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

CURRENT STATUS: UNDER REVIEW

Dong Hyuk Kang
Inha University School of Medicine

Kang Su Cho
Yonsei University College of Medicine

Doo Yong Chung
Inha University School of Medicine

Won Sik Jeong
Kwangju Christian Hospital

Hae Do Jung
Wonkwang University College of Medicine

Do Kyung Kim
Soonchunhyang University College of Medicine

Joo Yong Lee
Yonsei University College of Medicine

Corresponding Author
joouro@yuhs.ac
ORCiD: 0000-0002-3470-1767

DOI:
10.21203/rs.3.rs-16120/v1

SUBJECT AREAS
Urology & Nephrology

KEYWORDS
Ureteroscopy; Nephrostomy, Percutaneous; Meta-Analysis
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 meta-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’ $I^2 = 100\% \times (Q-df)/Q$ 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.

| 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 mPCNL | Renal stone < 2 cm | 67             | 1 month | Not stated | 63 | 94.0 | 13 |
|              | Cheng et al [23]. | 2010 | RCT       | PCNL mPCNL | Renal stone < 4 mm | 115           | 1 week | Not stated | 92 | 80.0 | 14 |
|              |            |      |           |         |                |              |          |              | 61 | 84.7 |              |
| Study          | Year | Design | Intervention 1  | Intervention 2  | Stone Size | Procedure 1  | Procedure 2  | Follow-up 1  | Follow-up 2  | Success Rate 1 | Success Rate 2 | Difference |
|----------------|------|--------|-----------------|-----------------|------------|---------------|---------------|--------------|--------------|----------------|----------------|------------|
| Knoll et al [24]. | 2010 | RCT    | mPCNL          | RIRS            | 1- to 3-cm | Solitary      | Solitary      | 1 week       | 1 week       | 94.3           | 92.6           | 1.7        |
| Li et al [25].   | 2010 | RCT    | PCNL mPCNL     | Renal stone     | 1- to 2-cm | Renal stone   | Renal stone   | 3 months     | 3 months     | 90.0           | 87.5           | 2.5        |
| Mishra et al [26]. | 2011 | RCT    | PCNL mPCNL     | Renal stone     | 1- to 2-cm | Renal stone   | Renal stone   | 3 months     | 3 months     | 73.3           | 70.0           | 3.3        |
| Song et al [27]. | 2011 | RCT    | PCNL mPCNL     | Renal stone     | 1- to 2-cm | Renal stone   | Renal stone   | 1 day        | 1 day        | 96.2           | 93.8           | 2.4        |
| Zhong et al [28]. | 2011 | RCT    | PCNL RIRS      | Staghorn calculi | 1- to 2-cm | Renal stone   | Renal stone   | 2 months     | 2 months     | 97.6           | 94.3           | 3.3        |
| Xu et al [29].   | 2014 | RCT    | PCNL mPCNL     | Renal stone     | 1- to 3-cm | Renal stone   | Renal stone   | 3 months     | 3 months     | 88.9           | 86.0           | 2.9        |
| Hyams et al [30]. | 2009 | RCT    | PCNL RIRS      | Lower calyceal radioluc, 1 to 2 cm | > 1-cm | Renal stone   | Renal stone   | 3 months     | 3 months     | 97.6           | 94.3           | 3.3        |
| Akman et al [31]. | 2011 | RCT    | PCNL RIRS      | 2- to 3-cm      | Renal stone   | Renal stone   | Renal stone   | 3 months     | 3 months     | 97.1           | 94.1           | 3.0        |
| Bozkurt et al [32]. | 2011 | RCT    | PCNL RIRS      | 1.5- to 2-cm    | Renal stone   | Renal stone   | Renal stone   | 2 months     | 2 months     | 97.6           | 94.3           | 3.3        |
| Aboutal et al [33]. | 2012 | RCT    | PCNL RIRS      | 1- to 2-cm      | Renal stone   | Renal stone   | Renal stone   | 3 weeks      | 3 weeks      | 93.8           | 90.0           | 3.8        |
| Bryniars et al [34]. | 2012 | RCT    | PCNL RIRS      | Renal pelvis     | 1- to 3-cm    | Renal stone   | Renal stone   | 3 months     | 3 months     | 93.8           | 90.0           | 3.8        |
| Study          | Year  | Type           | PCNL | mPCNL | RIRS | Length of stay | Operation time | OR     | 95% CI          |
|---------------|-------|----------------|------|-------|------|----------------|----------------|--------|----------------|
| Ozturk et al  | 2013  | Retrospective  | PCNL | 1-2   | RIRS | <3 mm          | Not stated     | 135    | 93.8           |
|               |       |                | 1-2  | cm    |      |                | 38              | 28     | 73.7           |
| Resorlu et al | 2013  | Retrospective  | PCNL | 1-2   | RIRS | <3 mm          | Not stated     | 128    | 91.4           |
|               |       |                | 1-2  | cm    |      |                | 46              | 40     | 87.0           |
| Bas et al     | 2014  | Retrospective  | PCNL | 1-2   | RIRS | <3 mm          | Not stated     | 49     | 98.0           |
|               |       |                | 1-2  | cm    |      |                | 47              | 43     | 91.5           |
| Jung et al    | 2015  | Retrospective  | PCNL | 15-30 | RIRS | <3 mm          | Not stated     | 37     | 84.1           |
|               |       |                | 15-30| mm    |      |                | 44              | 41     | 93.2           |
| Karakoy et al | 2015  | RCT            | PCNL |       | RIRS | >2 cm          | Not stated     | 26     | 86.7           |
|               |       |                | 30   | cm    |      |                | 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 | OR (95% CI) | OR (95% CI) | OR (95% CI) |
|----------------|-------------|-------------|-------------|
| 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 | OR (95% CI) | OR (95% CI) | OR (95% CI) |
|----------------|-------------|-------------|-------------|
| 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) |          |

