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REVIEW

Open versus robot-assisted partial nephrectomy for highly complex renal masses: a meta-analysis of perioperitive and functional outcomes

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Abstract
Robot-assisted partial nephrectomy (RAPN) is increasingly being used for the complex surgical management of renal masses. The comparison of RAPN with open partial nephrectomy (OPN) has not yet led to a unified conclusion with regard to perioperative outcomes. To conduct a systematic review and meta-analysis of the literature on the perioperative outcomes of RAPN compared with OPN. We performed a systematic search in PubMed, Embase, Web of Science, and Cochrane Library database for randomized control trials (RCTs) and non-RCTs that compare OPN to RAPN. The primary outcomes included perioperative, functional and oncologic. The odds ratio (OR) and weighted mean difference (WMD) were applied for the comparison of dichotomous and continuous variables with 95% confidence intervals (CIs). Five studies, comprising 936 patients, were included in the meta-analysis. Our findings indicated that there were no significant differences in blood loss, minor complication rate, eGFR decline from baseline, positive surgical margin, and ischemia time between OPN and RAPN. However, RAPN was associated with a shorter hospital stay (WMD 1.64 days, 95% CI − 1.17 to 2.11; $p < 0.00001$), lower overall complication rate (OR 1.72, 95% CI 1.21–2.45; $p < 0.002$), lower transfusion rate (OR 2.64, 95% CI 1.39–5.02; $p = 0.003$) and lower major complication rate (OR 1.76, 95% CI 1.11–2.79; $p < 0.02$) compared to OPN. Additionally, the operation time for OPN was shorter than that for RAPN (WMD − 10.77 min, 95% CI − 18.49 to − 3.05, $p = 0.006$). In comparison with OPN, RAPN exhibits better results in terms of hospital stay, overall complications, blood transfusion rate, and major complications, with no significant difference in intraoperative blood loss, minor complications, PSM, ischemia time, and short-term postoperative eGFR decline. However, the operation time of OPN is slightly shorter than that of RAPN.

Keywords Robotic-assisted nephrectomy · Open partial nephrectomy · Renal mass · Robotic surgery · Meta-analysis

Introduction

Recently, there has been a growing body of evidence suggesting that partial nephrectomy (PN) is a viable option for treating localized renal cell carcinoma, offering oncological outcomes equivalent to those of radical nephrectomy [1]. In addition, PN is associated with better preservation of renal function, which may lower the risk of cardiovascular disease and translate into improved overall survival [2]. With the advent of robotic-assisted surgery, the conservative management of renal masses has been extended to include clinical T2 tumors with favorable oncological outcomes [3]. Despite these advantages, PN remains a challenging procedure with a non-negligible risk of perioperative complications [4]. To assess this, the RENAL nephrometry score and the Preoperative Aspects and Dimensions Used for an Anatomical (PADUA) score have been developed as assessment tools to predict surgical complexity, including postoperative complications or warm ischemic time (WIT) [5, 6]. These evaluation systems consider various factors, such as tumor size, location relative to polar lines, and exophytic/endophytic characteristics, to plan the most appropriate surgical procedure for the patient.

Over time, the surgical technique for PN has evolved from open PN (OPN) to laparoscopic PN (LPN) and then to robotic-assisted PN (RAPN), with the use of RAPN

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increasing steadily with the diffusion of the da Vinci Surgical System [7]. RAPN has expanded the spectrum of indications for PN, particularly in large and complex tumors, with its advantages of more convenient tumor excision and renorrhaphy [8, 9]. However, for some tumors, OPN may still be the preferred surgical method depending on the situation. Currently, there are few differences in perioperative and postoperative functional outcomes between OPN and RAPN, especially in complex renal masses.

This systematic review summarizes recent research on the differences in perioperative and functional outcomes between OPN and RAPN for complex renal masses.

Methods

This systematic review and meta-analysis were conducted as per the PRISMA statement [10] (Fig. 1).

Literature search strategy, study selection, and data collection

We conducted a systematic electronic literature search in March 2023 in PubMed, Embase, Web of Science, and Cochrane Library database. Intervention and patient-related search terms were combined to build the following search string: (complex renal tumor or renal mass) and (open partial nephrectomy) and (Robotic Surgical Procedures or Robotics or Robot-assisted). The search was limited to English. Inclusion criteria were defined using the PICOS approach. P (patients): All the patients were found to have renal mass or renal tumor; I (intervention): undergoing OPN; C (comparator): RAPN was performed as a comparator; O (outcome): one or more of the following outcomes: perioperative outcomes, functional outcomes; S (study type): prospective comparative, retrospective studies or randomized control trials. Exclusion criteria: (1) noncomparative studies; (2) editorial comments, meeting abstracts, case reports, book chapters, or studies reporting experimental; (3) none of the defined outcome measure analysis. (4) RENAL score < 9 or PADUA score < 10.

Two reviewers individually extracted data from the included studies. Data extracted for individual study included: (1) general information related to the article: first author, country, year of publication; (2) population characteristics: sample size, age, body massindex (BMI), tumor size, preoperative estimated glomerular filtration rate (eGFR); Charlson's comorbidity index (CCI) score; the number of patients with solitary kidney;renal tumor surgical score (3) perioperative outcomes: operative time, blood loss, hospital stay (4) overall complications (defined as Clavien grade ≥ 1), minor complications (Clavien < 3), major complications (defined as Clavien grade ≥ 3); transfusion rate; ischemia time and ischemia type (5) functional outcomes: eGFR decline from baseline (tow studies as sessment time of postoperative eGFRs were not clear [17, 18]) (6) oncologic outcomes: Positive surgical margins (PSMs), Stage at final pathology (pT). Any dispute was resolved by consensus or consultation with a third reviewer.

Assessment of risk of bias

Among the studies, ROBINS-I was applied to determine [11] bias due to (1) confounding, (2) selection of participants, (3) classification of exposures, (4) departures from intended exposures, (5) missing data, (6) measurement of outcomes,and (7) selection of the reported result.

