Complications and outcomes of tubeless versus nephrostomy tube in percutaneous nephrolithotomy: a systematic review and meta-analysis of randomized clinical trials

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Abstract
We aimed to perform a systematic review of randomized trials to summarize the evidence on the safety and stone-free rate after Tubeless percutaneous nephrolithotomy (PCNL) (ureteral stent/catheter, no nephrostomy) compared to Standard PCNL (nephrostomy, with/without ureteral stent/catheter) to evaluate if the tubeless approach is better. The inverse variance of the mean difference with a random effect, 95% Confidence Interval (CI), and $p$ values was used for continuous variables. Categorical variables were assessed using Cochran–Mantel–Haenszel method with the random effect model, and reported as Risk Ratio (RR), 95% CI, and $p$ values. Statistical significance was set at $p < 0.05$ and a 95% CI. 26 studies were included.

Mean operative time was significantly shorter in the Tubeless group (MD—5.18 min, 95% CI — 6.56, $-3.80$, $p < 0.00001$).

Mean postoperative length of stay was also significantly shorter in the Tubeless group (MD—1.10 day, 95% CI — 1.48, $-0.71$, $p < 0.00001$).

Incidence of blood transfusion, angioembolization for bleeding control, pain score at the first postoperative day, the number of patients requiring postoperative pain medication, fever, urinary infections, sepsis, perirenal fluid collection, pleural breach, hospital readmission, and SFR did not differ between the two groups.

Incidence of postoperative urinary fistula was significantly lower in the Tubeless group (RR 0.18, 95% CI 0.07, 0.47, $p = 0.0005$). This systematic review shows that tubeless PCNL can be safely performed and the standout benefits are shorter operative time and hospital stay, and a lower rate of postoperative urinary fistula.

Keywords Percutaneous nephrolithotomy · Kidney stone · Percutaneous nephrostomy · Ambulatory surgical procedures
Introduction

The eternal debate for percutaneous nephrolithotomy (PCNL) exit strategy is whether a nephrostomy tube is necessary and its impact on the procedure and complications. Furthermore, the presence of a nephrostomy tube may hamper PCNL as a day surgery/ambulatory procedure. PCNL access and exit strategies have been well defined by CROES and large-volume randomized controlled trials [1]. Exit strategies in PCNL are typically tubeless (refers to the placement of a double J stent alone), totally tubeless (refers to no nephrostomy and no double J stent), and nephrostomy alone [2]. There is a lack of consensus on what measurable intraoperative and postoperative outcomes, including exit strategy, are best suited for a day surgery/ambulatory PCNL. Tubeless PCNL could be the ideal approach in selecting which patients might be suitable for same-day discharge.

Three past systematic reviews favored tubeless PCNL over PCNL with a nephrostomy tube as it significantly shortened hospital stay allowing for a faster return to normal activity facilitated by lower immediate postoperative pain scores, reduced analgesic requirement, and urine leakage [2–4]. However, questions persist if this approach could increase complications rates, such as bleeding, urinomas, or perinephric abscess as well as hospital readmissions. The present study aims to evaluate how recent technical and technological refinements in PCNL have influenced urologists toward a clearer understanding of which choices, surgical outcomes, and parameters can be considered for PCNL, especially when planning their exit strategy with the usage of a nephrostomy tube placement vis-a-vis a tubeless approach.

Methods

Aim of the review

The present study aims to systematically review the safety and stone-free rate after tubeless PCNL (ureteral stent/ureteral catheter and no nephrostomy tube) as compared to standard PCNL (with nephrostomy tube with or without ureteral stents) for kidney stones. The main outcome is to evaluate for differences in surgical time, length of stay, and postoperative complications between two procedures. The secondary outcome is to assess if there is any difference in the stone-free rate (SFR) between the two procedures. We also intend to observe if there were any specific trends in tract sizes over the years as well as the use of different exit strategies in the tubeless cohort. Finally, we aim to compare the results of our meta-analysis to those of previous years.

Literature search

This study was performed according to the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. A broad literature search was performed on 5th October 2021, using EMBASE, MEDLINE, and Cochrane Central Controlled Register of Trials (CENTRAL). Medical Subject Heading (MeSH) terms and keywords such as “kidney calculi”, “uroliithiasis”, “Percutaneous Nephrolithotomy”, “PCNL”, “percutaneous lithotripsy”, “JJ or double J or pigtail or stent or catheter, “tubeless”, or “no tube” were used. No date limits were imposed. The search was restricted to English papers only. Animal and pediatric studies were excluded. Appendix shows the search strategy. Additional articles were sought from the reference lists of the included articles. This review was registered in PROSPERO (CRD42021291272).

