Journal of Robotic Surgery (2024) 18:321
https://doi.org/10.1007/s11701-024-02066-7

REVIEW

Comparison of single-port versus multi-port robotic assisted partial nephrectomy: a systematic review and meta-analysis of perioperative and oncological outcomes

Anneng Hu[1] · Zongying Lv[1] · Guiyuan Chen[1] · Yuhang Lin[1] · Xiaole Zhu[1] · Junyang Li[1] · Xiaodong Yu[1]

Received: 6 July 2024 / Accepted: 27 July 2024

Abstract
The safety and efficacy of single-port and multi-port robot-assisted partial nephrectomy (SP-RAPN and MP-RAPN, respectively) were assessed for treating partial nephrectomy in this study. A systematic review of PubMed, Cochrane Library, and Web of Science databases was conducted up to June 2024 to compare studies on SP-RAPN and MP-RAPN. Primary outcomes included perioperative results, complications, and oncological outcomes. Eight studies involving 1014 patients were analyzed. For binary outcomes, comparisons were performed using odds ratios (OR), and for continuous variables, weighted mean differences (WMD) with 95% confidence intervals (CI). The search failed to discover significant meaningful variations in operating times ($p = 0.54$), off-clamp procedure ($P = 0.36$), blood loss ($p = 0.31$), positive surgical margins (PSMs) ($p = 0.78$), or major complications (Clavien–Dindo grade ≥ 3) ($p = 0.68$) between SP-RAPN and MP-RAPN. However, shorter hospital stays (WMD − 0.26 days, 95% CI − 0.36 to − 0.15; $p < 0.00001$) and longer warm ischemia times (WIT) (WMD 3.13 min, 95% CI 0.81–5.46; $p = 0.008$) were related to SP-RAPN, and higher transfusion rate (OR 2.99, 95% CI 1.31–6.80; $p = 0.009$) compared to MP-RAPN. SP-RAPN performed better in terms of hospital stay but had slightly higher rates of transfusion, off-clamp procedures, and warm ischemia time (WIT) compared to MP-RAPN. As an emerging technology, preliminary research suggests that SP-RAPN is a feasible and safe method for carrying out a nephrectomy partial. However, compared to MP-RAPN, it shows inferior outcomes regarding (WIT) and transfusion rates.

Keywords Single port · Multi-port · Robot · Partial nephrectomy · Perioperative · Oncologic outcomes

Introduction

Robotic assisted partial nephrectomy (RAPN), which combines minimally invasive procedures with improved accuracy and preservation of renal function, has completely changed the way that kidney tumors are surgically managed [1, 2]. We reviewed the relevant literature and learned that the Food and Drug Administration (FDA) in the United States issued a regulation in 2018 authorizing the use of a new single-port robotic surgical platform for partial nephrectomy [3]. This announcement quickly garnered global attention.

✉ Xiaodong Yu
21434379@qq.com

1 Department of Urology, Affiliated Hospital of North Sichuan Medical College, No. 1 Mao Yuan South Road, Wenhua Road 57, Shunqing, Nanchong 637000, Sichuan, People's Republic of China

Single-port robotic assisted partial nephrectomy (SP-RAPN) uses a single multi-channel port that is just 25 mm in size to insert all robotic equipment and a movable camera. Using a single access point, this feature lessens surgical stress and improves cosmetic results. It may also lessen postoperative discomfort and speed up recovery, which may encourage the use of laparoscopic surgery [4]. Conversely, multi-port robot-assisted partial nephrectomy (MP-RAPN) is presently the predominant surgical approach for managing renal masses in numerous medical centers globally and provide greater maneuverability and versatility, facilitating complex renal reconstructions and precise tumor excisions [5]. Both SP-RAPN and MP-RAPN have gained prominence, each offering unique advantages in surgical outcomes and patient recovery [6, 7].

As robotic technology continues to advance, comprehensive evaluations of perioperative and oncologic outcomes are essential. Important variables such as blood loss, operating time, complication rates and oncologic measures such as surgical margins and results of prolonged survival play crucial roles in assessing the clinical efficacy of these techniques [8–10].

By systematically reviewing literature, the objective of this meta-analysis is to thoroughly evaluate and contrast the perioperative and oncologic results connected to SP-RAPN and MP-RAPN. Such an analysis not only informs clinical decision-making, but also contributes to refining surgical practices and optimizing patient outcomes in nephron-sparing surgery. This study seeks to address the gap in current knowledge by providing a structured review and quantitative synthesis of the latest evidence, thereby guiding future research directions and enhancing the understanding of optimal robotic surgical strategies in urologic oncology.

Methods

The "Preferred reporting items for systematic reviews and meta-analysis" (PRISMA) [11] and the "Assessment of multiple systematic reviews" (AMSTAR) [12] criteria were followed in our study to conduct research in order to assess the caliber of our meta-analysis.

Search strategy and data extraction

In June 2024, a systematic literature review was carried out using the PubMed, Web of Science, Cochrane Library and Embase databases. Combine the patient-related search terms with intervention search terms to form the following search string: ("single site" OR "single-site" OR "Single Port" OR "Single-Port" OR SP) AND (Multiport OR standard OR conventional) AND (Robotics OR Robot-assisted) AND (Partial Nephrectomy). The search results are filtered to include only articles written in English, involving human subjects, and categorized as articles.

The selection criteria were established using the PICOS framework: patients (P): all patients were identified to have renal masses or renal tumors. Intervention (I): underwent a partial nephrectomy with single-port robot assistance (SP-RAPN). Comparator (C): the comparator in this case was the multi-port robot-assisted partial nephrectomy (MP-RAPN). Outcome (O): perioperative and oncologic results were among the outcomes that were evaluated. Study design (S): randomized controlled trials, prospective comparative studies, or retrospective studies with a minimum cohort size of 10 patients. Exclusion criteria: (1) not relevant to either surgical method; (2) non-comparative, editorial, book chapters, conference abstracts, case reports or experimental research reports; (3) the lack of measuring or analyzing the defined outcomes; (4) studies reporting fewer than 10 patients. To minimize redundancy, only the most recent or largest scale study from the same author or institution is included. In cases where two studies investigate overlapping time periods of the same national database, only the larger study is incorporated. However, smaller studies may be utilized to analyze outcomes not covered in larger studies.

Two independent authors (AH and ZL) conducted screening of titles and abstracts, as well as full-text review. Data extraction was performed independently by researchers, collecting baseline patient data, such as country, age, the number of patients, sex, body mass index (BMI), tumor size, Nephrometry score, major complications (Clavien–Dindo grade ≥ 3); perioperative effectiveness: operative time (OT), estimated blood loss (EBL), transfusion rate, off-clamp, warm ischemia time (WIT), length of hospital stay (LOS) and pathological outcomes: positive surgical margin (PSM).

Assessment of bias risk

The Risk of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool was used to assess the quality of observational studies used in non-randomized intervention studies: (1) participant selection, (2) intervention classification, (3) departure from the planned interventions, (4) missing data, (5) addressing bias related to confounding, (6) outcome measurement, and (7) outcome reporting [13]. The caliber of every study was evaluated separately by two authors, and disagreements were settled by consulting with additional co-authors until an agreement was achieved.