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 \((I^2 = 51.0\%, p = .05; \text{Fig. } 4)\), and between mPCNL and RIRS \((I^2 = 50.9\%, p = .06; \text{Fig. } 5)\). 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 \((\text{OR: } 2.31; 95\% \text{ CI: } 1.45-3.67; p < .001)\) (Fig. 3). Between PCNL and mPCNL, there was no significant difference in the stone-free rate \((\text{OR: } 0.89; 95\% \text{ CI: } 0.46-1.71; p = .73)\) (Fig. 4). Comparison of mPCNL and RIRS revealed that the stone-free rate of mPCNL was not significantly higher than RIRS \((\text{OR: } 2.12; 95\% \text{ CI: } 0.95-4.72; p = .07)\) (Fig. 5).

Network Meta-analysis of the Stone-free Rate

No difference in the stone-free rate was found between PCNL and mPCNL \((\text{OR: } 0.95; 95\% \text{ CI: } 0.51-1.9)\) in network meta-analysis. Between RIRS and mPCNL, the stone-free rate of RIRS was lower than mPCNL \((\text{OR: } 0.41; 95\% \text{ CI: } 0.021-0.82)\). Comparison of RIRS and PCNL revealed that RIRS was also lower than PCNL in terms of stone-free rate \((\text{OR: } 0.43; 95\% \text{ CI: }}\)
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).

| Methods | Complication | Clavien Grade I-II (Minor) | Clavien Grade III-IV (Major) |
|---------|--------------|----------------------------|-----------------------------|
|         | Total 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
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.

Funding

This study was supported by a faculty research grant from the Yonsei University College of Medicine for 2016 (6-2016-0119). The funders had no role in the study design, data collection, analysis, preparation of the manuscript, or decision to publish. Any opinions and findings expressed in this study are those of the authors alone, and do not necessarily reflect the views of funders.

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.