Selection criteria

The PICOS (Patient Intervention Comparison Outcome Study type) model was used to frame and answer the clinical question. P: adults undergoing PCNL for kidney stones; Intervention: standard PCNL (with nephrostomy tube with or without ureteral stents); Comparison: tubeless PCNL (no nephrostomy tube with ureteral stent); Outcome: surgical time, length of postoperative stay, infection complications (fever defined as body temperature > 38 °C, urinary tract infection, sepsis), bleeding complications (hemoglobin drop, blood transfusion, need for angioembolization rates), postoperative pain (visual analogue scale (VAS) score at first postoperative day, patients requiring pain medication), urinary fistula (urinary leakage that may necessitate secondary drainage), perirenal fluid collection, pleural breach, hospital readmission for any reason and stone-free rate; Study type: prospective randomized studies. Patients were assigned to two groups according to the type of mode of exit strategy after PCNL (Tubeless PCNL vs Standard PCNL).

Study screening and selection

Two independent authors screened all retrieved records through Covidence Systematic Review Management® (Veritas Health Innovation, Melbourne, Australia). A third author solved discrepancies. Studies were included based on PICOS eligibility criteria. Prospective randomized studies were accepted. Retrospective and prospective nonrandomized studies, reviews, meeting abstracts, letters to the editor, case reports, and editorials were excluded. The full text of the screened papers was selected if found relevant to
the purpose of this study. The search was further expanded by performing a manual search based on the references of the full-text relevant papers.

**Statistical analysis**

Surgical time, hemoglobin drop, postoperative length of stay, and VAS score were pooled using the inverse variance of the mean difference with a random effect, 95% confidence interval (CI), and p values. Incidence of blood transfusion, angioembolization for bleeding control, patients requiring postoperative pain medication, postoperative infection complications, urinary fistula, perirenal fluid collection, pleural breach, readmission, and stone-free rate were assessed using Cochran–Mantel–Haenszel Method with the random effect model and reported as risk ratio (RR), 95% CI, and p values. Analyses were two-tailed and the significance was set at p < 0.05 and a 95% CI. OR less than one indicates a lower risk in the tubeless group. Study heterogeneity was assessed utilizing the $I^2$ value. Substantial heterogeneity was defined as an $I^2$ value > 50%. Meta-analysis was performed using Review Manager (RevMan) 5.4 software by Cochrane Collaboration. The quality assessment of the included studies was performed using the RoB 2 Cochrane Risk of Bias tool.

**Results**

Literature search retrieved 1424 papers. Three papers were found from other sources. Thirty-two duplicates were excluded, leaving 1395 studies for screening. Another 1266 papers unrelated to the study purpose were further excluded after the title and abstract screening. The full texts of the remaining 129 studies were screened and 103 papers were further excluded. Finally, 26 studies were accepted and included for meta-analysis. Supplementary Fig. 1 shows the 2020 PRISMA flow diagram.

**Study characteristics and quality assessment**

Twenty-six randomized studies compared Tubeless and Standard PCNL [5–30]. Study characteristics are summarized in Table 1. There were 1839 patients included in 26 studies: 907 patients underwent Tubeless PCNL and 932 underwent Standard PCNL.

Supplementary Fig. 2 demonstrates the details of the quality assessment of included studies. Fourteen studies showed a low overall risk of bias. Ten studies showed some concerns regarding the overall risk of bias and the remaining two studies a high overall risk of bias. The most frequent reason for bias was bias due to deviation of the intended intervention and measurement outcomes, followed by bias due to the randomization process.

**Meta-analyses of surgical time and length of stay**

Meta-analysis from 16 studies (550 cases in Tubeless and 570 cases in Standard PCNL) showed that the mean operative time was significantly shorter in Tubeless compared to Standard PCNL (MD = –5.18 min, 95% CI = –6.56 to –3.80, p < 0.00001). There was no significant heterogeneity among the studies ($I^2$ 5%) (Fig. 1A).

Meta-analysis of 20 studies (742 cases in Tubeless and 756 cases in Standard PCNL) showed that the mean postoperative length of stay was also significantly shorter in Tubeless compared to Standard PCNL (MD = –1.10 days, 95% CI = –1.48 to –0.71, p < 0.00001). Study heterogeneity was considerable ($I^2$ 97%) (Fig. 1B).

**Meta-analyses of bleeding**

Meta-analysis from 19 studies (608 cases in Tubeless PCNL and 635 cases in Standard PCNL) showed that blood transfusion did not differ between the two groups (RR 0.76 95% CI 0.14–1.41, p = 0.38). There was no significant heterogeneity among the studies ($I^2$ 0%) (Fig. 2A).