Assessment of quality

For non-randomized controlled trials, the Newcastle–Ottawa Scale (NOS) was employed to evaluate the level of quality of the included research. Studies scoring 5 or below were categorized as low quality, those scoring 6–7 were deemed moderate quality, and studies scoring 8–9 were deemed to be of excellent quality.

Statistical analysis

Review Manager version 5.4.1 was implemented to carry out the meta-analysis., which was created by the Cochrane Collaboration, Oxford. The inverse variance approach was used to continuous outcomes in order to compute weighted mean differences (WMD) with 95% confidence intervals (CI), whereas for dichotomous outcomes, the 95% confidence intervals (CI) and odds ratios (OR) were estimated using the Mantel–Haenszel technique. The table of data transformation supplied by Luo and colleagues [14]. was employed to transform information from research that simply provided median, interquartile range (IQR) quartiles, or range to mean and standard deviation (SD); the quantile estimation and Box–Cox techniques described by McGrath et al. [15] were applied for time-based or other skewed data, given their enhanced efficacy with non-normally distributed datasets. The I^2 test [16] ($I^2 > 50\%$ indicating high risk) and the χ^2 test ($P < 0.10$ shows heterogeneity that is statistically significant) were employed to gauge the degree of variation among the research. A fixed-effects model was employed in the event that no discernible heterogeneity was seen. If not, a random-effects model was used, and in order to assess the robustness of the overall effect estimates, observational and outlier studies were not included in the sensitivity analyses.

Sensitivity analysis

Sensitivity analysis was performed using the leave-one-out approach to see how robust the results were, which involves eliminating a single study at a time from the pooled effect, and study cohort size, which involves deleting studies with less than 50 patients. Sensitivity analysis was not carried out for comparisons involving three or fewer studies.

Publication bias

Funnel plots are widely utilized in research for visualizing data distribution and assessing publication bias in meta-analyses. However, we did not assess publication bias due to insufficient statistical power when there were 10 or fewer available studies [17, 18]. To improve statistical power, future research should consider increasing sample sizes or conducting multi-center studies to obtain more reliable conclusions. Publication bias can lead to an exaggeration or underestimation of research results, as unpublished negative results or small studies are often overlooked. Although we made efforts to conduct a comprehensive literature search, it is still possible that not all relevant studies were included. Future research should attempt to register and report all relevant research findings to reduce the impact of publication bias on the results. To mitigate publication bias and enhance statistical power, future studies can adopt the following strategies: (1) design larger scale studies to increase statistical power and ensure the detection of true effects. (2) Conduct extensive literature searches to include all relevant studies, including unpublished results, to minimize selective reporting bias. (3) Promote and encourage the publication of all research findings, regardless of significance, to ensure comprehensive and accurate research results. (4) Encourage the registration of studies at the outset to document all research plans and expected outcomes, thereby reducing reporting bias.

Results

Baseline characteristics

A comprehensive full-text review and preliminary screening were followed by the inclusion of 1014 patients from 8 studies in the meta-analysis. 477 underwent SP-RAPN and 537 underwent MP-RAPN [19–26]. The PRISMA flowchart is shown in Fig. 1. Every study that was included was judged to be of excellent quality. An overview of the essential characteristics of the included articles, encompassing the first author's name, study period, country, study design, patient number, surgical approach, and Newcastle–Ottawa Scale (NOS) score is given in Table 1. Table 2 displays the particulars of the included studies along with baseline patient and tumor characteristics. Perioperative and oncologic outcomes are outlined in Table 3.

Outcome analysis

Baseline patient and tumor characteristics outcomes: all 8 studies reported on patient age, gender (male vs female), BMI, Nephrometry score and tumor size. The analysis indicated no significant differences between SP-RAPN and MP-RAPN regarding age ($p = 0.86$), BMI ($p = 0.08$), Nephrometry score ($p = 0.46$), tumor size ($P = 0.75$), sex (male vs female) ($P = 0.29$). Table 4 presents meta-analysis of baseline patient and tumor characteristics outcomes.

Perioperative outcomes and major complications (Fig. 2 a, b, c, d, e, f, g): according to our analysis, there were no noteworthy differences in operational time (aggregated from 8 studies; $p = 0.54$), off-clamp ($p = 0.36$), blood loss (8 studies; $p = 0.31$) and major complications (Clavien–Dindo grade ≥ 3) (4 studies; $p = 0.68$) between SP-RAPN and MP-RAPN. However, SP-RAPN was associated with a shorter hospital stay (5 studies; WMD − 0.26 day, 95% CI − 0.36–− 0.15; $p < 0.00001$), longer warm ischemia time (WIT) (7 studies; WMD 3.13 min, 95% CI 0.81 to 5.46; $p = 0.008$) and higher transfusion rate (4 studies; OR 2.99, 95% CI 1.31–6.80; $p = 0.009$) compared to SP-RAPN.

Oncological outcomes (Fig. 3): the analysis revealed no noteworthy differences between SP-RAPN and MP-RAPN regarding positive surgical margins (PSMs) (6 studies; $p = 0.78$).

Heterogeneity

Most outcomes displayed moderate to high levels of heterogeneity. Low heterogeneity was identified in age, BMI, Nephrometry score, tumor size, gender (male vs female), blood loss, transfusion rate, PSM, and major complications. However, caution is warranted when interpreting the heterogeneity of these results as low, given that I^2 exhibits significant bias when there are few studies [27].