References

1. Hennessey DB, Kinnear NK, Troy A, Angus D, Bolton DM, Webb DR. Mini PCNL for renal calculi: does size matter? BJU Int. 2017;119 Suppl 5:39-46. Epub 2017/05/26. doi: 10.1111/bju.13839. PubMed PMID: 28544299.

2. Helal M, Black T, Lockhart J, Figueroa TE. The Hickman peel-away sheath: alternative for pediatric percutaneous nephrolithotomy. J Endourol. 1997;11(3):171-2. Epub 1997/06/01. doi: 10.1089/end.1997.11.171. PubMed PMID: 9181444.

3. Gadzhiev N, Sergei B, Grigoryev V, Okhunov Z, Ganpule A, Pisarev A, et al. Evaluation of the effect of Bernoulli maneuver on operative time during mini-percutaneous nephrolithotomy: A prospective randomized study. Investigative and clinical urology. 2017;58(3):179-85. Epub 2017/05/10. doi: 10.4111/icu.2017.58.3.179. PubMed PMID: 28480343; PubMed Central PMCID: PMCPmc5419106.

4. Sakr A, Salem E, Kamel M, Desoky E, Ragab A, Omran M, et al. Minimally invasive percutaneous nephrolithotomy vs standard PCNL for management of renal stones in the flank-free modified supine position: single-center experience. 2017. doi: 10.1007/s00240-017-0966-1. PubMed PMID: 28229197.

5. Giusti G, Piccinelli A, Taverna G, Benetti A, Pasini L, Corinti M, et al. Miniperc? No, thank you! Eur Urol. 2007;51(3):810-4; discussion 5. Epub 2006/08/30. doi: 10.1016/j.eururo.2006.07.047. PubMed PMID: 16938385.

6. Lahme S, Bichler KH, Strohmaier WL, Gotz T. Minimally invasive PCNL in patients with renal pelvic and calyceal stones. Eur Urol. 2001;40(6):619-24. Epub 2002/01/24. PubMed PMID: 11805407.

7. Turk C, Petrik A, Sarica K, Seitz C, Skolarikos A, Straub M, et al. EAU Guidelines on
1. Lawler AC, Ghiraldi EM, Tong C, Friedlander JL. Extracorporeal Shock Wave Therapy: Current Perspectives and Future Directions. Curr Urol Rep. 2017;18(4):25. Epub 2017/03/02. doi: 10.1007/s11934-017-0672-0. PubMed PMID: 28247327.

2. Kang HW, Cho KS, Ham WS, Kang DH, Jung HD, Kwon JK, et al. Predictive factors and treatment outcomes of Steinstrasse following shock wave lithotripsy for ureteral calculi: A Bayesian regression model analysis. Investig Clin Urol. 2018;59(2):112-8. Epub 2018/03/10. doi: 10.4111/icu.2018.59.2.112. PubMed PMID: 29520387; PubMed Central PMCID: PMCPMC5840115.

3. Han DH, Jeon SH. Stone-breaking and retrieval strategy during retrograde intrarenal surgery. Investigative and clinical urology. 2016;57(4):229-30. Epub 2016/07/21. doi: 10.4111/icu.2016.57.4.229. PubMed PMID: 27437531; PubMed Central PMCID: PMCPmc4949690.

4. Lee JY, Jeh SU, Kim MD, Kang DH, Kwon JK, Ham WS, et al. Intraoperative and postoperative feasibility and safety of total tubeless, tubeless, small-bore tube, and standard percutaneous nephrolithotomy: a systematic review and network meta-analysis of 16 randomized controlled trials. BMC urology. 2017;17(1):48. Epub 2017/06/29. doi: 10.1186/s12894-017-0239-x. PubMed PMID: 28655317; PubMed Central PMCID: PMCPmc5488341.

5. Lu Y, Ping JG, Zhao XJ, Hu LK, Pu JX. Randomized prospective trial of tubeless versus conventional minimally invasive percutaneous nephrolithotomy. World J Urol. 2012. Epub 2012/08/21. doi: 10.1007/s00345-012-0921-2. PubMed PMID: 22903789.