Statistical analysis

Meta-analyses were performed using odds ratios (ORs) for dichotomous outcomes, while weighted mean differences (WMDs) were used for continuous outcomes. The results were reported with 95% confidence intervals (CIs). Meta-analyses of dichotomous variables were pooled using the Mantel–Haenszel method, and continuous variables were performed using the inverse variance method. Taking account of predictable substantial between-trial heterogeneity, a random-effects model was used to combine all summary data. Review Manager V5.4 software (Cochrane Collaboration, Oxford, United Kingdom) was used for result synthesis. Heterogeneity across the included studies was assessed using the I^2 statistic [12]. p values of < 0.05 were regarded as statistically significant. Data that could not be measured by meta-analysis were presented narratively.

Subgroup analysis

We performed a subgroup analysis based on the different ischemia type for this comparison: cold ischemia and warm ischemia. Subgroup analysis was performed on the difference between postoperative eGFR and baseline. There were two studies that included cold ischemia and warm ischemia in the literature sample [15, 16], but due to the small sample size of Beksac et al. [15]. Only the data of Garisto et al. [16] were collected.

Sensitivity analysis

We performed sensitivity analyses to assess the robustness of the estimates according to the size of the study cohort (excluding studies with < 150 patients) and

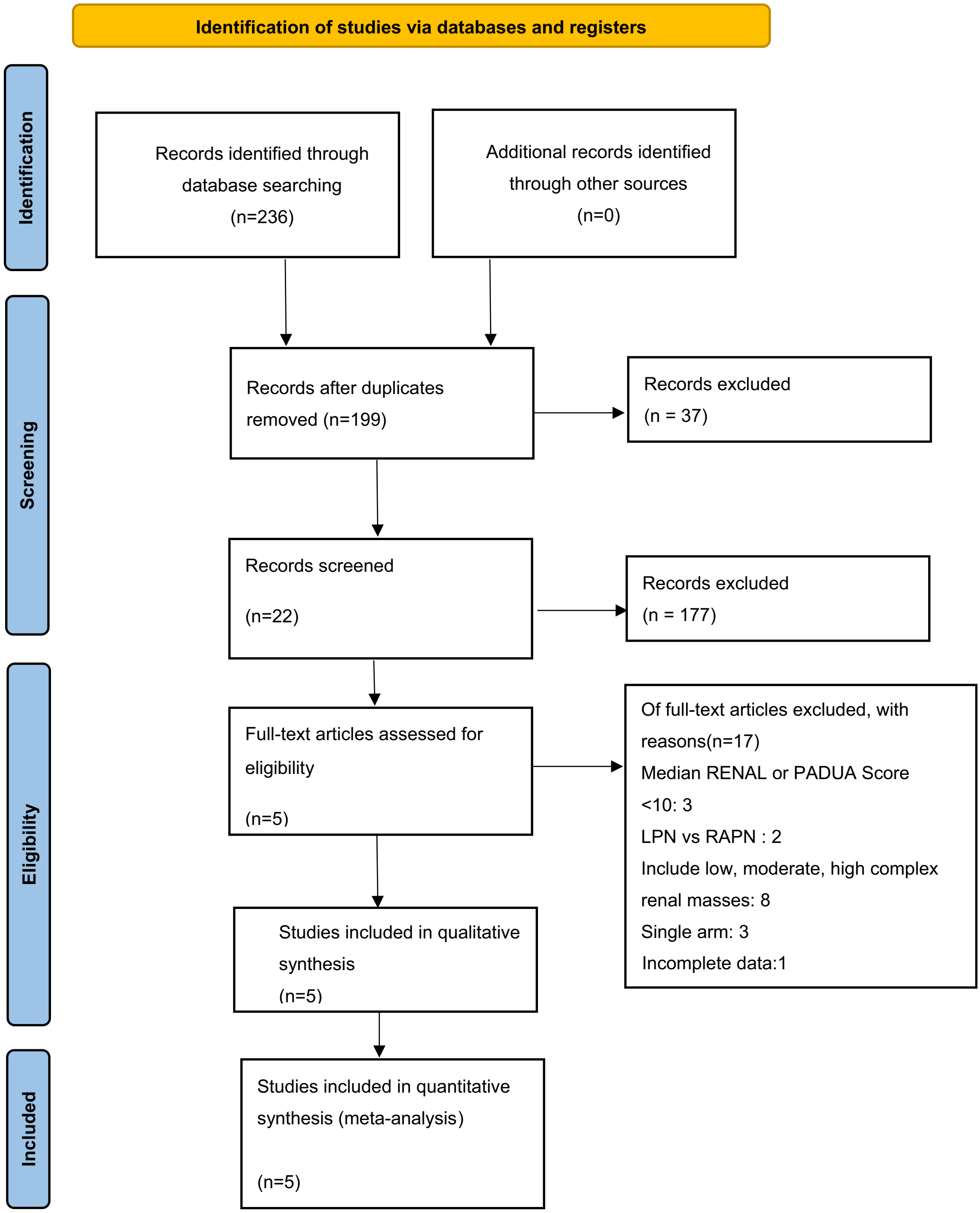

Fig. 1 PRISMA flow diagram for the systematic review

applied the leave-one-out method to exclude studies one at a time from the pooled effect. However, sensitivity analyses were not performed when comparing three or fewer studies.

Publication bias

Because the test power was lacking when ten or fewer studies were included, we could not evaluate the publication bias [13, 14].

Table 1 Characteristics of included studies

Author	Year	Region	Study type	No. of patients		Surgical approach		NOS score
				OPN	RAPN	OPN	RAPN	
Beksac	2022	USA	Retrospective	15	20	–	–	7
Garisto	2018	USA	Retrospective	76	203	Extraperitoneal	Transperitoneal	9
Harke	2018	Germany	Retrospective	76	64	Extraperitoneal	Transperitoneal	8
Kim	2019	Korea	Retrospective	64	85	–	–	9
Mari	2020	Italy	Retrospective	188	145	–	–	9

NOS Newcastle–Ottawa Scale; *OPN* open partial nephrectomy; *RAPN* robotic assisted partial nephrectomy

Results

Study characteristics

After preliminary screening and full-text review, we included 936 patients in 5 studies for meta-analysis (Fig. 1) [15–19]. Table 1 summarizes the key characteristics of the included articles, including the first author's name, publication year, geographic region, article type, sample size, surgical route, and Newcastle–Ottawa Scale (NOS) score, Table 2 summarizes the number and baseline demographics of the included patients having each intervention and their associated preoperative variables (age, BMI, gender rate, preoperative tumor size, Preoperative eGFR, CCI score, the number of patients with solitary kidney, and renal tumor surgical scoring system score). The baseline characteristics of the number of patients with solitary kidney were not relatively equal in one study (there were 10 (13.2%) patients with solitary kidney in OPN and 1 (16.%) in RAPN, respectively). However, the preoperative demographics were comparable in other studies, with similar age, BMI, gender rate, preoperative tumor size, Preoperative eGFR, CCI score observed in each of the included studies. Perioperative outcomes are summarized in Table 3.