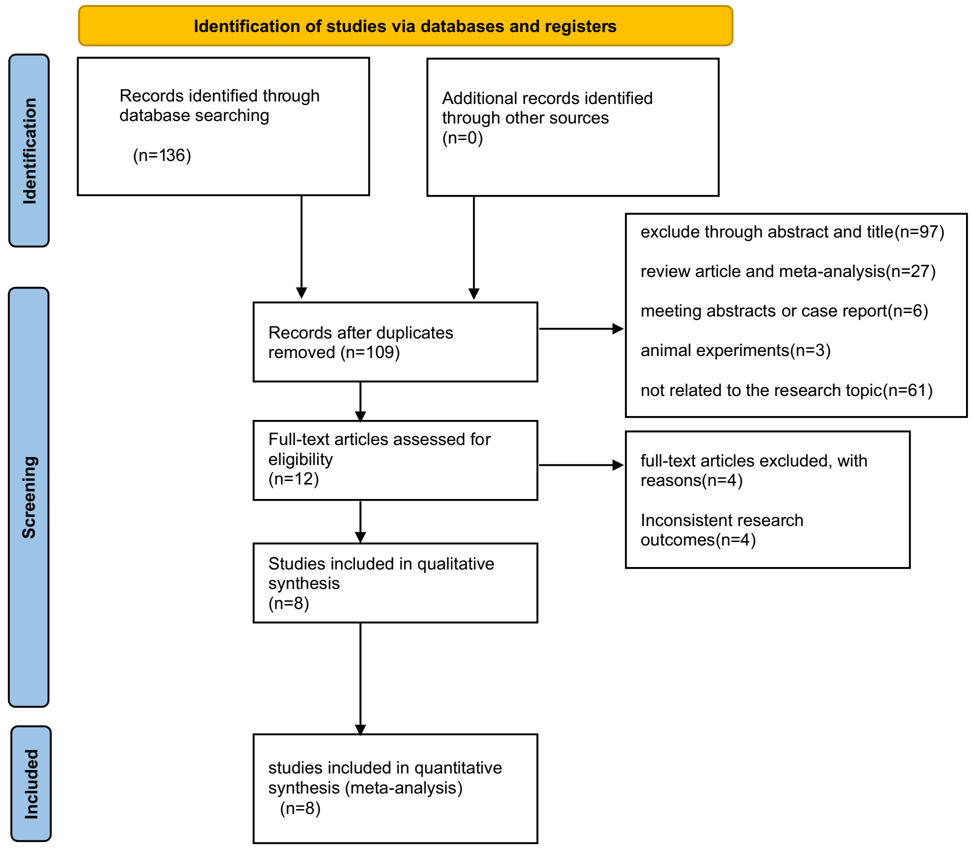

Fig. 1 PRISMA flow diagram for the meta-analysis

Table 1 Characteristics of studies

Author	Study period	Country	Study design	Patient numbers		Surgical methods	NOS score
				SP	MP		
Glaser et al. [19]	2019–2020	USA	Retrospective	26	52	Transperitoneal and retroperitoneal	8
Harrison et al. [20]	2019–2020	USA	Prospective	48	48	Transperitoneal and retroperitoneal	9
Komninos et al. [21]	2006–2012	Korea	Retrospective	78	89	Transperitoneal	9
Licari et al. [22]	2021–2023	USA	Prospective	30	30	Transperitoneal and retroperitoneal	7
Mehrazin et al. [23]	2019–2020	USA	Prospective	50	50	Transperitoneal and retroperitoneal	9
Okhawere et al. [24]	2015–2022	USA	Prospective	146	146	Retroperitoneal	8
Palacios et al. [25]	2013–2021	USA	Retrospective	20	42	Retroperitoneal	9
Shin et al.[26]	2006–2012	Korea	Retrospective	79	80	Transperitoneal	9

Sensitivity analysis

In our meta-analysis, certain outcomes exhibited significant heterogeneity (off-clamp $I^2=82\%$, LOS $I^2=52\%$, OT $I^2=65\%$, WIT $I^2=77\%$). Off-clamp and WIT showed particularly high heterogeneity, while length of hospital stay and OT displayed moderate heterogeneity. Other outcomes showed no significant heterogeneity. Sensitivity analyses were conducted on the target parameters to ensure stable and robust conclusions. We conducted leave-one-out analyses to investigate the stability of summary effects, excluding studies one by one. We found that the heterogeneity in off-clamp decreased from $I^2=82\%$ to 0% after excluding data from Glaser 2022. This variation might stem from preferences of surgeons in Glaser 2022 for "off-clamp" procedures, significantly influencing the proportion of "off-clamp" cases. Similarly, after excluding data from Palacios 2022, the heterogeneity in length of hospital stay decreased from $I^2=52\%$ to 0%. This reduction could be attributed to the use of a retroperitoneal robotic assisted approach in that study, which potentially reduced surgical duration. Even after employing the leave-one-out analyses to remove data from Glaser

Table 2 Baseline characteristics of included studies

Author	Year	Patient numbers		Age (years)		Sex (Male/Female)		BMI		Tumor size(cm)		Nephrometry score	
		SP	MP	SP	MP	SP	MP	SP	MP	SP	MP	SP	MP
Glaser et al. [19]	2022	26	52	58.4 ± 13.4	53.2 ± 13.2	21/5	34/18	32.5 ± 6.6	33.8 ± 7.8	3.5 ± 1.3	3.3 ± 1.6	NA	NA
Harrison et al. [20]	2022	48	48	59.5 ± 13.7	62 ± 13.7	22/26	22/26	27.4 ± 5.11	28.8 ± 6.15	2.4 ± 1.63	2.2 ± 1.11	7 ± 2.96	7 ± 2.96
Komninos et al. [21]	2014	78	89	52.3 ± 13	50.7 ± 13.3	51/27	53/36	23.9 ± 3	24.3 ± 3.2	3 ± 1.6	3.1 ± 1.7	7.4 ± 2	7.1 ± 1.9
Licari et al. [22]	2024	30	30	63 ± 9.33	58 ± 10.37	12/18	18/12	29.4 ± 5.56	32.6 ± 6.96	3.1 ± 1.33	3.5 ± 2	5 ± 2.22	5 ± 2.22
Mehrazin et al. [23]	2023	50	50	54.5 ± 13.93	59 ± 10.22	24/26	31/19	28.8 ± 5.5	28.5 ± 4.3	2.75 ± 0.89	3.24 ± 1.22	NA	NA
Okhawere et al. [24]	2022	146	146	58 ± 12	59 ± 12	79/67	70/76	30.15 ± 6.48	30.06 ± 6.86	2.94 ± 1.34	2.96 ± 1.61	6 ± 2.22	6 ± 2.22
Palacios et al. [25]	2022	20	42	56.5 ± 12.22	60 ± 7.41	16/4	25/17	30.75 ± 10.07	29.88 ± 5.93	2.8 ± 0.89	2.4 ± 1.63	4 ± 1.48	6 ± 1.48
Shin et al.[26]	2014	79	80	52.4 ± 12.9	52.0 ± 13.2	51/29	47/33	24.0 ± 3.0	24.6 ± 3.2	3.4 ± 1.9	3.1 ± 1.8	7.5 ± 2.1	7.1 ± 1.9

2022 (off-clamp) and Palacios 2022 (length of hospital stay), our results consistently demonstrated that SP-RAPN outperforms MP-RAPN in terms of OT. Furthermore, after utilizing the leave-one-out method to exclude, we discovered that the remaining findings stayed consistent (Fig. 4).

Discussion

In 2019, Kaouk et al. published the first report on the safety and viability of SP-RAPN [28]. With the goal of improving surgical outcomes, such as better pain management and cosmetic outcomes, minimally invasive robotic surgery (MIRS) is more popular than traditional laparoscopic and open surgeries [29]. Therefore, single-port robotic surgery has been adopted by multiple specialties aiming to further reduce incision size, alleviate postoperative pain, and improve patient satisfaction in aspects such as scar recovery and length of hospital stay. We systematically assessed the impact of single-port vs. multi-port robotic surgery on perioperative outcomes and oncological prognosis across various surgical disciplines in our meta-analyses, our results offer insightful information on the relative efficacy of two surgical techniques, contributing to the ongoing discourse on optimizing surgical techniques. This result of meta-analysis is especially significant since it compares a novel surgical technique—which usually entails a learning curve [30]—with an established surgical methodology.