6. Caldwell DM, Ades AE, Higgins JP. Simultaneous comparison of multiple treatments: combining direct and indirect evidence. BMJ. 2005;331(7521):897-900. Epub 2005/10/15. doi: 10.1136/bmj.331.7521.897. PubMed PMID: 16223826; PubMed Central PMCID: PMC1255806.

7. Mills EJ, Thorlund K, Ioannidis JP. Demystifying trial networks and network meta-analysis. BMJ. 2013;346:f2914. Epub 2013/05/16. doi: 10.1136/bmj.f2914. PubMed PMID: 23674332.
5. Kang DH, Cho KS, Ham WS, Lee H, Kwon JK, Choi YD, et al. Comparison of High, Intermediate, and Low Frequency Shock Wave Lithotripsy for Urinary Tract Stone Disease: Systematic Review and Network Meta-Analysis. PLoS One. 2016;11(7):e0158661. doi: 10.1371/journal.pone.0158661. PubMed PMID: 27387279.

6. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):e1000097. Epub 2009/07/22. doi: 10.1371/journal.pmed.1000097. PubMed PMID: 19621072; PubMed Central PMCID: PMCPmc2707599.

7. Nomura K, Nakao M, Morimoto T. Effect of smoking on hearing loss: quality assessment and meta-analysis. Preventive medicine. 2005;40(2):138-44. Epub 2004/11/10. doi: 10.1016/j.ypmed.2004.05.011. PubMed PMID: 15533522.

8. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ. 2003;327(7414):557-60. Epub 2003/09/06. doi: 10.1136/bmj.327.7414.557. PubMed PMID: 12958120; PubMed Central PMCID: PMC192859.

9. Lee JY, Kang DH, Chung DY, Kwon JK, Lee H, Cho NH, et al. Meta-Analysis of the Relationship between CXCR4 Expression and Metastasis in Prostate Cancer. World J Mens Health. 2014;32(3):167-75. Epub 2015/01/22. doi: 10.5534/wjmh.2014.32.3.167. PubMed PMID: 25606566; PubMed Central PMCID: PMCPmc4298820.

10. Fleiss JL. Analysis of data from multiclinic trials. Control Clin Trials. 1986;7(4):267-75. Epub 1986/12/01. PubMed PMID: 3802849.

11. L'Abbe KA, Detsky AS, O'Rourke K. Meta-analysis in clinical research. Ann Intern Med. 1987;107(2):224-33. Epub 1987/08/01. PubMed PMID: 3300460.

12. Galbraith RF. A note on graphical presentation of estimated odds ratios from several clinical trials. Stat Med. 1988;7(8):889-94. Epub 1988/08/01. PubMed PMID: 3413368.

13. Cheng F, Yu W, Zhang X, Yang S, Xia Y, Ruan Y. Minimally invasive tract in percutaneous
nephrolithotomy for renal stones. J Endourol. 2010;24(10):1579-82. Epub 2010/09/16. doi: 10.1089/end.2009.0581. PubMed PMID: 20839954.

4. Knoll T, Wezel F, Michel MS, Honeck P, Wendt-Nordahl G. Do patients benefit from miniaturized tubeless percutaneous nephrolithotomy? A comparative prospective study. J Endourol. 2010;24(7):1075-9. Epub 2010/06/26. doi: 10.1089/end.2010.0111. PubMed PMID: 20575685.

5. Li LY, Gao X, Yang M, Li JF, Zhang HB, Xu WF, et al. Does a smaller tract in percutaneous nephrolithotomy contribute to less invasiveness? A prospective comparative study. Urology. 2010;75(1):56-61. Epub 2009/10/06. doi: 10.1016/j.urology.2009.06.006. PubMed PMID: 19800671.

