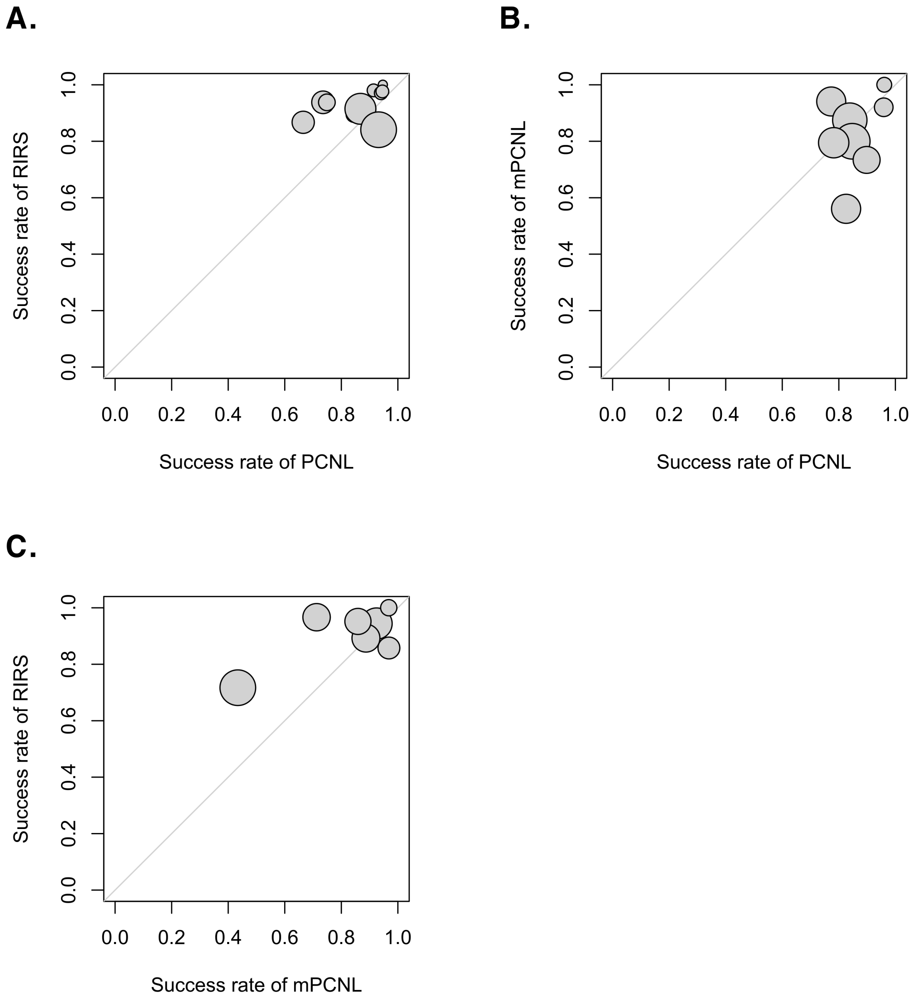

Figure 6

L'Abbe plots of the success rate between RIRS and PCNL (A), mPCNL and PCNL (B), and RIRS and mPCNL (C)