While the trifecta idea is well known for analyzing the efficiency of radical prostatectomy, it is a relatively new word for evaluating the efficacy of various partial nephrectomy methods, independent of the methodology. It is critical to properly assess and contrast the early safety and effectiveness of various kidney-sparing surgical techniques. The meaning of trifecta results in PN situations is still up for debate. In order to identify the optimal result for patients undergoing PN, Buffi et al. define the term MIC (margins, ischemia time, and complications), which refers to surgical margins negative, warm ischemia duration < 20 min, and minimum surgical sequelae [31–33]. Thus, it is vital to recognize that low surgical complications and negative surgical margins are necessary to achieve the trifecta. However, there is still disagreement on the inclusion of WIT (Warm Ischemia Time) as the third element in the trifecta definition. According to Frank et al., a safe duration of therapy (WIT) is between 20 and 30 min; nonetheless, each minute counts when clamping the renal hilum [34].

Our meta-analysis revealed no statistically significant differences in severe complications or surgical duration; however, SP-RAPN tended to have longer WIT than MP-RAPN surgery. According to Komninos et al., there is a greater chance of not achieving the trifecta outcome when there is

Table 3 Perioperative and oncologic outcomes

Author	Year	Patient numbers		Operative time (mins)		Hospital stay (day)		Warm ischemia time (mins)		Blood loss(ml)		PSM(n)		Transfusion(n)		Off-clamp (n)		Total perioperative MME		major complications	
		SP	MP	SP	MP	SP	MP	SP	MP	SP	MP	SP	MP	SP	MP	SP	MP	SP	MP	SP	MP
Glaser et al. [19]	2022	26	52	183.9 ± 63.5	208.6 ± 65	NA	NA	NA	NA	> 500 ml:8	> 500 ml:8	NA	NA	3	1	24	20	149 ± 130.1	235 ± 316.4	2	2
Harrison et al. [20]	2022	48	48	102 ± 51.85	96.5 ± 28.15	1.4 ± 0.34	1.6 ± 0.29	17 ± 7.41	16 ± 6.67	50 ± 51.85	60 ± 37.04	3	4	0	0	9	13	5.1 ± 12.3	9.3 ± 20.59	1	1
Komninos et al. [21]	2014	78	89	208 ± 83	173 ± 75.8	NA	NA	26.5 ± 10.5	20.2 ± 12.8	335 ± 332	313 ± 309	4	1	7	4	NA	NA	NA	NA	NA	NA
Licari et al. [22]	2024	30	30	155.5 ± 85.33	189.5 ± 43.56	1.04 ± 0.32	1.42 ± 0.55	25 ± 12.59	27 ± 8.15	50 ± 138.89	100 ± 111.11	5	4	1	0	6	8	NA	NA	2	2
Mehrazin et al. [23]	2023	50	50	90 ± 22.22	90 ± 23.56	1 ± 0	1 ± 0	12 ± 5.19	12 ± 3.70	50 ± 37.04	50 ± 18.52	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Okhawere et al. [24]	2022	146	146	137.02 ± 59.59	142.35 ± 60.69	1.19 ± 1.9	1.33 ± 1.05	18.29 ± 10.49	13.79 ± 6.29	89.38 ± 111.19	112.46 ± 157.79	9	7	NA	NA	NA	NA	NA	NA	NA	NA
Palacios et al. [25]	2022	20	42	166.5 ± 48.52	158.5 ± 37.04	1 ± 0.89	2 ± 1.48	25 ± 7.41	20 ± 6.67	50 ± 22.22	50 ± 55.57	0	4	NA	NA	1	0	NA	NA	1	2
Shin et al. [26]	2014	79	80	210.3 ± 83.4	183.1 ± 76.1	4.6 ± 2.1	4.8 ± 2.2	26.5 ± 10.5	19.8 ± 13.1	334.9 ± 380	313.0 ± 392.5	2	7	9	3	NA	NA	NA	NA	NA	NA

Table 4 Meta-analysis of baseline characteristics

Variable	Included studies	WMD/OR	95% CI	*p* value
Age (years)	8	− 0.14	(− 1.67, 1.39)	0.86
Sex (male/female)	8	1.15	(0.89, 1.48)	0.29
BMI	8	− 0.5	(− 1.04, 0.05)	0.08
Tumor size (cm)	8	− 0.03	(− 0.21, 0.15)	0.75
Nephrometry score	6	− 0.21	(− 0.90, 0.49)	0.56

a larger tumor, higher PADUA and RENAL scores, higher EBL, involvement of the collecting system, and involvement of the renal sinus. They discovered that the only factors that can predict trifecta success are distinct surgical techniques and tumor sizes. However, in the literature, we included, only one article mentioned the trifecta definition, so it was not possible to evaluate whether tumor size can affect trifecta outcomes (margins, ischemia time, and complications). Therefore, more literature is needed in the future to fill this gap.

Perioperative outcomes are a paramount concern in RAPN. Our analysis revealed several significant findings regarding perioperative outcomes. SP-RAPN demonstrated advantages regarding shorter length of hospital stay (WMD − 0.26 day, 95% CI − 0.36–− 0.15; $p < 0.00001$) contrasted to MP-RAPN. In most included studies, the average LOS for SP-RAPN is approximately 1.04–1.4 days [20, 22, 24, 25], while Shin et al. reported an average discharge duration of approximately 4.6 days [26]. Regarding postoperative recovery, using the SP system requires only a small incision, potentially reducing postoperative pain, decreasing the need for analgesics, and shortening hospital stays. Although there was no difference in hospital stays in the previously mentioned study including Komninos et al. [21], Mehrazin et al. [23] and Okhawere et al. [24]. Harrison et al.[20], Licari et al. [22] and Palacios et al. [25] reported a significant difference in hospital stays. It can also be inferred that a more significant factor may be the more widespread adoption of retroperitoneal access in SP-RAPN. A retroperitoneal technique was used for all procedures in the SP-RAPN and MP-RAPN groups, according to Palacios et al. [25], underscoring the substantial influence of SP platform utilization on length of hospital stay.

Our research revealed no discernible difference in operational time (OT) between MP-RAPN and SP-RAPN. This observation might be explained by a number various items: (1) a quick learning curve for using the novel surgical approach; (2) prospects for a quicker and more effective docking procedure. However, when compared to the MP-RAPN, Komninos et al. and Berry et al. [35] discovered that the SP-RAPN required longer OT. This might mean that when the new platform's difficulties become more obvious, SP-RAPN should be carefully chosen during the early stages of adoption.