Meta-analysis from 6 studies (246 cases in Tubeless PCNL and 244 cases in Standard PCNL) showed that angioembolization for bleeding control did not differ between the two groups (RR 1.91 95% CI 0.34–10.74, p = 0.46). There was no significant heterogeneity among the studies ($I^2$ 0%) (Fig. 2B).

**Meta-analyses of postoperative pain**

Meta-analysis from 12 studies (428 cases in Tubeless PCNL and 443 cases in Standard PCNL) showed that the mean VAS score at the first postoperative day did not differ between the two groups (MD = –3.14 points 95% CI = –8.75 to 2.47, p = 0.27) (Fig. 3A). Study heterogeneity was considerable ($I^2$ 100%).

Meta-analysis from 7 studies (140 cases in Tubeless PCNL and 140 cases in Standard PCNL) showed that patients requiring postoperative pain medication did not differ between the two groups (RR 0.96 95% CI 0.61–1.51, p = 0.86) (Fig. 3B). Heterogeneity among the studies was significant ($I^2$ 93%).

**Meta-analyses of infection complications**

Meta-analysis from 13 studies (435 cases in Tubeless PCNL and 431 cases in Standard PCNL) showed that the incidence of postoperative fever did not differ between the two groups (RR 0.67 95% CI 0.40–1.13, p = 0.13) (Fig. 4A). There was no significant heterogeneity among the studies ($I^2$ 0%).
| Author year of publication | Tract dilatation | Amplatz sheath size, Fr | Nephrostomy tube size, Fr | Stent size, Fr | Tract closure | Stent dwelling time | Nephrostomy dwelling time | Definition of stone-free | Mean age Tubeless PCNL, years | Mean age Standard PCNL, years | Mean stone burden Tubeless PCNL | Mean stone burden Standard PCNL |
|---------------------------|-----------------|------------------------|--------------------------|---------------|--------------|-------------------|------------------------|--------------------------|-----------------------------|-----------------------------|-------------------------------|-------------------------------|
| Agrawal 2008 [5]          | NA              | 26                     | 16                       | 6             | Suture       | 2 weeks           | 2–3 days              | NA                       | 33                          | 31                          | 3.8 cm²                       | 3.6 cm²                       |
| Ali 2019 [6]              | Alken coaxial metallic dilators | 26                    | NA                       | NA            | no           | NA                | NA                    | NA                       | NA                          | NA                          | NA                            | NA                            |
| Bhat 2017 [7]             | One-shot Amplatz dilator | 30                    | 22                       | NA            | no           | NA                | NA                    | NA                       | NA                          | NA                          | NA                            | NA                            |
| Chalise, 2017 [8]         | NA              | 20–24                  | NA                       | Suture        | NA           | 36–48 h           | NA                    | 37.1                     | 37.9                        | 23 mm                       | 23.7 mm                       |
| Choi 2006 [9]             | Serial metal dilators | 34                    | 8.2                      | 6             | Gel matrix thrombin | 3–5 Days if no significant residual fragments | 3–5 Days if no significant residual fragments | No fragments | 52.9                        | 47                          | 28.5 mm                       | 26.8 mm                       |
| Cormio 2012 [10]          | Balloon/plastic dilators | 30                    | 16                       | 7             | Tachoseal    | 1 day             | 3 days                | 4 mm or less             | 51.38                       | 49.24                       | 32.17 mm                     | 30.22 mm                     |
| Desai 2004 [11]           | Alken metal dilators | 26–30                  | 20                       | 6             | No           | 4 weeks           | 2 days                | NA                       | 43.4                        | 41.1                        | 25 mm³                      | 264 mm³                      |
| Etemadian 2011 [12]       | One-shot Amplatz dilator | 30                    | 24                       | NA            | No           | 24–48 h           | 24–48 h               | NA                       | 44.58                       | 46.55                       | 36.26 mm                     | 35.35 mm                     |
| Feng 2001 [13]            | Amplatz dilators | 34                    | 22                       | NA            | NA           | 1 week            | 2 days                | No stones                | 62                          | 53                          | 4.38 cm²                     | 8.36 cm²                     |
| Garg 2019 [14]            | NA              | NA                     | NA                       | NA            | NA           | NA                | NA                    | NA                       | 36.78                       | 36.78                       | NA                            | NA                            |
| Goldberg 2020 [15]        | Balloon         | 30                     | 12                       | 6             | NA           | 2 weeks           | 2 days                | ≤ 3 mm                   | 55.37                       | 55.38                       | 23 mm                        | 24.2 mm                       |