For pathological and functional outcomes, the positive surgical margin (PSM) and stage at final pathology (pT) were documented in four articles, with the pathological grade referring to the grade of the malignant tumor. Four studies reported on the follow-up of the eGFR after one year. The pathological and functional outcomes of all the literature reviewed have been documented in Table 3.

Assessment of quality

No prospective studies comparing OPN vs RAPN were identified. Instead, all included studies were retrospective comparative studies conducted from 2018 to 2022. Overall, these five studies had a moderate risk of bias, as assessed by the Newcastle–Ottawa Scale (NOS) score.

Outcome analysis

Perioperative outcomes and complications. In the meta-analysis, it was observed that OPN had a slightly shorter operating time than RAPN (pooled from five studies; WMD − 10.77 min, 95% CI − 18.49 to − 3.05, $p = 0.006$) [15–19] (Fig. 2A). However, OPN patients had a longer hospital stay (four studies; WMD 1.64, 95%CI 1.17–2.11, $p < 0.00001$) [15, 16, 18, 19] (Fig. 2B). There was no statistically significant difference in blood loss between OPN and RAPN (four studies; $p = 0.08$) [15, 16, 18, 19] (Fig. 2C). Additionally, the ischemia time during surgery did not show any significant difference between the two approaches (five studies; $p = 0.06$) [15–19] (Fig. 3A). When comparing only studies that reported on warm ischemia time (WIT), there was still no significant difference (three studies; $p = 0.81$) [15–19]. RAPN required less intraoperative or postoperative blood transfusion (five studies; OR 2.64, 95% CI 1.39–5.02, $p = 0.003$) [15–19] (Fig. 3B). The overall complication rates were 28.2% (118 out of 419 cases) for OPN and 21.5% (111 out of 517 cases) for RAPN, respectively. OPN had a higher incidence of complications than RAPN (five studies; OR 1.72, 95% CI 1.21–2.45, $p = 0.002$) [15–19] (Fig. 3C), and the occurrence of major complications (Clavien ≥3) was also higher in OPN (from five studies; OR 1.76, 95% CI 1.11–2.79, $p = 0.02$) [15–19] (Fig. 4A). However, no statistical significance was found in minor complications (Clavien<3) (five studies; $p = 0.15$) [15–19] (Fig. 4B).

Pathological and functional outcomes In cases of warm ischemia, there was no statistical significance in the comparison of eGFR decline between OPN and RAPN (pooled from three studies; $p = 0.43$) [17–19] (Fig. 5). Similarly, there was no statistical significance in positive surgical margins (PSM) (four studies; $p = 0.13$) [15, 16, 18, 19] (Fig. 4C).

Heterogeneity

Most of the outcomes exhibited moderate to high heterogeneity. Low heterogeneity was found for PSM, overall

Table 2 The number of patients included in the five original articles and their baseline demographic characteristics

Reference	Beksac 2022		Garisto 2018		Harke 2018		Kim 2019		Mari 2020	
	OPN	RAPN	OPN	RAPN	OPN	RAPN	OPN	RAPN	OPN	RAPN
Number of patients, n	15	20	76	203	76	64	64	85	188	145
Age, years	62 (8)	60 (11)	60.7 (11.2)	59.8 (12.1)	59.2 (14.3)	63 (9.8)	50.9 (15.1)	51.5 (13.5)	63.7 (13.6)	59.5 (12.2)
Male gender, n (%)	11 (73.3)	13 (65)	44 (57.9)	125 (61.6)	46 (60.5)	44 (68.8)	42 (65.6)	55 (64.7)	116 (61.7)	86 (59.3)
BMI, kg/m^2	29.7 (5.1)	33.4 (7.8)	31.2 (6.1)	31 (6.8)	26.5 (4.1)	27 (3.5)	24.7 (2.7)	25 (3.4)	25.7 (3.7)	26 (3.5)
Tumor size, cm	6 (2.5)	5.8 (2)	5.2 (2)	5 (1.8)	2.5 (1)	2.6 (0.8)	3.4 (1.9)	4.1 (1.7)	–	–
Preoperative eGFR, mL/min/1.73m^2	54.9 (18.9)	61.1 (17.9)	75.9 (30.9)	79.9 (23.1)	91.2 (38)	97.7 (30.6)	85.4 (18.4)	90.4 (18)	83.9 (20.5)	83.3 (18.4)
CCI score	–	–	0.8 (1.1)	1 (1.49)	0.7 (1.5)	1 (1.5)	2 (1.5)	1.6 (0.8)	0.7 (1.5)	0.35(0.7)
Solitary kidney, n (%)	15 (100)	20 (100)	0	0	10 (13.2)	1 (1.6)	0	0	4 (2.2)	2 (1.4)
Renal tumor surgical scoring system										
RENAL score	9.6 (2.4)	8.6 (2.3)	10 (0)	10 (0)	–	–	–	–	–	–
PADUA score	–	–	–	–	10.6 (2.3)	10.6 (2.3)	10 (0)	10 (0)	10.6 (0.7)	10.3 (0.7)

OPN open partial nephrectomy; *RAPN* robotic assisted partial nephrectomy; *BMI* body mass index; *CCI* Charlson's comorbidity index; *eGFR* estimated glomerular filtration rate

complications, major complications, and operative time. However, it may be misleading to assume that the heterogeneity of these results was low because the I^2 has a substantial bias when the number of studies is small [20].