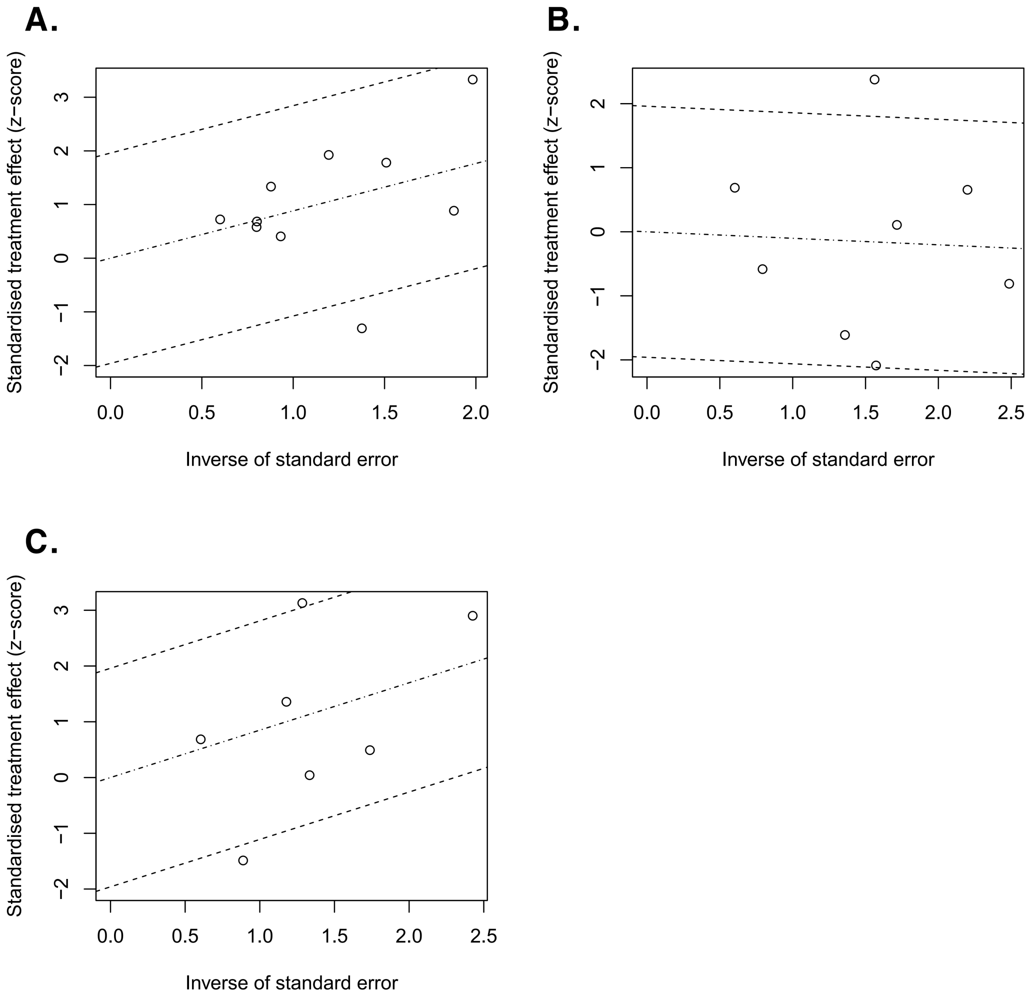

Figure 7

Radical plots of the success rate between RIRS and PCNL (A), mPCNL and PCNL (B), and RIRS and mPCNL (C).