6. Mishra S, Sharma R, Garg C, Kurien A, Sabnis R, Desai M. Prospective comparative study of miniperc and standard PNL for treatment of 1 to 2 cm size renal stone. BJU Int. 2011;108(6):896-9; discussion 9-900. Epub 2011/04/12. doi: 10.1111/j.1464-410X.2010.09936.x. PubMed PMID: 21477212.

7. Song L, Chen Z, Liu T, Zhong J, Qin W, Guo S, et al. The application of a patented system to minimally invasive percutaneous nephrolithotomy. J Endourol. 2011;25(8):1281-6. Epub 2011/07/13. doi: 10.1089/end.2011.0032. PubMed PMID: 21745116.

8. Zhong W, Zeng G, Wu W, Chen W, Wu K. Minimally invasive percutaneous nephrolithotomy with multiple mini tracts in a single session in treating staghorn calculi. Urol Res. 2011;39(2):117-22. Epub 2010/09/08. doi: 10.1007/s00240-010-0308-z. PubMed PMID: 20821200.

9. Xu S, Shi H, Zhu J, Wang Y, Cao Y, Li K, et al. A prospective comparative study of haemodynamic, electrolyte, and metabolic changes during percutaneous nephrolithotomy and minimally invasive percutaneous nephrolithotomy. World J Urol. 2014;32(5):1275-80. Epub 2013/11/02. doi: 10.1007/s00345-013-1204-2. PubMed PMID: 24177788.

10. Hyams ES, Shah O. Percutaneous nephrostolithotomy versus flexible ureteroscopy/holmium laser lithotripsy: cost and outcome analysis. J Urol. 2009;182(3):1012-7. Epub 2009/07/21. doi:
1. Akman T, Binbay M, Ozgor F, Ugurlu M, Tekinarslan E, Kezer C, et al. Comparison of percutaneous nephrolithotomy and retrograde flexible nephrolithotripsy for the management of 2-4 cm stones: a matched-pair analysis. BJU Int. 2012;109(9):1384-9. Epub 2011/11/19. doi: 10.1111/j.1464-410X.2011.10691.x [pii]. PubMed PMID: 22093679.

2. Bozkurt OF, Resorlu B, Yildiz Y, Can CE, Unsal A. Retrograde intrarenal surgery versus percutaneous nephrolithotomy in the management of lower-pole renal stones with a diameter of 15 to 20 mm. J Endourol. 2011;25(7):1131-5. Epub 2011/06/11. doi: 10.1089/end.2010.0737 [pii]. PubMed PMID: 21657824.

3. Aboutaleb H, El-Shazly M, Badr Eldin M. Lower pole midsize (1-2 cm) calyceal stones: outcome analysis of 56 cases. Urol Int. 2012;89(3):348-54. Epub 2012/08/28. doi: 000341557 [pii] 10.1159/000341557 [doi]. PubMed PMID: 22922771.

4. Bryniarski P, Paradysz A, Zyczkowski M, Kupilas A, Nowakowski K, Bogacki R. A randomized controlled study to analyze the safety and efficacy of percutaneous nephrolithotripsy and retrograde intrarenal surgery in the management of renal stones more than 2 cm in diameter. J Endourol. 2012;26(1):52-7. Epub 2011/10/19. doi: 10.1089/end.2011.0235 [doi]. PubMed PMID: 22003819.

5. Ozturk U, Sener NC, Goktug HN, Nalbant I, Gucuk A, Imamoglu MA. Comparison of percutaneous nephrolithotomy, shock wave lithotripsy, and retrograde intrarenal surgery for lower pole renal calculi 10-20 mm. Urol Int. 2013;91(3):345-9. Epub 2013/07/03. doi: 000351136 [pii] 10.1159/000351136 [doi]. PubMed PMID: 23816573.