Discussion

Partial nephrectomy has been shown to reduce renal function impairment while yielding no difference in oncological outcomes, including better long-term survival, when compared to radical nephrectomy [21, 22]. When assessing the best PN approach, three objectives are considered: (a) minimizing perioperative complications, (b) completely removing the tumor, and (c) maximizing the preservation of remaining renal function. The previously proposed "trifecta", "margin, ischemia, and complications (MIC)" and other combined outcomes were all based on these three objectives [23]. For decades, the open approach has been the standard for performing PN. However, with advancements in minimally invasive surgery, LPN has rapidly gained interest for localized renal cell carcinoma due to its reduced invasiveness. Nonetheless, given that LPN is a challenging procedure, robot-assisted surgery now represents a valuable alternative, particularly for more complex tumors. Features such as improved dexterity, three-dimensional optics, a high-definition camera, and tremor filtration allow the surgeon to perform more precise excision and renorrhaphy. A meta-analysis by Aboumarzouk et al. compared LPN to RAPN [24], and the latter was found to offer significantly reduced warm ischemia time, making it a feasible and safe alternative to its laparoscopic counterpart. Additionally, other reports have shown satisfactory outcomes in the application of RAPN for larger (> 7 cm) and more complex tumors [25, 26]. Therefore, the robotic surgical system has been able to reproduce the techniques of OPN and LPN. With the adoption of minimally invasive approaches by many tertiary care centers, RAPN has replaced OPN as the preferred technique. This change in practice pattern has compelled us to conduct a study specifically focusing on highly complex renal masses to compare the outcomes of RAPN versus OPN. Therefore, This article presents the first comparative analysis of perioperative outcomes between OPN and RAPN for complex renal masses.

In this study, we compared the perioperative, functional, and oncologic outcomes of 517 patients who underwent RARP. Operative time, blood loss, hospital stay, postoperative renal functionand and complication were the main perioperative parameters of RARP and OPN. This data analysis shows that the surgical time for OPN is slightly shorter than RAPN. Both surgical procedures were performed by experienced surgeons, but this may be related to the learning curve of robot-assisted surgery and the longer

Table 3 Details of perioperative outcomes of five articles

Reference	Beksac 2022		Garisto 2018		Harke 2018		Kim 2019		Mari 2020	
	OPN	RAPN	OPN	RAPN	OPN	RAPN	OPN	RAPN	OPN	RAPN
Number of patients, n	15	20	76	203	76	64	64	85	188	145
Operative time, min	235.2 (74.4)	254.4 (97.3)	211.7 (49.9)	213.6 (68.7)	141.4 (51.3)	159.5 (46.2)	143.2 (56.9)	150 (60.3)	147.5 (54.5)	162.2 (70.4)
Estimated blood loss, mL	372.6 (327)	522.9 (638.2)	335.3 (226.7)	217.5 (186.7)	–	–	200 (151.7)	200 (150.8)	235.1 (224.1)	117.6 (112.3)
Hospital stay, days	6 (2.5)	4.2 (2.4)	4.8 (1.1)	3.4 (0.7)	–	–	7 (3)	5.7 (1.5)	5.4 (0.7)	3.4 (0.7)
Overall postoperative complications, n	8	8	32	57	16	14	15	16	47	16
Minor complications (Clavien < 3)	3	6	23	43	7	7	6	8	29	9
Major complications (Clavien ≥ 3)	5	2	9	14	9	7	9	8	18	7
Transfusion, n	3	2	12	6	7	4	7	8	26	6
Ischemia time, mins	48.9 (19.6)	27.3 (14.4)	38.4 (16.6)	27.6 (9.7)	17.6 (8.3)	13 (3)	23.1 (9.1)	25.8 (11.3)	19 (6)	19.7 (7.5)
Ischemia type (Cold or Warm)	Cold and warm	Cold and warm	Cold and warm	Cold and warm	Warm	Warm	Warm	Warm	Warm	Warm
Pathological and functional outcomes										
Positive surgical margins (PSM), n	3	3	10	18	–	–	1	0	13	7
eGFR decline from baseline	–	–	19.1 (36.73)	4.3 (30.1)	21 (19)	23.7 (20.6)	3.8 (16.6)	6.5 (18)	13.3 (14.1)	10.3 (15.3)
Stage at final pathology (pT), n										
pT1	0	7	41	133	–	–	57	74	131	102
pT2	2	0	8	18	–	–	3	10	3	4
pT3	13	13	18	28	–	–	4	1	18	14

OPN open partial nephrectomy; *RAPN* robotic assisted partial nephrectomy; *eGFR* estimated glomerular filtration rate