| Gonen 2019 [16]           | Amplatz dilator | 30                    | 14                       | 6             | 24 h         | 2 days           | NA                    | 47.5                     | 45                          | 35.73 mm³                   | 386.2 mm³                   |
| Jiang 2017 [17]           | NA              | NA                     | 18                       | 5             | NA           | 2 weeks           | 2 days                | NA                       | 45.9                        | 48.1                        | 166 mm³                     | 189.7 mm³                   |
| Kara 2020 [18]            | NA              | 28                     | 18                       | NA            | 24 h         | 3–5 days          | NA                    | 67.7                     | 66.5                        | 25.6 mm                     | 22.3 mm                       |
| Kirac 2013 [19]           | NA              | 30                     | 14                       | NA            | NA           | 14–21 days        | 1–3 days              | No fragments             | 43.5                        | 42.5                        | 25.4 mm                      | 30.5 mm                       |
| Kumar 2020 [20]           | NA              | 26                     | 20                       | NA            | no           | NA                | NA                    | NA                       | NA                          | NA                          | NA                            | NA                            |
| Author year of publication | Tract dilatation | Amplatz sheath size, Fr | Nephrostomy tube size, Fr | Stent size, Fr | Tract closure | Stent dwelling time | Nephrostomy dwelling time | Definition of stone-free | Mean age Tubeless PCNL, years | Mean age Standard PCNL, years | Mean stone burden Tubeless PCNL | Mean stone burden Standard PCNL |
|-----------------------------|-----------------|----------------------|--------------------------|---------------|--------------|------------------|----------------------|--------------------------|-----------------------------|-------------------------------|-------------------------------|-------------------------------|
| Liu 2017 [21]               | NA              | 16–18                | 16                       | 6             | NA           | 4 weeks          | 4–5 days             | <4 mm                   | 46.08                       | 48.6                          | 1.98 cm                       | 1.82 cm                       |
| Marchant 2011 [22]          | Fascial dilators | 28                   | 18                       | 7             | Oxidized cellulose gauze | 10–14 days      | 3 days               | NA                      | 52.8                        | 6.4 cm²                      | 7.8 cm²                       |
| Mishra 2010 [23]            | Metallic telescopic coaxial dilators | 28                   | 20                       | NA           | Manual compression for 5 min | 24 h If no re-treatment was planned | 24 h If no re-treatment was planned | No evidence of clinically insignificant residual fragments on CT | 55                          | 50                           | NA                           | NA                           |
| Sebaey 2016 [24]            | 14-F Teflon     | 14                   | 14                       | NA           | Suture       | 2–3 days         | NA                   | NA                      | 48.4                        | 50.1                          | 182 mm³                       | 191 mm³                       |
| Shah 2008 [25]              | Telescopic dilators | 30                   | 8                        | 6             | Strapped with a pressure dressing | Until clearing urine | 24 h                 | <4 mm                   | 48.66                       | 42.08                         | 535.3 mm³                     | 495.91 mm³                    |
| Shoma 2011 [26]             | NA              | NA                   | 22                       | NA           | Suture       | Until clearing urine | Until clearing urine | Residual stones of 4 mm | 31                          | 34                           | 1226 mm³                      | 1004 mm²                     |
| Singh 2008 [27]             | NA              | NA                   | 22                       | NA           | NA           | NA               | NA                   | NA                      | 52.6                        | 55.2                          | 750 mm²                       | 800 mm²                      |
| Sofikerim 2007 [28]         | NA              | 30                   | 18                       | 6             | Suture       | 14 days          | 2 days              | No stones               | 38.4                        | 41.3                          | 425 mm²                       | 428 mm²                      |
| Tefekli 2007 [29]           | NA              | 30                   | 14                       | NA           | Suture       | 24 h             | 48 h                 | No stones               | 58                          | 57.4                          | 300 mm²                       | 310 mm²                      |
| Zhao 2016 [30]              | NA              | 30                   | 12                       | NA           | Suture or fibrine sealant | 2 weeks          | 48 h                 | No stones               | 48.88                       | 53.05                         | 259 mm²                       | 276.6 mm²                    |