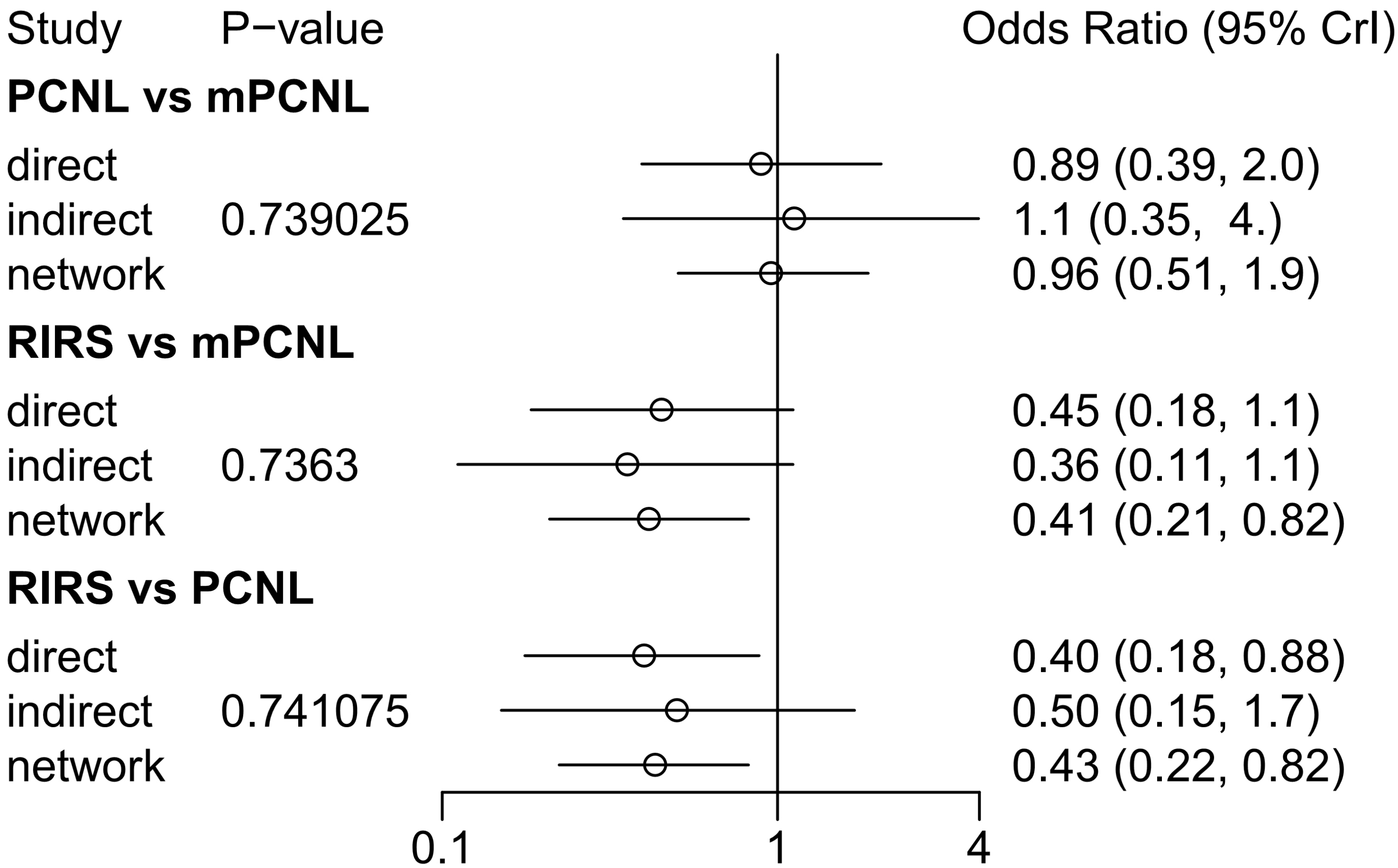

Figure 8

Network meta-analysis of the success rate of mPCNL, PCNL, and RIRS and node-splitting analyses of inconsistency.