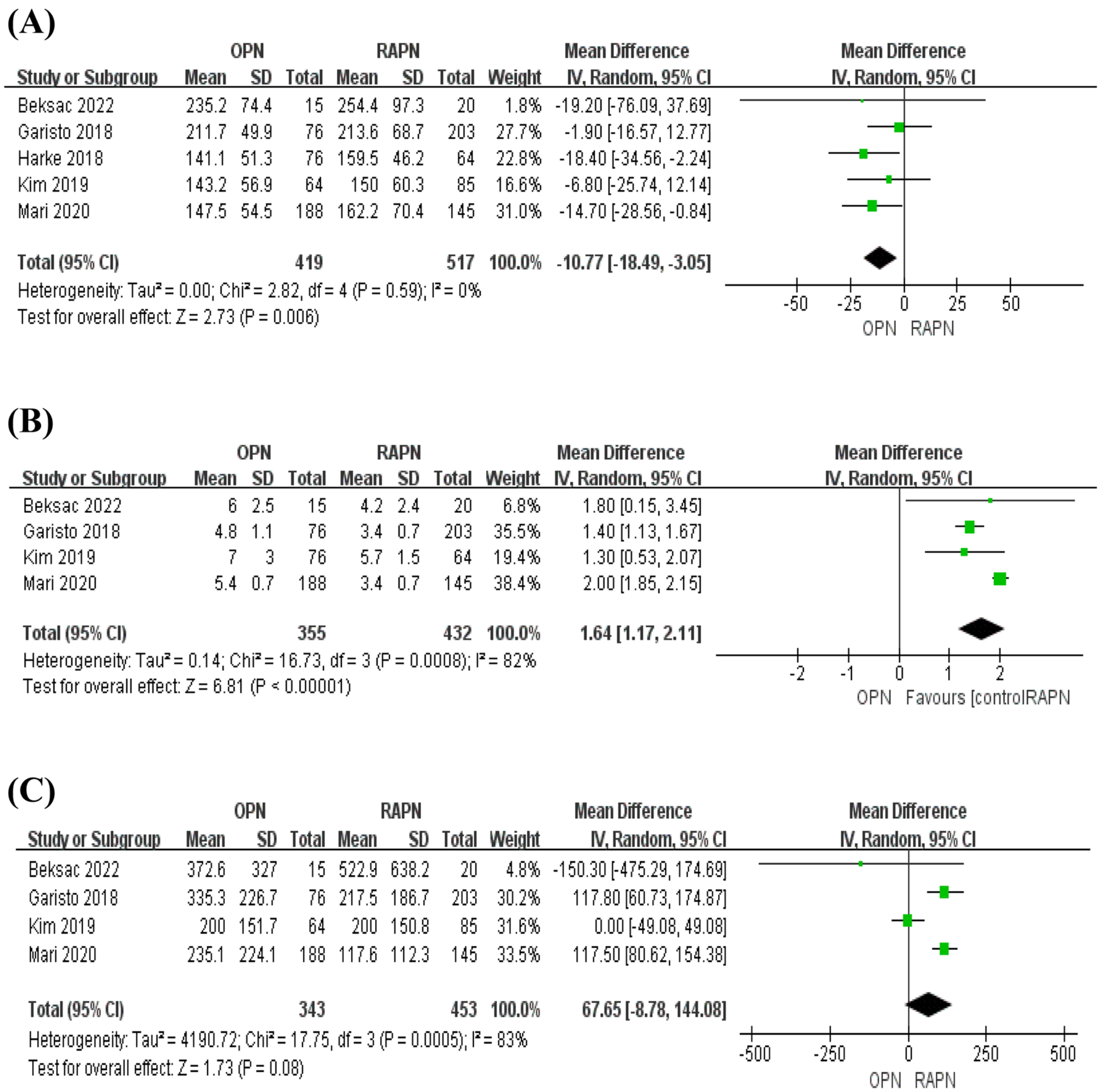

Fig. 2 Forest plot of meta-analysis of the following variables: **A** operative time, **B** hospital stay, **C** estimated blood loss, *CI* confidence interval; *df* degrees of freedom; *IV* inverse varianc; *SD* standard deviation

set-up time required for the robotic platform. It is believed that in the future, with continuous accumulation of experience, the surgical time for RAPN is expected to be comparable to that of OPN, and even shortened. There was no significant difference in intraoperative blood loss and ischemia time between the two, but the transfusion rate for OPN was significantly higher than RAPN. This may be due to the larger incision in open surgery and the inability to achieve the same level of precision in tissue and vascular separation during tumor resection as in robot-assisted surgery. As commonly acknowledged, the data shows that the length of hospital stay for OPN is longer than RAPN, which is consistent with the conclusions of previous studies [27, 28]. This may be related to the longer incision healing time for OPN patients, in which robot-assisted surgery has a significant advantage. Of course, complications have an inseparable relationship with the length of hospital stay. In terms of overall complications, the incidence of postoperative complications in RAPN is lower than that in open surgery, with no significant difference in minor complications, but in major complications, OPN is significantly higher than RAPN. That is to say, the severity of complications in OPN patients is higher than that in RAPN, which may significantly prolong the length of hospital stay, even though OPN mostly adopts the retroperitoneal approach.

Nephron sparing surgery (NSS) is currently the gold standard method to treat small renal masses [29]. Preserving as much residual nephron as possible is also important in complex renal masses, as patient quality of life after surgery