6. Resorlu B, Unsal A, Ziypak T, Diri A, Atis G, Guven S, et al. Comparison of retrograde intrarenal surgery, shockwave lithotripsy, and percutaneous nephrolithotomy for treatment of medium-sized radiolucent renal stones. World J Urol. 2013;31(6):1581-6. Epub 2012/11/28. doi: 10.1007/s00345-012-0991-1 [doi]. PubMed PMID: 23179732.
7. Bas O, Bakirtas H, Sener NC, Ozturk U, Tuygun C, Goktug HN, et al. Comparison of shock wave lithotripsy, flexible ureterorenoscopy and percutaneous nephrolithotripsy on moderate size renal pelvis stones. Urolithiasis. 2014;42(2):115-20. Epub 2013/10/29. doi: 10.1007/s00240-013-0615-2 [doi]. PubMed PMID: 24162954.

8. Jung GH, Jung JH, Ahn TS, Lee JS, Cho SY, Jeong CW, et al. Comparison of retrograde intrarenal surgery versus a single-session percutaneous nephrolithotomy for lower-pole stones with a diameter of 15 to 30 mm: A propensity score-matching study. Korean J Urol. 2015;56(7):525-32. Epub 2015/07/16. doi: 10.4111/kju.2015.56.7.525 [doi]. PubMed PMID: 26175872; PubMed Central PMCID: PMC4500810.

9. Karakoyunlu N, Goktug G, Sener NC, Zengin K, Nalbant I, Ozturk U, et al. A comparison of standard PCNL and staged retrograde FURS in pelvis stones over 2 cm in diameter: a prospective randomized study. Urolithiasis. 2015;43(3):283-7. Epub 2015/04/04. doi: 10.1007/s00240-015-0768-2 [doi]. PubMed PMID: 25838180.

10. Resorlu B, Unsal A, Tepeler A, Atis G, Tokatli Z, Oztuna D, et al. Comparison of retrograde intrarenal surgery and mini-percutaneous nephrolithotomy in children with moderate-size kidney stones: results of multi-institutional analysis. Urology. 2012;80(3):519-23. Epub 2012/06/08. doi: 10.1016/j.urology.2012.04.018. PubMed PMID: 22673546.

11. Kirac M, Bozkurt OF, Tunc L, Guneri C, Unsal A, Biri H. Comparison of retrograde intrarenal surgery and mini-percutaneous nephrolithotomy in management of lower-pole renal stones with a diameter of smaller than 15 mm. Urolithiasis. 2013;41(3):241-6. Epub 2013/03/14. doi: 10.1007/s00240-013-0552-0. PubMed PMID: 23483226.

12. Pan J, Chen Q, Xue W, Chen Y, Xia L, Chen H, et al. RIRS versus mPCNL for single renal stone of 2-3 cm: clinical outcome and cost-effective analysis in Chinese medical setting. Urolithiasis. 2013;41(1):73-8. Epub 2013/03/28. doi: 10.1007/s00240-012-0533-8. PubMed PMID: 23532427.

13. Sabnis RB, Jagtap J, Mishra S, Desai M. Treating renal calculi 1-2 cm in diameter with
minipercutaneous or retrograde intrarenal surgery: a prospective comparative study. BJU Int. 2012;110(8 Pt B):E346-9. Epub 2012/04/11. doi: 10.1111/j.1464-410X.2012.11089.x. PubMed PMID: 22487401.

4. Kumar A, Kumar N, Vasudeva P, Kumar Jha S, Kumar R, Singh H. A prospective, randomized comparison of shock wave lithotripsy, retrograde intrarenal surgery and miniperc for treatment of 1 to 2 cm radiolucent lower calyceal renal calculi: a single center experience. J Urol. 2015;193(1):160-4. Epub 2014/07/30. doi: 10.1016/j.juro.2014.07.088. PubMed PMID: 25066869.

5. Lee JW, Park J, Lee SB, Son H, Cho SY, Jeong H. Mini-percutaneous Nephrolithotomy vs Retrograde Intrarenal Surgery for Renal Stones Larger Than 10 mm: A Prospective Randomized Controlled Trial. Urology. 2015;86(5):873-7. Epub 2015/09/01. doi: 10.1016/j.urology.2015.08.011. PubMed PMID: 26320082.