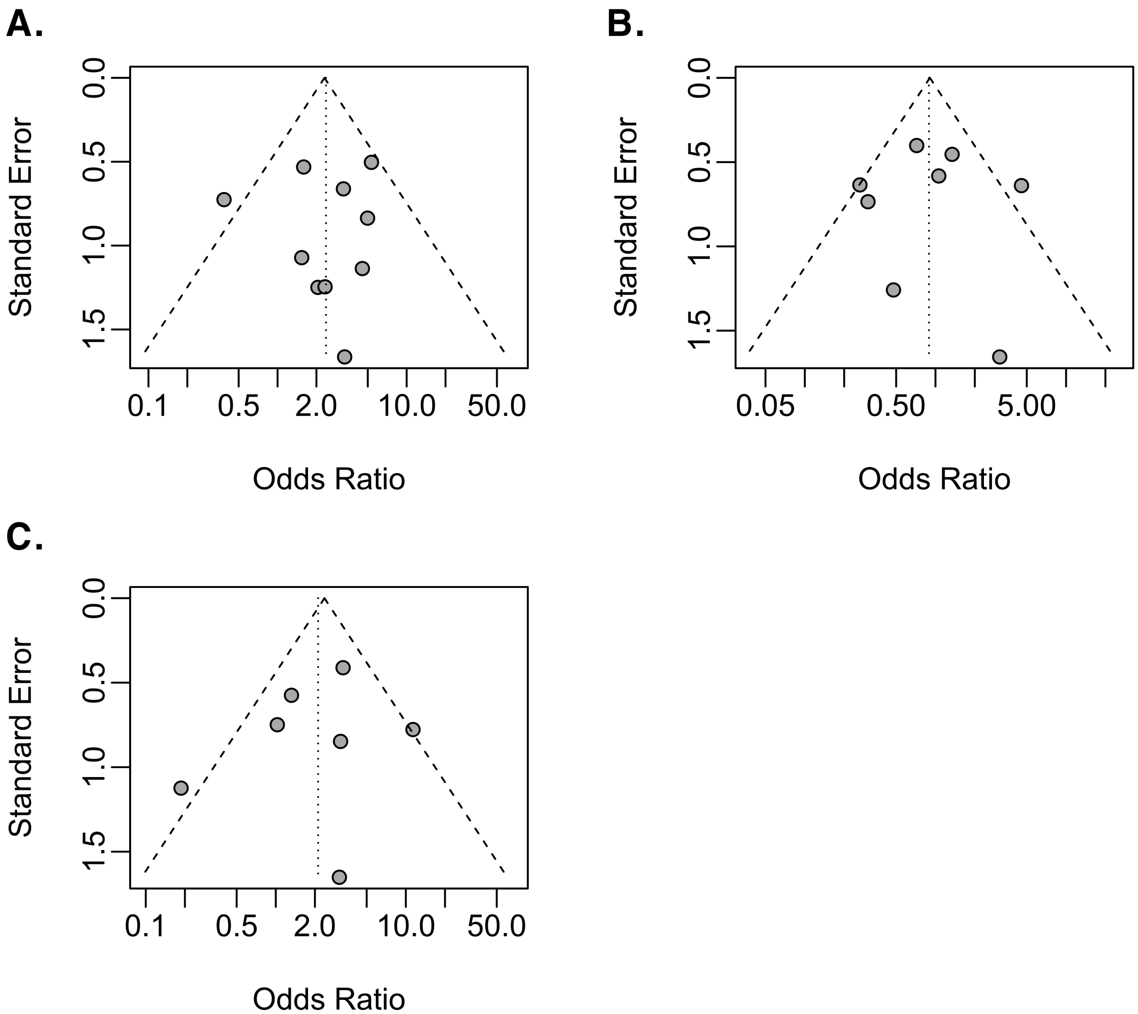

Figure 9

Funnel plots of the success rate between RIRS and PCNL (A), mPCNL and PCNL (B), and RIRS and mPCNL (C).

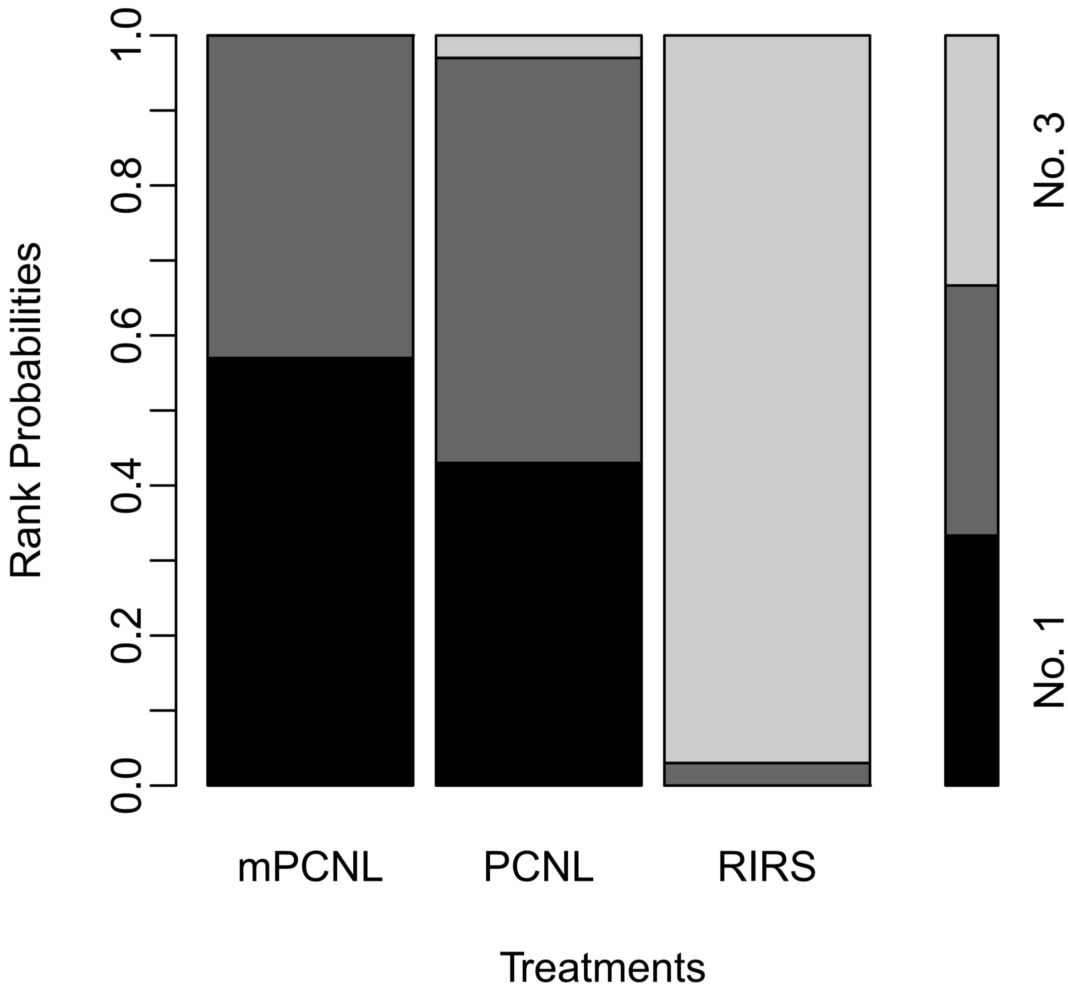

Figure 10

Rank-probability test of network meta-analyses. In the rank-probability test, mPCNL was ranked as No. 1 and RIRS was ranked as No. 3.

Supplementary Files

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