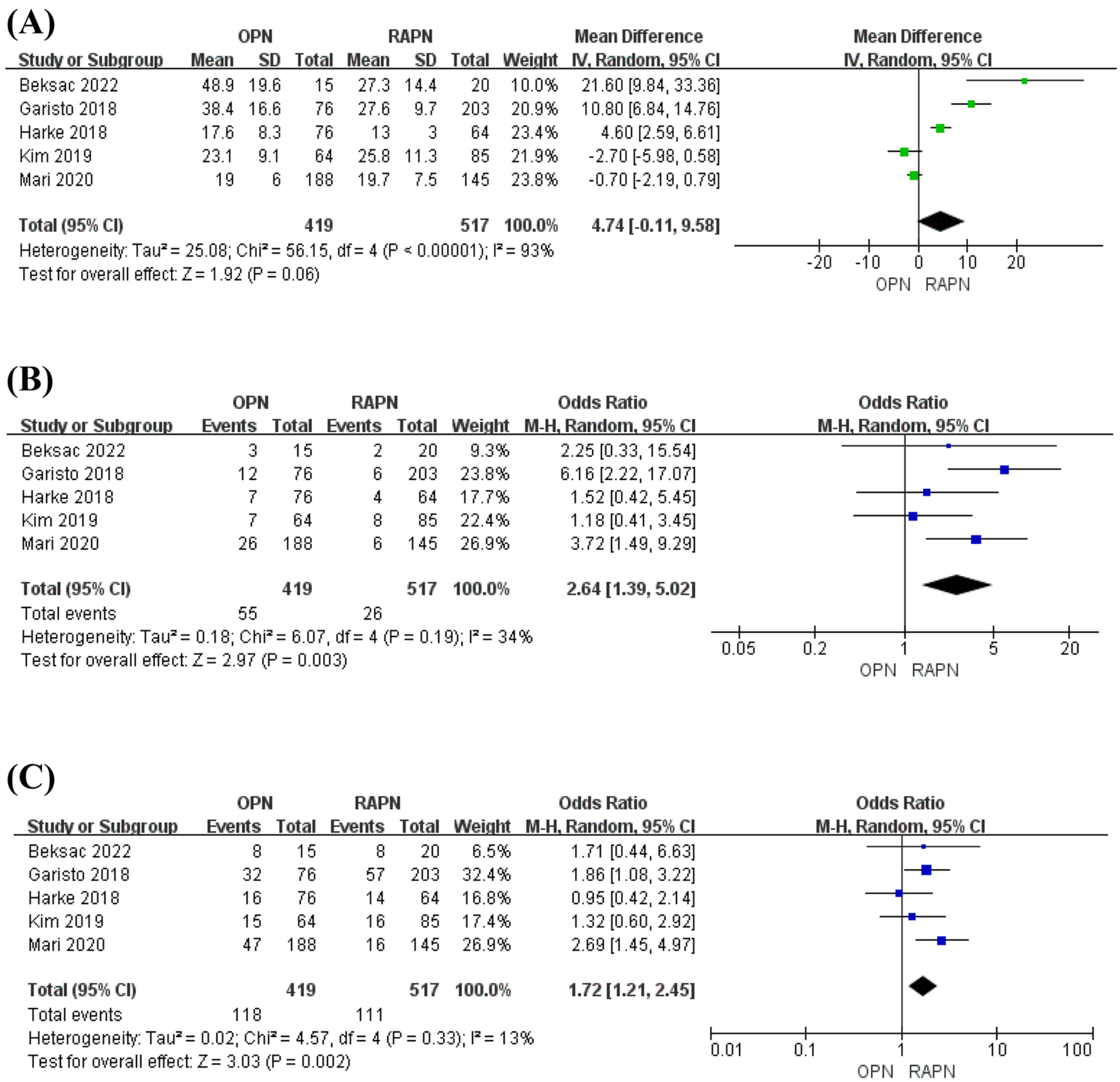

Fig. 3 Forest plot of meta-analysis of the following variables: **A** ischemia time, **B** transfusion, **C** overall complication, *CI* confidence interval; *df* degrees of freedom; *IV* inverse varianc; *M-H* Mantel-Haenszel; *SD* standard deviation

is closely related to postoperative renal function recovery. However, ensuring the integrity of tumor resection is also necessary, resulting in the “trifecta” concept. Studies indicate that the TRIFECTA completion rate decreases with a higher tumor score, making it challenging to strike a balance between nephron preservation and complete tumor removal. Nevertheless, RAPN demonstrates a higher completion rate than OPN in most score groups [17], and robot-assisted partial nephrectomy is expected to overcome this challenge over time. Additionally, WIT can also affect renal function. The study by Patel et al. in solitary kidney partial nephrectomy, each minute of WIT was found to be associated with a 6% increased risk of acute renal failure, a 7% increased risk of acute-onset end-stage renal disease (ESRD), and a 4% increased risk of new-onset ESRD while controlling for preoperative renal function, tumor size, and surgical approach [30]. The available data presented in this article demonstrate that there is no statistically significant difference in postoperative renal function between OPN and RAPN under similar warm ischemia conditions, which is consistent with the conclusion of Xia et al. [31]. Furthermore, the same PSM was not statistically significant. However, we still need more data to support those conclusions.

The present study has some limitations which need to be mentioned for the interpretation of the results. First, the included studies are retrospective with intermediate quality; they may have been affected by selection bias and unmeasurable confounding factors, also, we used two scoring systems