6. Zeng G, Zhu W, Li J, Zhao Z, Zeng T, Liu C, et al. The comparison of minimally invasive percutaneous nephrolithotomy and retrograde intrarenal surgery for stones larger than 2 cm in patients with a solitary kidney: a matched-pair analysis. World J Urol. 2015;33(8):1159-64. Epub 2014/10/22. doi: 10.1007/s00345-014-1420-4. PubMed PMID: 25331936.

7. Rucker G, Schwarzer G. Ranking treatments in frequentist network meta-analysis works without resampling methods. BMC Med Res Methodol. 2015;15:58. Epub 2015/08/01. doi: 10.1186/s12874-015-0060-8. PubMed PMID: 26227148; PubMed Central PMCID: PMCPmc4521472.

8. Jeong JY, Kim JC, Kang DH, Lee JY. Digital Videoscopic Retrograde Intrarenal Surgeries for Renal Stones: Time-to-Maximal Stone Length Ratio Analysis. Yonsei Med J. 2018;59(2):303-9. Epub 2018/02/13. doi: 10.3349/ymj.2018.59.2.303. PubMed PMID: 29436200; PubMed Central PMCID: PMCPMC5823834.

9. Jung HD, Kim JC, Ahn HK, Kwon JH, Han K, Han WK, et al. Real-time simultaneous endoscopic
combined intrarenal surgery with intermediate-supine position: Washout mechanism and transport technique. Investigative and clinical urology. 2018;59(5):348-54. Epub 2018/09/06. doi: 10.4111/icu.2018.59.5.348. PubMed PMID: 30182081; PubMed Central PMCID: PMCPMC6121022.

Nagele U, Horstmann M, Sievert KD, Kuczyk MA, Walcher U, Hennenlotter J, et al. A newly designed amplatz sheath decreases intrapelvic irrigation pressure during mini-percutaneous nephrolitholapaxy: an in-vitro pressure-measurement and microscopic study. J Endourol. 2007;21(9):1113-6. Epub 2007/10/19. doi: 10.1089/end.2006.0230. PubMed PMID: 17941796.

1. Loftus CJ, Hinck B, Makovey I, Sivalingam S, Monga M. Mini Versus Standard Percutaneous Nephrolithotomy: The Impact of Sheath Size on Intrarenal Pelvic Pressure and Infectious Complications in a Porcine Model. J Endourol. 2018;32(4):350-3. Epub 2018/02/02. doi: 10.1089/end.2017.0602. PubMed PMID: 29385812.

2. Atalay HA, Canat L, Bayraktarli R, Alkan I, Can O, Altunrende F. Evaluation of stone volume distribution in renal collecting system as a predictor of stone-free rate after percutaneous nephrolithotomy: a retrospective single-center study. Urolithiasis. 2018;46(3):303-9. Epub 2017/06/25. doi: 10.1007/s00240-017-0995-9. PubMed PMID: 28646306.

3. Jiang H, Yu Z, Chen L, Wang T, Liu Z, Liu J, et al. Minimally Invasive Percutaneous Nephrolithotomy versus Retrograde Intrarenal Surgery for Upper Urinary Stones: A Systematic Review and Meta-Analysis. BioMed research international. 2017;2017:2035851. Epub 2017/05/30. doi: 10.1155/2017/2035851. PubMed PMID: 28553645; PubMed Central PMCID: PMCPMC5434463.

4. Kang SK, Cho KS, Kang DH, Jung HD, Kwon JK, Lee JY. Systematic review and meta-analysis to compare success rates of retrograde intrarenal surgery versus percutaneous nephrolithotomy for renal stones >2 cm: An update. Medicine. 2017;96(49):e9119. doi: 10.1097/md.0000000000009119. PubMed PMID: 00005792-201712080-00136.
5. Zheng C, Xiong B, Wang H, Luo J, Zhang C, Wei W, et al. Retrograde intrarenal surgery versus percutaneous nephrolithotomy for treatment of renal stones >2 cm: a meta-analysis. Urol Int. 2014;93(4):417-24. Epub 2014/08/30. doi: 10.1159/000363509. PubMed PMID: 25170589.