Fr French, PCNL percutaneous nephrolithotomy, NA not available
### A) Surgical time (minutes)

| Study or Subgroup | Tubeless PCNL Mean | Tubeless PCNL SD | Tubeless PCNL Total | Standard PCNL Mean | Standard PCNL SD | Standard PCNL Total | Mean Difference (95% CI) |
|------------------|--------------------|------------------|---------------------|-------------------|------------------|---------------------|-----------------------|
| All 2009         | 73.0              | 21.5             | 235                     | 84.64            | 20.09            | 230                     | -1.60 (1.58, 2.68)     |
| Chlette          | 73.3              | 23.0             | 49                      | 79.0             | 22.5             | 47                     | -6.30 (11.58, 0.08)    |
| Chat 2006        | 82.06             | 17.99            | 112                     | 79.5             | 13.07            | 112                     | -2.54 (0.15, 5.67)     |
| Germain 2012     | 83.67             | 42.95            | 49                      | 88.44            | 43.41            | 47                     | 4.73 (11.62, 2.52)     |
| Desai 2004       | 44.5              | 13.2             | 10                      | 45.73            | 10               | 10                     | 1.64 (0.13, 3.15)      |
| Tietel 2011      | 68.4              | 4.0              | 100                     | 74.5             | 6.0              | 100                    | -6.00 (11.62, 0.08)    |
| Peng 2015        | 128.8             | 8                | 120                     | 8                | 6                | 28                     | -1.00 (6.44, 6.44)     |
| Kang 2016        | 59.97             | 26.4             | 40                      | 67.55            | 28               | 40                     | -7.58 (15.15, 4.35)    |
| Goldberg 2020    | 161.6             | 28.4             | 38                      | 116.88           | 38.8             | 37                     | -40.70 (63.16, 5.32)   |
| Jiang 2017       | 40.6              | 16.1             | 30                      | 47.22            | 18.1             | 30                     | -6.60 (11.62, 2.37)    |
| Kaur 2015        | 38.5              | 6.83             | 30                      | 42.5             | 7.35             | 30                     | -3.00 (6.00, 0.00)     |
| Kumar 2020       | 61.7              | 13.4             | 25                      | 63.2             | 18.1             | 36                     | -1.50 (5.41, 6.41)     |
| Sheth 2016       | 66.44             | 20.34            | 44                      | 78.69            | 24.29            | 56                     | 2.46 (13.10, 1.08)     |
| Telek 2007       | 60.6              | 11.9             | 40                      | 46.1            | 18.4             | 40                     | -5.50 (12.28, 1.38)    |
| Shale 2008       | 34.55             | 10.44            | 33                      | 46.81            | 16.07            | 32                     | 2.69 (11.62, 10.25)    |

### B) Postoperative stay (days)

| Study or Subgroup | Tubeless PCNL Mean | Tubeless PCNL SD | Tubeless PCNL Total | Standard PCNL Mean | Standard PCNL SD | Standard PCNL Total | Mean Difference (95% CI) |
|------------------|--------------------|------------------|---------------------|-------------------|------------------|---------------------|-----------------------|
| All 2009         | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Chlette          | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Chat 2006        | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Germain 2012     | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Desai 2004       | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Tietel 2011      | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Peng 2015        | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Kang 2016        | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Goldberg 2020    | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Jiang 2017       | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Kaur 2015        | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Kumar 2020       | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Sheth 2016       | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Telek 2007       | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |
| Shale 2008       | 10.0              | 3.8              | 100                   | 14.88            | 3.8              | 100                   | -4.88 (11.62, 0.08)    |

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**Fig. 1** Meta-analysis of surgical time and length of stay in studies comparing Tubeless PCNL vs Standard PCNL

**Fig. 2** Meta-analysis of bleeding in studies comparing Tubeless PCNL vs Standard PCNL

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Fig. 1 Meta-analysis of surgical time and length of stay in studies comparing Tubeless PCNL vs Standard PCNL

A) Blood transfusion

| Study or Subgroup | Events Total | Events Total | Events Total | Risk Ratio | Risk Ratio |
|------------------|--------------|--------------|--------------|------------|------------|
| All 2009         | 606          | 635          | 100%         | 0.79 (0.61, 1.01) |

B) Angioembolization for bleeding control

| Study or Subgroup | Events Total | Events Total | Events Total | Risk Ratio | Risk Ratio |
|------------------|--------------|--------------|--------------|------------|------------|
| All 2009         | 480          | 500          | 100%         | 0.92 (0.71, 1.19) |

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Meta-analysis from 6 studies (247 cases in Tubeless PCNL and 245 cases in Standard PCNL) showed that the incidence of postoperative urinary tract infection did not differ between the two groups (RR 0.74 95% CI 0.33–1.62, \( p = 0.45 \)) (Fig. 4B). There was no significant heterogeneity among the studies (\( I^2 0\% \)).

Meta-analysis from 9 studies (384 cases in Tubeless PCNL and 380 cases in Standard PCNL) showed that the incidence of postoperative sepsis did not differ between the two groups (RR 0.86 95% CI 0.44–1.67, \( p = 0.66 \)) (Fig. 4C). There was no significant heterogeneity among the studies (\( I^2 0\% \)).