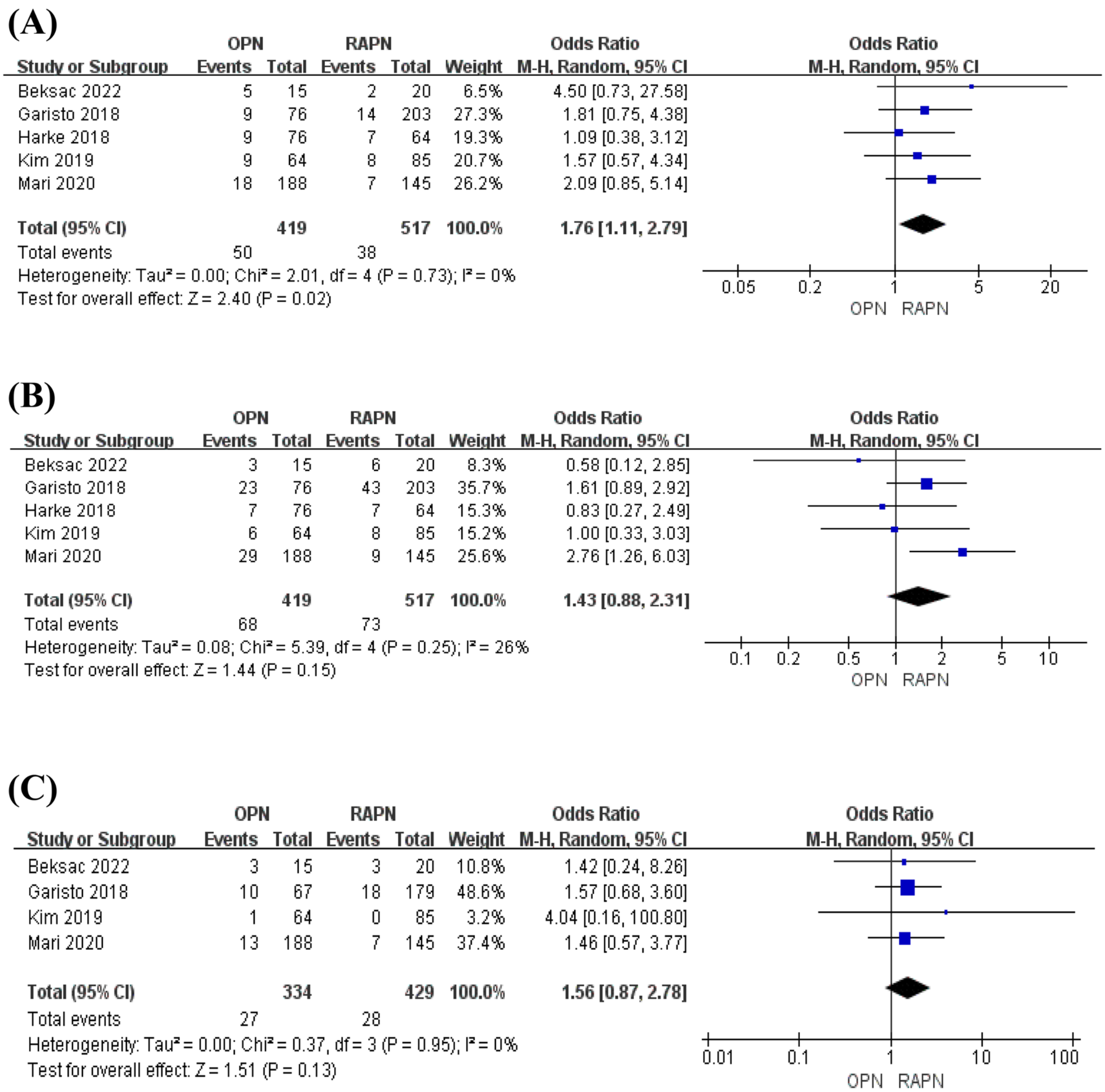

Fig. 4 Forest plot of meta-analysis of the following variables: **A** major complications (Clavien ≥ 3), **B** minor complications (Clavien < 3), **C** *PSM* positive surgical margins, *CI* confidence interval; *df* degrees of freedom; *M-H* Mantel-Haenszel

for tumor characteristics, which may have introduced bias. Second, some studies included more patients with only one kidney and higher preoperative chronic renal disease (CKD) stage (≥ 3), which had a potential impact on the postoperative renal function. Third, the short follow-up and the absence of standard definition limit the comparison between the surgical methods in terms of functional or oncologic outcomes.

Conclusion

The meta-analysis revealed that while the operation time for OPN is marginally shorter than that of RAPN for complex renal masses, the latter results in superior outcomes in terms of hospital stay, transfusion, overall complications, and major complications. However, there were no significant differences observed in Ischemia time, minor

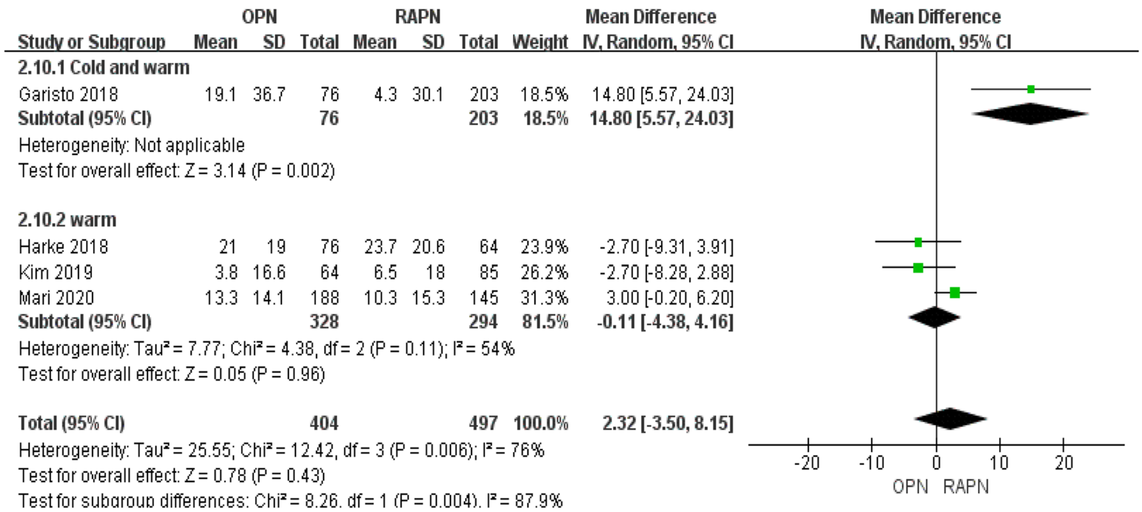

Fig. 5 Forest plot of meta-analysis of the following variables: eGFR decline from baseline, *CI* confidence interval; *df* degrees of freedom; *IV* inverse varianc, *SD* standard deviation

complications, PSM, short-term postoperative eGFR decline, or estimated blood loss between the two groups. Further well-designed randomized controlled trials (RCTs) with larger sample sizes and long-term follow-up are still necessary to validate and update the findings of this study.

Author contributions Protocol development: LZ, CG, CX, LY; literature search and database creation: LZ, CX and YX; formal analysis: LZ, CG, CX, LY; methodology: LZ, LY, and YX; supervision: YX; writing manuscript: LZ, CG, CX, LY, BE, HK, YX; All authors have read and approved the final manuscript.

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Data availability All relevant data are within the paper.

Declarations

Conflict of interest The authors declare no competing interests. No competing financial interests exist.