We demonstrated a significant difference in WIT for our study (WMD 3.13 min, 95% CI 0.81 to 5.46; $p = 0.008$) between SP-RAPN and MP-RAPN. While Licari et al. [22], Mehrazin et al. [23], Palacios et al. and Harrison et al. observed no discernible differences in WIT between MP-RAPN and SP-RAPN. One explanation for this result is that the early series also feature the surgeons' first "learning phase." In single-port systems, instruments are typically more complex in design, requiring additional time for adjustment and manipulation, particularly when dealing with deep tissues or vascular structures. First, using clips for suturing may take longer if auxiliary ports are not used since every time a clip is used, single-port systems must be disassembled, loaded, and reinserted. Second, surgeons skilled in using the Da Vinci Si or Xi systems execute SP-RAPN. Furthermore, the SP system is simpler to dock and needs fewer port sites than the MP system, which can help seasoned robotic surgeons get over their learning curve. Thus, we think that for surgeons who have performed Con-RARP (conventional robotic assisted radical prostatectomy), the learning curve for SP-RAPN is rather short [19]. Third, longer WIT and OT are linked to bigger tumor size, higher tumor complexity, and more complicated vascular architecture, according to a study by Pandolfo et al. Tumor size and location were found to be independent determinants of WIT by multivariate analysis. The study also clarified that functional results are comparable between the renal pedicle and non-pedicle groups, even if the intricacy of anatomical localization is linked to longer WIT and higher EBL. This implies that tumor complexity resulting from the hilar site has no effect on functional results once RAPN is executed effectively [36, 37].

It is noteworthy to note that there were more transfusions rate (OR 2.99, 95% CI 1.31–6.80; $p = 0.009$) in the SP-RAPN. First, because most surgeons depend on visual judgment rather than more accurate procedures, there is a chance that intraoperative blood loss estimates might be inaccurate, which makes it important to evaluate this observed outcome carefully. Second, many studies did not clearly define transfusion criteria, transfusion protocols, units transfused, or time of postoperative transfusions. Therefore, future research should emphasize reporting methods for estimating blood loss, transfusion criteria, and time of transfusions. Third, the initial learning curve may also be associated with higher transfusion requirements. Inexperienced handling during the surgical process can increase the risk of bleeding, especially when dealing with large or complex tumors. However, as the surgical team's skills improve and the surgical process is optimized, the transfusion rate often decreases significantly.

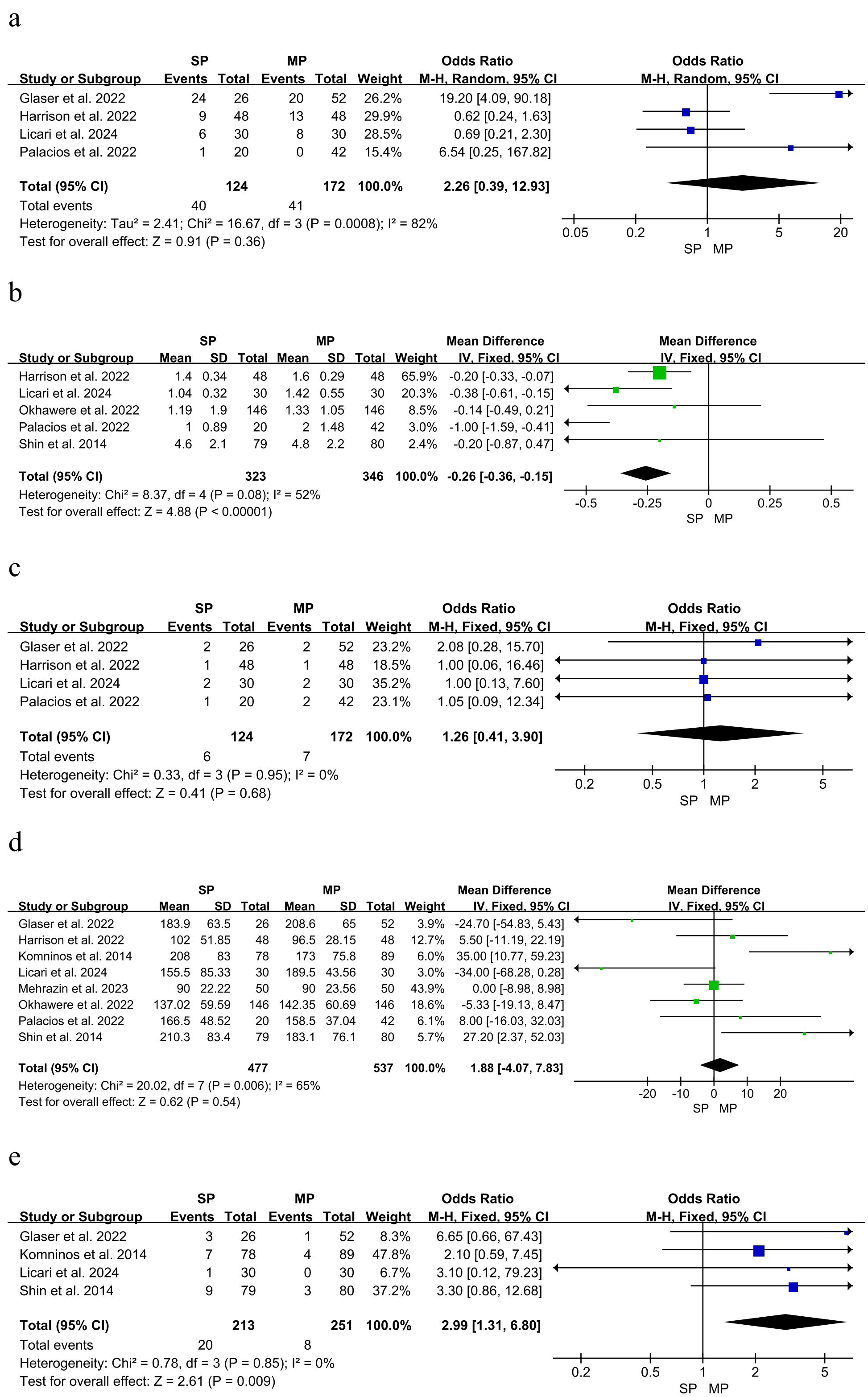

Fig. 2 Forest plot of meta-analysis of the following variables: **a** off-clamp, **b** hospital stay, **c** major complications, **d** operative time, **e** transfusion rate, **f** warm ischemia time (WIT), **g** blood loss

Tumor size and Nephrometry score do not significantly differ between SP-RAPN and MP-RAPN. Despite comparing SP-RAPN to MP-RAPN using positive surgical margin PSM without differences, negative surgical margin (NSM) is generally considered representative of tumor safety, but the clinical impact of PSM remains controversial [38]. Licari et al. [22] demonstrated no recurrence during follow-up with SP-RAPN.