**Meta-analyses of urinary fistula, perirenal fluid collection, and pleural breach**

Meta-analysis from 14 studies (466 cases in Tubeless PCNL and 464 cases in Standard PCNL) showed that the incidence of the postoperative urinary fistula was significantly lower in the Tubeless PCNL group (RR 0.18 95% CI 0.07–0.47, \( p = 0.0005 \)) (Fig. 5A). Heterogeneity among the studies was not important (\( I^2 11\% \)).

Meta-analysis from 13 studies (478 cases in Tubeless PCNL and 474 cases in Standard PCNL) showed that the incidence of the postoperative perirenal fluid collection did not differ between the two groups (RR 1.00 95% CI 0.42–2.40, \( p = 0.99 \)) (Fig. 5B). There was no significant heterogeneity among the studies (\( I^2 0\% \)).

Meta-analysis from 14 studies (449 cases in Tubeless PCNL and 468 cases in Standard PCNL) showed that the incidence of pleural breach did not differ between the two groups (RR 0.01 95% CI -0.01–0.03, \( p = 0.49 \)) (Fig. 5C). There was no significant heterogeneity among the studies (\( I^2 0\% \)).

**Meta-analyses of hospital readmission and stone-free rate**

Meta-analysis from 8 studies (268 cases in Tubeless PCNL and 278 cases in Standard PCNL) showed that the incidence of hospital readmission for any reason did not significantly differ between the two groups (RR 1.02 95% CI 0.46–2.27, \( p = 0.96 \)) (Fig. 6A). There was no significant heterogeneity among the studies (\( I^2 0\% \)).

Meta-analysis from 18 studies (573 cases in Tubeless PCNL and 583 cases in Standard PCNL) showed that the stone-free rate did not differ between the groups (RR 1.03 95% CI 0.99–1.07, \( p = 0.13 \)) (Fig. 6B). There was no significant heterogeneity among the studies (\( I^2 0\% \)).
### A) Fever

| Study or Subgroup | Tubeless PCNL | Standard PCNL | Risk Ratio | M-H, Random, 95% CI |
|-------------------|---------------|---------------|------------|---------------------|
| Agrawal 2008      | 5 161        | 4 161         | 1.26 (0.12, 13.3) |                      |
| Bhat 2017         | 3 25          | 2 25          | 1.10 (0.12, 9.8)  |                      |
| Chee 2006         | 5 49          | 4 47          | 1.04 (0.13, 8.8)  |                      |
| Goldberg 2010     | 6 12          | 6 12          | Not estimable  |                      |
| Gorr 2019         | 1 30          | 1 30          | 1.00 (0.11, 9.5)  |                      |
| Jang 2017         | 2 30          | 3 30          | 0.69 (0.10, 4.9)  |                      |
| Kar 2006          | 2 30          | 3 30          | 0.93 (0.14, 5.3)  |                      |
| Lu 2017           | 1 51          | 0 31          | Not estimable  |                      |
| Malve 2010        | 1 11          | 1 11          | 0.45 (0.01, 15.0) |                      |
| Sing 2008         | 0 30          | 0 30          | Not estimable  |                      |
| Sodhi 2008        | 0 30          | 0 30          | Not estimable  |                      |
| Total (95% CI)    | 423           | 433           | 1.06 (0.48, 2.42) |                      |

### B) Urinary tract infection

| Study or Subgroup | Tubeless PCNL | Standard PCNL | Risk Ratio | M-H, Random, 95% CI |
|-------------------|---------------|---------------|------------|---------------------|
| Agrawal 2008      | 0 161        | 1 161         | 0.80 (0.22, 2.8)  |                      |
| Bhat 2017         | 0 33          | 2 34          | 0.72 (0.12, 4.3)  |                      |
| Chee 2006         | 0 12          | 0 12          | Not estimable  |                      |
| Goldberg 2010     | 0 40          | 6 40          | 0.67 (0.20, 2.1)  |                      |
| Gorr 2019         | 0 30          | 1 30          | 1.05 (0.18, 6.1)  |                      |
| Gorr 2019         | 0 30          | 1 30          | 1.05 (0.18, 6.1)  |                      |
| Lu 2017           | 0 31          | 1 31          | Not estimable  |                      |
| Shina 2011        | 0 30          | 0 30          | Not estimable  |                      |
| Shina 2011        | 0 30          | 0 30          | Not estimable  |                      |
| Total (95% CI)    | 247           | 245           | 0.74 (0.33, 1.6)  |                      |