6. Zhang W, Zhou T, Wu T, Gao X, Peng Y, Xu C, et al. Retrograde Intrarenal Surgery Versus Percutaneous Nephrolithotomy Versus Extracorporeal Shockwave Lithotripsy for Treatment of Lower Pole Renal Stones: A Meta-Analysis and Systematic Review. J Endourol. 2015;29(7):745-59. Epub 2014/12/23. doi: 10.1089/end.2014.0799. PubMed PMID: 25531986.

7. Zhu W, Liu Y, Liu L, Lei M, Yuan J, Wan SP, et al. Minimally invasive versus standard percutaneous nephrolithotomy: a meta-analysis. Urolithiasis. 2015;43(6):563-70. Epub 2015/08/06. doi: 10.1007/s00240-015-0808-y. PubMed PMID: 26242465.

8. Proietti S, Giusti G, Desai M, Ganpule AP. A Critical Review of Miniaturised Percutaneous Nephrolithotomy: Is Smaller Better? European urology focus. 2017;3(1):56-61. Epub 2017/07/20. doi: 10.1016/j.euf.2017.05.001. PubMed PMID: 28720368.

9. Jackman SV, Docimo SG, Cadeddu JA, Bishoff JT, Kavoussi LR, Jarrett TW. The "mini-perc" technique: a less invasive alternative to percutaneous nephrolithotomy. World J Urol. 1998;16(6):371-4. Epub 1998/12/31. PubMed PMID: 9870281.

10. Nicklas AP, Schilling D, Bader MJ, Herrmann TR, Nagele U. The vacuum cleaner effect in minimally invasive percutaneous nephrolitholapaxy. World J Urol. 2015;33(11):1847-53. Epub 2015/04/03. doi: 10.1007/s00345-015-1541-4. PubMed PMID: 25833660.

Figures
Figure 1

Flow diagram of evidence acquisition. Thirteen studies were ultimately included in the qualitative and quantitative synthesis.
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.
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).

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).
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 5**

| Study        | mPCNL Events | Total | RIRS Events | Total | Odds Ratio | OR  | 95%–CL | Weight |
|--------------|--------------|-------|-------------|-------|------------|-----|--------|--------|
| Resorlu 2012 | 100          | 106   | 88          | 95    | 1.33       | 1.33| [0.43; 4.09] | 19.1%  |
| Sabnis 2013  | 32           | 32    | 31          | 32    | 3.10       | 3.10| [0.12; 78.87] | 5.1%   |
| Kirac 2013   | 33           | 37    | 32          | 36    | 1.03       | 1.03| [0.24; 4.48]  | 15.2%  |
| Pan 2013     | 57           | 59    | 40          | 56    | 11.40      | 11.40| [2.48; 52.36] | 14.6%  |
| Zeng 2015    | 38           | 53    | 23          | 53    | 3.30       | 3.30| [1.47; 7.41]  | 23.5%  |
| Lee 2015     | 30           | 35    | 32          | 33    | 0.19       | 0.19| [0.02; 1.70]  | 9.3%   |
| Kumar 2015   | 39           | 41    | 37          | 43    | 3.16       | 3.16| [0.60; 16.67] | 13.3%  |

**Random effects model** 363 348

Heterogeneity: $I^2 = 51\%$, $t^2 = 0.5462$, $p = 0.06$

Favour RIRS  Favour mPCNL

2.12  [0.95; 4.72]  100.0%
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).
Table and figure representing network meta-analysis of success rate of mPCNL, PCNL, and RIRS and node-splitting analyses of inconsistency.
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

This is a list of supplementary files associated with the primary manuscript. Click to download.

PRISMA NMA checklist (1).docx