References

1. Albiges L, Abu-ghanem Y, Bensalah K et al (2019) European Association of Urology guidelines on renal cell carcinoma: the 2019 update. EurUrol 75:799–810
2. Van Poppel H, Da Pozzo L, Albrecth W et al (2011) A prospective randomized EORTC intergroup phase 3 studies comparing the oncologic outcomes of elective nephron sparing surgery and radical nephrectomy for low stage renal cell carcinoma. Eur Urol 59:543–552
3. Bertolo R, Autorino R, Simone G et al (2018) Outcomes of robot-assisted partial nephrectomy for clinical T2 renal tumors: a multicenter analysis (ROSULA Collaborative Group). Eur Urol 74:226–232
4. Mari A, Campi R, Schiavina R et al (2019) Nomogram for predicting the likelihood of postoperative surgical complications in patients treated with partial nephrectomy: a prospective multicentre observational study (the RECORd 2 project). BJU Int 124:93–102
5. Kutikov A, Uzzo RG (2009) The R.E.N.A.L. nephrometryscore: a comprehensive standardized system for quantitating renal tumor size, location and depth. J Urol 182:844–853. https://doi.org/10.1016/j.juro.2009.05.035. (**PMID:19616235**)
6. Ficarra V, Novara G, Secco S, Macchi V, Porzionato A, De Caro R, Artibani W (2009) Preoperative aspects and dimensions used for an anatomical (PADUA) classification of renal tumours in patients who are candidates for nephron-sparing surgery. Eur Urol 56(5):786–793. https://doi.org/10.1016/j.eururo.2009.07.040. (**Epub 2009 Aug 4 PMID: 19665284**)
7. Patel HD, Mullins JK, Pierorazio PM, Jayram G, Cohen JE, Matlaga BR et al (2013) Trends in renal surgery: robotic technology is associated with increased use of partial nephrectomy. J Urol 189:1229–1235. https://doi.org/10.1016/j.juro.2012.10.024. (**PMID:23085300**)
8. Malkoc E, Ramirez D, Kara O, Maurice MJ, Nelson RJ, Caputo PA et al (2017) Robotic and open partial nephrectomy for localized renal tumors larger than 7 cm: a single-center experience. World J Urol 35:781–787. https://doi.org/10.1007/s00345-016-1937-9. (**PMID:27663423**)
9. Bertolo R, Autorino R, Simone G, Derweesh I, Garisto JD, Minervini A et al (2018) Outcomesof robot-assisted partial nephrectomy for clinical T2 renal tumors: a multicenter analysis (ROSULA collaborative group). Eur Urol 74:226–232. https://doi.org/10.1016/j.eururo.2018.05.004. (**PMID:29784191**)
10. Shamseer L, Moher D, Clarke M et al (2015) Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. BMJ 350:g7647
11. Sterne JA, Herna´n MA, Reeves BC et al (2016) ROBINS-I: A tool for assessing risk of bias in non-randomised studies of interventions. BMJ 355:i4919
12. Higgins JP, Thompson SG, Deeks JJ et al (2003) Measuring inconsistency in meta-analyses. BMJ 327:557–560

13. 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
14. Lau J, Ioannidis JP, Terrin N et al (2006) The case of the misleading funnel plot. BMJ 333:597–600
15. Beksac AT, Okhawere KE, Abou Zeinab M, Harrison B, Stifelman MD, Eun DD et al (2022) Robotic partial nephrectomy for management of renal mass in patients with a solitary kidney: can we expand the indication to T2 and T3 disease? Minerva Urol Nephrol 74:203–208. https://doi.org/10.23736/S2724-6051.22.04671-7
16. Garisto J, Bertolo R, Dagenais J, Sagalovich D, Fareed K, Fergany A, Stein R, Kaouk J (2018) Robotic versus open partial nephrectomy for highly complex renal masses: Comparison of perioperative, functional, and oncological outcomes. Urol Oncol 36(10):471.e1-471.e9. https://doi.org/10.1016/j.urolonc.2018.06.012. (**Epub 2018 Aug 9 PMID: 30100111**)
17. Harke NN, Mandel P, Witt JH et al (2018) Are there limits of robotic partial nephrectomy? TRIFECTA outcomes of open and robotic partial nephrectomy for completely endophytic renal tumors. J Surg Oncol 118(1):206–211. https://doi.org/10.1002/jso.25103 (**Epub 2018 Jun 7**)
18. Kim JK, Lee H, Oh JJ, Lee S, Hong SK, Lee SE, Byun SS (2019) Comparison of robotic and open partial nephrectomy for highly complex renal tumors (RENAL nephrometry score ≥10). PLoS ONE 14(1):e0210413. https://doi.org/10.1371/journal.pone.0210413. (**PMID: 30629644; PMCID: PMC6328203**)
19. Mari A, Tellini R, Porpiglia F, Antonelli A et al (2021) Perioperative and mid-term oncological and functional outcomes after partial nephrectomy for complex (PADUA score ≥10) renal tumors: a prospective multicenter observational study (the RECORD2 project). Eur Urol Focus 7(6):1371–1379. https://doi.org/10.1016/j.euf.2020.07.004. (**Epub 2020 Aug 15 PMID: 32811779**)
20. von Hippel PT (2015) The heterogeneity statistic I(2) can be biased in small meta-analyses. BMC Med Res Methodol 15:35
21. Patard JJ, Shvarts O, Lam JS et al (2004) Safety and efficacy of partial nephrectomy for all T1 tumors based on an international multicenter experience. J Urol 171:2181–2182
22. MacLennan S, Imamura M, Lapitan MC et al (2012) Systematic review of oncological outcomes following surgical management of localized renal cancer. Eur Urol 61:972–993
23. Zargar H, Autorino R, Akca O, Brandao LF, Laydner H, Kaouk J (2015) Minimally invasive partial nephrectomy in the age of the "trifecta." BJU Int 116:505–506
24. Aboumarzouk OM, Stein RJ, Eyraud R et al (2012) Robotic versus laparoscopic partial nephrectomy: a systematic review and meta-analysis. Eur Urol 62(6):1023–1033
25. Malkoc E, Raimrez D, Kara O (2017) Robotic and open partial nephrectomy for localized renal tumors larger than 7 cm: a single-center experience. World J Urol 35(5):781–787
26. Porpiglia F, Mari A, Bertolo R (2016) Partial nephrectomy in clinical T1b renal tumors: multicenter comparative study of open, laparoscopic and robot-assisted approach (the RECORd project). Urology 89:45–51
27. Simhan J, Smaldone MC, Tsai KJ et al (2012) Perioperative outcomes of robotic and open partial nephrectomy for moderately and highly complex renal lesions. J Urol 187(6):2000–2004
28. Masson-Lecomte A, Yates DR, Hupertan V et al (2013) A prospective comparison of the pathologic and surgical outcomes obtained after elective treatment of renal cell carcinoma by open or robot-assisted partial nephrectomy. Urol Oncol 31:924–929
29. Ljungberg B, Albiges L, Bensalah K, Bedke J, Bex A, Capitanio U, et al (2020) eaU guidelines on renal Cell Carcinoma 2020. In: European association of Urology guidelines. 2020 edition. Arnhem, The Netherlands: European association of Urology Guidelines Office
30. Patel AR, Eggener SE (2011) Warm ischemia less than 30 minutes is not necessarily safe during partial nephrectomy: every minute matters. Urol Oncol 29(6):826–828
31. Xia L, Wang X, Xu T, Guzzo TJ (2017) Systematic review and meta-analysis of comparative studies reporting perioperative outcomes of robot-assisted partial nephrectomy versus open partial nephrectomy. J Endourol 31:893–909