### C) Sepsis

| Study or Subgroup | Tubeless PCNL | Standard PCNL | Risk Ratio | M-H, Random, 95% CI |
|-------------------|---------------|---------------|------------|---------------------|
| Agrawal 2008      | 0 161        | 1 161         | 0.80 (0.22, 2.8)  |                      |
| Chee 2006         | 0 24          | 0 24          | Not estimable  |                      |
| Goldberg 2010     | 0 30          | 1 30          | 0.33 (0.01, 13.2) |                      |
| Gorr 2019         | 0 12          | 1 12          | Not estimable  |                      |
| Shina 2011        | 0 30          | 0 30          | Not estimable  |                      |
| Shina 2011        | 0 30          | 0 30          | Not estimable  |                      |
| Total (95% CI)    | 18 380        | 18 380        | 0.86 (0.44, 1.7)  |                      |

**Fig. 4** Meta-analysis of infection complications in studies comparing Tubeless PCNL vs Standard PCNL

### A) Urinary fistula

| Study or Subgroup | Tubeless PCNL | Standard PCNL | Risk Ratio | M-H, Random, 95% CI |
|-------------------|---------------|---------------|------------|---------------------|
| Agrawal 2008      | 0 161        | 1 161         | 0.87 (0.08, 8.0)  |                      |
| Bhat 2017         | 0 33          | 0 34          | 0.05 (0.01, 2.1)  |                      |
| Chee 2006         | 0 30          | 0 30          | Not estimable  |                      |
| Goldberg 2010     | 0 30          | 0 30          | Not estimable  |                      |
| Gorr 2019         | 0 30          | 0 30          | Not estimable  |                      |
| Gorr 2019         | 0 30          | 0 30          | Not estimable  |                      |
| Lu 2017           | 0 31          | 0 31          | Not estimable  |                      |
| Shina 2011        | 0 30          | 0 30          | Not estimable  |                      |
| Shina 2011        | 0 30          | 0 30          | Not estimable  |                      |
| Total (95% CI)    | 466           | 444           | 0.18 (0.07, 0.47) |                      |

**Fig. 5** Meta-analysis of urinary fistula, perirenal fluid collection, and pleural breach in studies comparing Tubeless PCNL vs Standard PCNL
Discussion

PCNL was first described in 1976 by Fernström and Johansson, and has evolved and revolutionized the way renal calculi are managed [31] and is the current standard in stones larger than 2 cm across international guidelines [32, 33]. In 1999, Goh et al. described PCNL using a 30–34 Ch Amplatz sheath with this trend carrying into the early 2000s [34]. In 2007, Brusky et al. performed mini-PCNL through a 20 Ch percutaneous access starting the trend for miniaturization in PCNL [35]. After initial skepticism, miniaturized PCNL is now an accepted way forward with tract sizes dropping from 30 to 24 Fr for a standard PCNL and sizes less than 20 Fr being considered a mini-PCNL surgery [36].

This led to the belief that miniaturized PCNL should ideally replace standard PCNL; however, as seen in our review, many centers continue using standard access in both arms of their study (Supplementary Fig. 3). Our study is the only systematic review that has looked at tract size, and only two studies out of 26 studies used a 16 Fr and 14 Fr tract, respectively [21, 24]. Postprocedure, the most common nephrostomy tube placed was 20 Fr and above. Only two studies placed an 8 Fr nephrostomy tube as an exit in a 34 Fr tract [9, 25]. Supplementary Fig. 3 shows the correlation between the tract size and the nephrostomy tube used in studies included in this review.

In our analysis, no specific trends were noted between tract size and nephrostomy tube size based on stone volume. Most series were comparable in the stone volume included in both groups, and these often included partial and complete staghorn stones. However, the specific number of these cases was not available in individual studies to consider a subset analysis to see if this has any impact on outcomes.

Our findings suggest that a tailored and personalized approach is the need of the day for modern PCNL, and urologists should not shy away from using bigger tracts to achieve a good outcome [37]. Significant advancements in miniaturization [36], adoption of new positions [38], and technological enhancements have provided a plethora of choices for lithotripsy, ranging from ballistic to laser to combined energy devices [39]. The aforementioned improvements tackle any stone composition and volume, with minimal complications and maximum efficacy, making PCNL feasible for a day surgery/ambulatory procedure in a select group of patients.