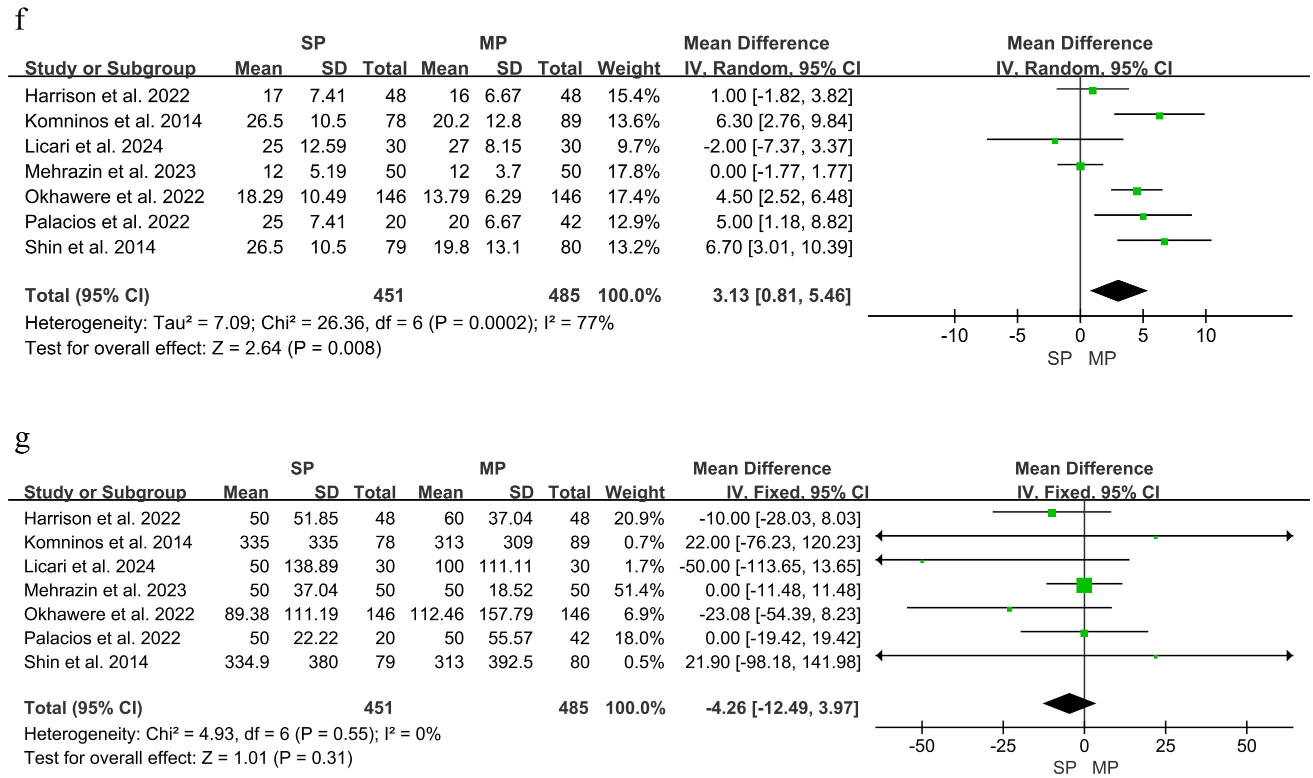

Fig. 2 (continued)

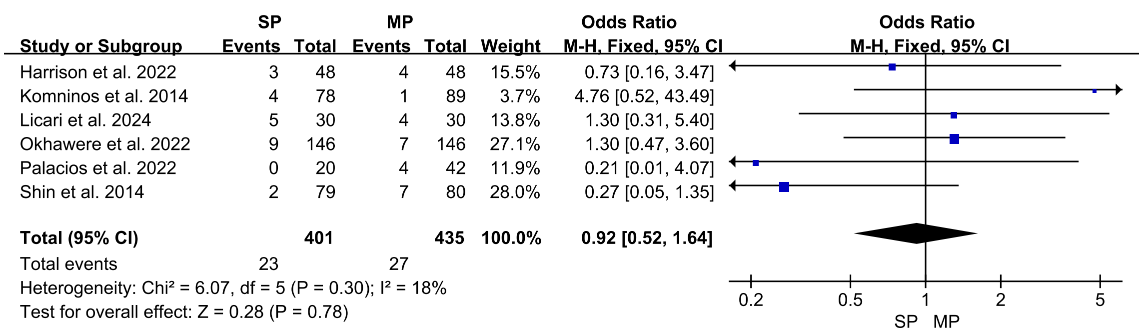

Fig. 3 Forest plot of meta-analysis of PSM

With the maturation of surgical experience and confidence, the utilization of SP-RAPN has increased in recent years. Importantly, it is crucial to recognize that a variety of factors might influence the choice between a novel surgical strategy and an established one, including but not limited to patient and tumor-related concerns, platform accessibility, and most significantly, the surgeon's own inclinations. Lastly, it is important to keep in mind that managing complicated kidney malignancies may benefit greatly from the application of modern technology. Sustaining continuous technological improvements and advancements, such as the application of augmented reality, new ultrasound techniques, adjustments to surgical techniques and reconstruction, and early postoperative recovery protocols, may prove to be indispensable in managing cases this difficult. According to preliminary findings, the preoperative and perioperative use of three-dimensional models can optimize the preservation of renal function, providing additional tools to improve functional results in partial nephrectomy [36, 37].

Limitations

Even with these encouraging outcomes, there are still several shortcomings in our meta-analysis. The eight studies we included comprised comparable cohorts of low complexity

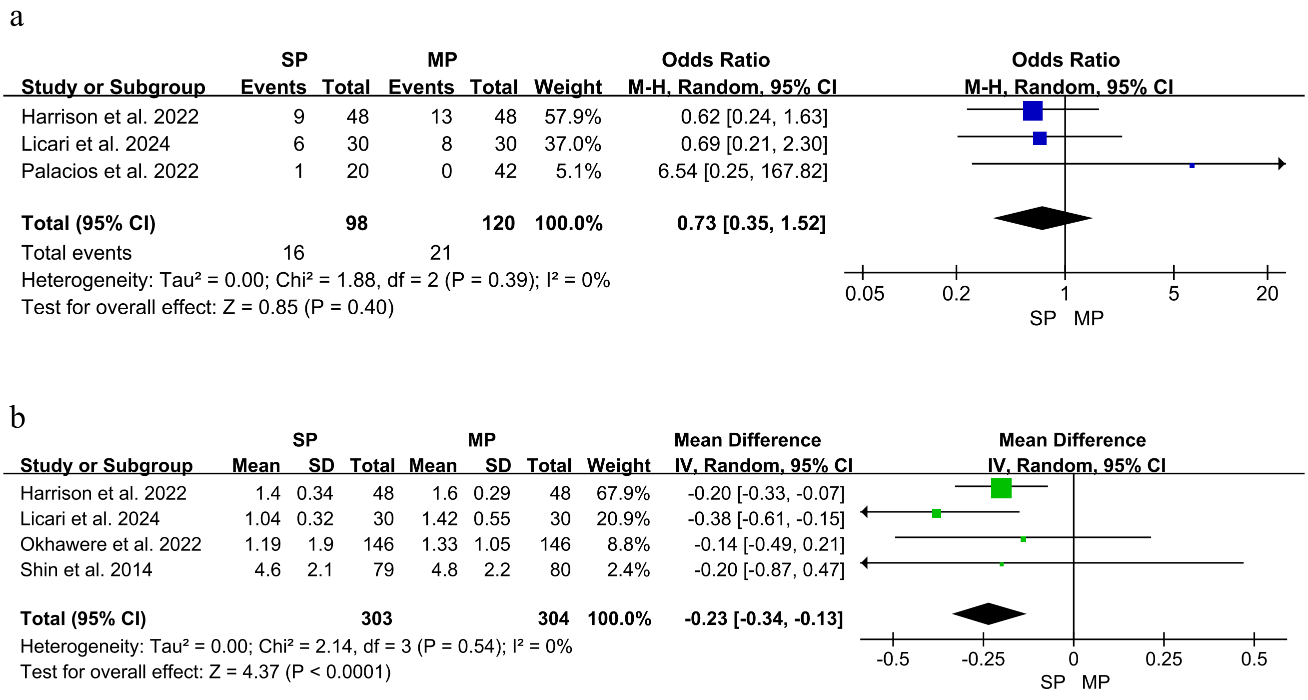

Fig. 4 Forest plot of meta-analysis of the following variables: **a** off-clamp, **b** hospital stay