The first work about tubeless PCNL was published in 1997 by Bellman et al. without significant complications and early discharge of all 50 patients [40]. Limb et al. tried to specify discharge criteria to objectively compare the length of stay between standard and tubeless PCNL [41]. They reported different factors that may bias this variable such as health care system policies, patient’s concomitant morbidities, and the variability of subjective pain assessment.
readmission, and the 30-day readmission rate was 4.2% [46]. However, 2.4% required early
in 77% of cases, and 99% of cases had a ureteral stent as the
they reported the use of a standard tract dilation (24–30 Fr)
shown recently by a 500-patient study by Chong et al., where
[25]. Same-day discharge PCNL is indeed a reality today as
intraoperative tract infiltration for pain management is now
minor effects on postoperative pain. We could not identify if
erative pain medication was not different between the two
statistically significant. Furthermore, the need for postop-
eral stent and no nephrostomy tube) as compared with standard
significantly lower in totally tubeless PCNL (no ureteral
also found that the amount of narcotic use and pain were
less, and recovery is faster [44]. Interestingly, Eslahi et al.
found that the amount of narcotic use and pain were
significantly lower in totally tubeless PCNL (no ureteral
s,tent and no nephrostomy tube) as compared with standard
and tubeless PCNL [45]. Our meta-analysis on postopera-
tive pain favored the tubeless cohort; however, it was not
statistically significant. Furthermore, the need for postop-
erative pain medication was not different between the two
groups. This reiterates the concept that tubes probably have
minor effects on postoperative pain. We could not identify if
intraoperative tract infiltration for pain management is now
a common trend, but this could aid in immediate postop-
erative pain management and analgesic requirements, espe-
cially if a patient is being considered for same-day discharge
[25]. Same-day discharge PCNL is indeed a reality today as
shown recently by a 500-patient study by Chong et al., where
they reported the use of a standard tract dilation (24–30 Fr)
in 77% of cases, and 99% of cases had a ureteral stent as the
only form of drainage [46]. However, 2.4% required early
readmission, and the 30-day readmission rate was 4.2% [46].
While systematic reviews in the past have shown that Tube-
less PCNL allowed for a faster return to work, and this is an
important aspect to take into account if patients are getting
readmitted which defeats the purpose of a day surgery [2, 4].

Complications are a dreaded part of PCNL. In the past
systematic reviews, no statistical differences for hemog-
lobin drop and blood transfusion were seen [3, 4]. In
our analysis, 19 studies did not show any difference in the
rate of blood transfusion, and in the 6 studies that reported
incidence of angioembolization post-PCNL, no absolute
difference was noted. Most studies in our review had tract
size greater than 20 Fr and serial dilatation was the pre-
ferred approach in 10 of the 13 reported series. These find-
ings have practical utility for urologists while planning a
desired tract size and technique of renal access. Complica-
tions like fever, sepsis, urinary infections, pleural injury,
and incidence of perirenal fluid collections did not differ
between the two groups in our analysis, but the incidence
of postoperative urinary fistula was significantly lower in
the Tubeless PCNL group (RR 0.18 95% CI 0.07–0.47,
p = 0.0005). There was no trend noted for using sealants
and only 4 of the 26 studies used some tract sealants, but
the use of sealants disappeared after 2016. Another impor-
tant finding of our meta-analysis was that the incidence of
hospital readmission for any reason did not significantly
differ between the two groups (RR 1.02 95% CI 0.46–2.27,
p = 0.96). This is very important as it allows urologists full
flexibility in choosing any approach feasible to their realm
of practice and is the quintessential for counseling patients
during preoperative planning.

While our review has the inherent bias associated with
patient selection that may vary across the world, we have
a significantly higher number of included studies as com-
pared to any past similar meta-analysis, and this allows us
to dive deeper and compare the pros and cons of Tubeless
PCNL vis-a-vis Standard PCNL. Hence, this could account
for the differences from other reviews. The lack of reported
outcomes such as the number of staghorn stones prevented
any form of subset analysis. We also could not perform a
cost analysis and assess quality of life of patients.

Conclusions

Our review shows that the standout benefits of Tubeless
PCNL are shorter operative time, shorter hospital stay, and
a lower rate of postoperative urinary fistula. However, pain
scores, need for readmission, use of analgesia, and com-
pliation rates did not differ between the groups, making
Tubeless PCNL a safe option that deserves further studies
to assess its role in a same-day discharge approach.

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Author contributions VG and DC conceived the study. JCT, VG,
VVSC, and DC designed the study protocol. VG and DC led the
development of the manuscript. DC performed statistics. EGR, EJL, SS,
MPP, EP, DC, VG, MLW, MC, performed data extraction and analysis.
BKS, OT, HYT, JdlR and CTH reviewed the paper for critical intel-
lectual content. All authors participated in manuscript writing, review,
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Declarations

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

Ethical approval  No ethical concerns.

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