renal tumors based on Nephrometry score (5–8) and average tumor sizes (2.2 to 3.5 cm). We note that these findings may not generalize to individuals with more complex renal tumors. The ability of SP-RAPN to provide patients with complicated or larger renal tumors with perioperative results and a tumor prognosis comparable to MP-RARP is still unknown. Thus, more investigation is required to confirm MP-RAPN's effectiveness and safety in treating complicated or larger kidney masses. Furthermore, we are aware of the dearth of long-term follow-up information, especially with regard to long-term renal function and recurrence rates. This restriction can affect a thorough evaluation of surgical results. But certain important matters cannot be disregarded. First, we were unable to perform a meta-analysis to assess other oncological outcomes such overall survival, recurrence-free survival, and long-term renal function since there was not enough research. Second, the included studies' follow-up periods were too short to allow for the drawing of firm conclusions. Although preliminary data should come before comparing long-term outcomes for new technologies in our study, bigger sample long-term follow-up studies are still necessary to confirm these results, even if they should not be the main focus. This will help to give clinical practice more comprehensive guidelines and decision assistance. Among the studies we reviewed, Palacios et al. [25] reported that patients undergoing retroperitoneal SP-RAPN had shorter postoperative hospital stays compared to those undergoing retroperitoneal multi-port RAPN (MP-RAPN). For renal tumors of modest complexity, retroperitoneal SP-RAPN appears to be safe and does not negatively impact the perioperative course. Similarly, Vazquez-Martul et al. [39] have also demonstrated that a safe and efficient surgical technique is single-port retroperitoneal partial nephrectomy (SP-RAPN). We have reason to suspect that various surgical techniques may impact the outcomes of SP-RAPN and MP-RAPN. However, there is not enough literature in our analysis to do subgroup analyses based on various surgical techniques (transperitoneal or retroperitoneal). Therefore, to assess the perioperative results and the effectiveness of transperitoneal or retroperitoneal SP-RAPN and MP-RAPN as cancer treatments, more investigation is required.

Conclusion

SP-RAPN demonstrates comparable perioperative safety and efficacy to multi-port robotic assisted surgery. The longer WIT and maybe greater blood transfusion rates notwithstanding SP-RAPN performs better than MP-RAPN in terms of LOS. Furthermore, there is no discernible variation in terms of blood loss, operational duration, or incidence of postoperative complications when compared to multi-port robotically assisted surgery. However, regarding the analysis of tumor volume, especially for larger or more complex tumors, and its guidance on the choice between SP-RAPN and MP-RAPN, it is difficult to determine whether

SP-RAPN can provide perioperative and oncological outcomes similar to MP-RAPN. This is because in the studies included, both groups had an average RENAL score of 5–8 and average tumor sizes ranging from approximately 2.2 to 3.5 cm (indicating inclusion of predominantly small renal masses). Whether SP-RAPN can offer comparable outcomes to MP-RAPN for complex or large renal tumors remains uncertain. Therefore, more research is needed to validate the effectiveness and safety of the SP platform for complex or large renal tumors. In addition, due to the lack of relevant data in the studies we included, subgroup analyses based on transperitoneal versus retroperitoneal approaches were not feasible. Hence, more studies are required to evaluate the effectiveness of transperitoneal or retroperitoneal SP-RAPN and MP-RAPN as treatment modalities for renal cancer. Further research is required to ascertain its optimal application in surgical practice. Through a comprehensive synthesis of recent literature, this meta-analysis endeavors to contribute valuable insights into the evolving landscape of robotic assisted partial nephrectomy. By critically appraising the evidence and delineating the strengths and limitations of different robotic approaches, this study aims to inform clinical practice and guide future research directions.

Author contributions AH: protocol development, data collection and management, data analysis and manuscript writing. LZ and GC: protocol development and management, data analysis and manuscript writing. XZ, JL and YL: protocol development, data management and manuscript writing. XY: data management, data analysis, supervision and manuscript writing. All the authors have read and approved the final manuscript.

Funding The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Data availability All relevant data are within the paper.

Declarations

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical approval Not applicable since this is a systematic review and meta-analysis.

References

1. Pal RP, Koupparis AJ (2018) Expanding the indications of robotic surgery in urology: a systematic review of the literature, Arab. J Urol 16:270–284. https://doi.org/10.1016/j.aju.2018.05.005
2. Rassweiler JJ, Autorino R, Klein J et al (2017) Future of robotic surgery in urology. Bju int 120:822–841. https://doi.org/10.1111/bju.13851
3. Dobbs RW, Halgrimson WR, Talamini S et al (2020) Single-port robotic surgery: the next generation of minimally invasive urology. World J Urol 38:897–905. https://doi.org/10.1007/s00345-019-02898-1
4. Franco A, Ditonno F, Manfredi C et al (2024) Single port robot-assisted radical and simple prostatectomy: a systematic review and meta-analysis. Prostate Cancer Prostatic Dis. https://doi.org/10.1038/s41391-024-00787-2
5. Leang YJ, Kong JCH, Mosharaf Z et al (2024) Emerging multi-port soft tissue robotic systems: a systematic review of clinical outcomes. J Robot Surg 18:145. https://doi.org/10.1007/s11701-024-01887-w
6. Choi JE, You JH, Kim DK et al (2015) Comparison of perioperative outcomes between robotic and laparoscopic partial nephrectomy: a systematic review and meta-analysis. Eur Urol 67:891–901. https://doi.org/10.1016/j.eururo.2014.12.028
7. Hinata N, Shiroki R, Tanabe K et al (2021) Robot-assisted partial nephrectomy versus standard laparoscopic partial nephrectomy for renal hilar tumor: a prospective multi-institutional study. Int J Urol 28:382–389. https://doi.org/10.1111/iju.14469
8. Kaouk JH, Goel RK (2009) Single-port laparoscopic and robotic partial nephrectomy. Eur Urol 55:1163–1169. https://doi.org/10.1016/j.eururo.2008.12.029
9. Patel MN, Krane LS, Bhandari A et al (2010) Robotic partial nephrectomy for renal tumors larger than 4 cm. Eur Urol 57:310–316. https://doi.org/10.1016/j.eururo.2009.11.024
10. Khosla A, Wagner AA (2016) Robotic surgery of the kidney, bladder, and prostate. Surg Clin North Am 96:615–636. https://doi.org/10.1016/j.suc.2016.02.015
11. Page MJ, McKenzie JE, Bossuyt PM et al (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372:n71. https://doi.org/10.1136/bmj.n71
12. Shea BJ, Reeves BC, Wells G et al (2017) AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ 358:j4008. https://doi.org/10.1136/bmj.j4008
13. Sterne JA, Hernan MA, Reeves BC et al (2016) ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ 355:i4919. https://doi.org/10.1136/bmj.i4919
14. Luo D, Wan X, Liu J et al (2018) Optimally estimating the sample mean from the sample size, median, mid-range, and/or mid-quartile range. Stat methods med res 27:1785–1805. https://doi.org/10.1177/0962280216669183
15. McGrath S, Zhao X, Steele R et al (2020) Estimating the sample mean and standard deviation from commonly reported quantiles in meta-analysis. Stat methods med res 29:2520–2537. https://doi.org/10.1177/0962280219889080
16. Higgins JP, Thompson SG, Deeks JJ et al (2003) Measuring inconsistency in meta-analyses. BMJ 327:557–560. https://doi.org/10.1136/bmj.327.7414.557
17. Lau J, Ioannidis JP, Terrin N et al (2006) The case of the misleading funnel plot. BMJ 333:597–600. https://doi.org/10.1136/bmj.333.7568.597
18. Sterne JA, Gavaghan D, Egger M (2000) Publication and related bias in meta-analysis: power of statistical tests and prevalence in the literature. J clin epidemiol 53:1119–1129. https://doi.org/10.1016/s0895-4356(00)00242-0
19. Glaser ZA, Burns ZR, Fang AM et al (2022) Single- versus multi-port robotic partial nephrectomy: a comparative analysis of perioperative outcomes and analgesic requirements. J Robot Surg 16:695–703. https://doi.org/10.1007/s11701-021-01271-y
20. Harrison R, Ahmed M, Billah M et al (2023) Single-port versus multiport partial nephrectomy: a propensity-score-matched comparison of perioperative and short-term outcomes. J Robot Surg 17:223–231. https://doi.org/10.1007/s11701-022-01415-8
21. Komninos C, Shin TY, Tuliao P et al (2014) R-LESS partial nephrectomy trifecta outcome is inferior to multiport robotic

partial nephrectomy: comparative analysis. Eur Urol 66:512–517. https://doi.org/10.1016/j.eururo.2013.10.058
22. Licari LC, Bologna E, Franco A et al (2024) Single-port vs multi-port robot-assisted partial nephrectomy: a single center propensity score-matched analysis. Eur J Surg Oncol 50:108011. https://doi.org/10.1016/j.ejso.2024.108011
23. Mehrazin R, Ranti D, Altschuler J (2023) Early perioperative outcomes of single-port compared to multi-port robot-assisted laparoscopic partial nephrectomy. J Robot Surg 17:2409–2414. https://doi.org/10.1007/s11701-023-01617-8
24. Okhawere KE, Beksac AT, Wilson MP et al (2022) A propensity-matched comparison of the perioperative outcomes between single-port and multi-port robotic assisted partial nephrectomy: a report from the single port advanced research consortium (SPARC). J Endourol 36:1526–1531. https://doi.org/10.1089/end.2022.0115
25. Palacios AR, Morgantini L, Trippel R et al (2022) Comparison of perioperative outcomes between retroperitoneal single-port and multiport robot-assisted partial nephrectomies. J Endourol 36:1545–1550. https://doi.org/10.1089/end.2022.0346
26. Shin TY, Lim SK, Komninos C et al (2014) Laparoendoscopic single-site (LESS) robot-assisted partial nephrectomy (RAPN) reduces postoperative wound pain without a rise in complication rates. Bju int 114:555–561. https://doi.org/10.1111/bju.12783
27. von Hippel PT (2015) The heterogeneity statistic I(2) can be biased in small meta-analyses. BMC Med Res Methodol 15:35. https://doi.org/10.1186/s12874-015-0024-z
28. Kaouk J, Garisto J, Eltemamy M et al (2019) Pure single-site robot-assisted partial nephrectomy using the sp surgical system: initial clinical experience. Urology 124:282–285. https://doi.org/10.1016/j.urology.2018.11.024
29. Garisto J, Bertolo R, Reese SW et al (2021) Minimizing minimally invasive surgery: current status of the single-port robotic surgery in Urology. Actas Urol Esp (Engl Ed) 45:345–352. https://doi.org/10.1016/j.acuroe.2021.04.011
30. Lai A, Chen GL, di Meo NA et al (2022) Single-port robotic surgery: general principles and troubleshooting. J Endourol 36:S25–S28. https://doi.org/10.1089/end.2022.0313
31. Bianco FJ Jr, Scardino PT, Eastham JA (2005) Radical prostatectomy: long-term cancer control and recovery of sexual and urinary function ("trifecta"). Urology 66:83–94. https://doi.org/10.1016/j.urology.2005.06.116
32. Buffi N, Lista G, Larcher A et al (2012) Margin, ischemia, and complications (MIC) score in partial nephrectomy: a new system for evaluating achievement of optimal outcomes in nephron-sparing surgery. Eur Urol 62:617–618. https://doi.org/10.1016/j.eururo.2012.06.001
33. Hung AJ, Cai J, Simmons MN et al (2013) "Trifecta" in partial nephrectomy. J Urol 189:36–42. https://doi.org/10.1016/j.juro.2012.09.042
34. Becker F, Van Poppel H, Hakenberg OW et al (2009) Assessing the impact of ischaemia time during partial nephrectomy. Eur Urol 56:625–634. https://doi.org/10.1016/j.eururo.2009.07.016
35. Berry JM, Hill H, Vetter JM et al (2023) Single-port vs multi-port robot-assisted renal surgery: analysis of perioperative outcomes for excision of high and low complexity renal masses. J Robot Surg 17:2149–2155. https://doi.org/10.1007/s11701-023-01637-4
36. Pandolfo SD, Cerrato C, Wu Z et al (2023) A systematic review of robot-assisted partial nephrectomy outcomes for advanced indications: large tumors (cT2-T3), solitary kidney, completely endophytic, hilar, recurrent, and multiple renal tumors. Asian j urol 10:390–406. https://doi.org/10.1016/j.ajur.2023.06.001
37. Pandolfo SD, Wu Z, Campi R et al (2024) Outcomes and techniques of robotic-assisted partial nephrectomy (RAPN) for renal hilar masses: a comprehensive systematic review. Cancers (Basel). https://doi.org/10.3390/cancers16040693
38. Shah PH, Moreira DM, Okhunov Z et al (2016) Positive surgical margins increase risk of recurrence after partial nephrectomy for high risk renal tumors. J Urol 196:327–334. https://doi.org/10.1016/j.juro.2016.02.075
39. Vazquez-Martul D, Iglesias-Alvarado J, Altez-Fernandez C et al (2023) Single-port retroperitoneoscopic partial nephrectomy: Initial description and standardisation of technique. J Minim Access Surg 19:278–281. https://doi.org/10.4103/jmas.jmas_109_22