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REVIEW ARTICLE

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Open versus robotic partial nephrectomy: Systematic review and meta-analysis of contemporary studies

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Abstract

Objectives: To compare perioperative outcomes of robotic-assisted partial nephrectomy (RaPN) with open partial nephrectomy (OPN).

Methods: Systematically search through PubMed, Embase, ClinicalKey, Cochrane Library, ProQuest, ScienceDirect, Web of Science, and ClinicalTrials.gov for eligible studies was performed to April 11, 2018. A meta-analysis was conducted for studies comparing RaPN and OPN. Confounding variables were assessed by meta-regression or subgroup analysis.

Results: This study included 34 studies with 60 808 patients. Meta-analysis revealed less blood loss, less transfusion, longer operative time, less postoperative complications, lower readmission rate, shorter length of stay, and less estimated glomerular filtration rate (eGFR) decline in RaPN groups. The superiority of RaPN in blood loss was attenuated with highly complex renal masses. The superiority of RaPN in intraoperative complications was strengthened with renal hilar control. The advantage of RaPN in surgical margin was increased in patient with body mass index (BMI) < 28.

Conclusions: Compared with OPN, RaPN provided lower morbidities and better renal function preservation.

KEYWORDS

meta-analysis, open procedure, partial nephrectomy, reobotic surgical procedures

1 | INTRODUCTION

Partial nephrectomy (PN) is a preferred surgical approach for small renal masses.[1-4] Larger and more complex renal tumors are increasingly managed by PN with technical advancement.[5] While traditional open partial nephrectomy (OPN) has been the standard approach, evolution of minimal invasive techniques led to the adoption of laparoscopic partial nephrectomy (LPN) and robotic-assisted partial nephrectomy (RaPN) and are becoming the standard of care.[6]

RaPN, first described by Gettman et al in 2004, provides magnified stereoscopic visualization and precise control of articulated robotic-assisted instruments.[7] The learning curve of RaPN is much shorter than LPN and only requires 25 cases as suggested by Pierorazio et al.[8] A population-based study showed widespread adoption of the robotic-assisted technique by 45.4% annual increase use in RaPN comparing with 7.9% in OPN.[9] RaPN is also feasible in dealing with large, complex, and hilar renal masses.[10,11] Rapid adoption and expanded indications of RaPN challenged the traditional

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standard open technique. Randomized controlled trials to compare RaPN and OPN have been difficult due to ethical, financial, and time limitations. With the aim to fill this gap, we performed the update meta-analysis of comparative perioperative, functional, and oncologic outcomes for RaPN and OPN.

2 | METHOD AND MATERIALS

The current meta-analysis that was conducted under rigorous guidelines as described in the preferred reporting items for systematic reviews and meta-analyses (PRISMA) recommendations (Figure 1).[12]

2.1 | Database searches and identification of eligible papers

A systematic literature review was performed by using PubMed, Embase, ClinicalKey, Cochrane Library, ProQuest, ScienceDirect, Web of Science, and ClinicalTrials.gov to April 11, 2018, with keyword of (open partial nephrectomy) AND (robotic assisted partial nephrectomy OR robotic partial nephrectomy). To include as many eligible articles as possible, we did not set any limitation term during literature search strategy except for only limitation of language of English written. To expand the potentially eligible articles, we searched for articles from the reference lists of specific review and original articles relevant to current topic.[6,13,14]

2.2 | Inclusion and exclusion criteria

Inclusion criteria included (a) articles investigating differences of demographic profiles and perioperative outcomes between RaPN and OPN; (b) articles that compare RaPN, OPN, and LPN where data between RaPN and OPN could be extracted; and (c) articles written in English. Exclusion criteria included (a) articles in which radical nephrectomy was performed as a comparator; (b) articles in which single-port or hand-assisted approach was performed; (c) not primary articles such as, review articles, letters, and commentaries; and (d) papers with abstract only. If two or more studies were presented in an overlapping time by the same authors and/or same institution, the study in which the largest number of patients and/or articles provided the more comprehensive information and/or the most recently published study were used.

2.3 | Assessment of study quality

The quality of enrolled studies was determined using the Newcastle-Ottawa scale (NOS) (www.ohri.ca/programs/clinical_epidemiology/oxford.asp). A NOS score of 5 or less was considered low, 6 to 7 was intermediate, and 8 to 9, high quality. The level of evidence of each study was also rated.

2.4 | Data analysis

Two independent authors reviewed the full texts of the included studies. Patient baseline demographics (age, sex, body mass index [BMI], American Society of Anesthesiologists [ASA] physical status classification, tumor size, baseline renal function, and tumor complexity), perioperative outcomes (operative time, ischemic time, estimate blood loss [EBL], blood transfusion rate, conversion rate, complications, marginal status, and hospital stay), and postoperative outcomes (postoperative renal function, decline in estimated glomerular filtration rate [eGFR], readmission, positive surgical margin [PSM], and tumor recurrence rate) were extracted from each eligible study whenever available.

What is already known about this subject?

- Traditional open partial nephrectomy (OPN) has been the standard approach for larger and more complex renal tumors.
- Evolution of minimal invasive techniques led to the adoption of robotic-assisted partial nephrectomy (RaPN).
- Previous observational studies showed that RaPN is also feasible in dealing with large, complex, and hilar renal masses.

What are the new findings?

- Compared with OPN, RaPN carried the advantage not only of decreased blood loss, less blood transfusion, lower postoperative complication rate, and shorter length of hospital stay but also lower readmission rate and less eGFR decline.
- The superiority of RaPN in estimated blood loss was attenuated with highly complex renal masses (RENAL score > 9).
- The superiority of RaPN in intraoperative complication rate was strengthened with renal hilar control.
- The advantage of RaPN in positive surgical margin was increased in patient with BMI < 28.

How might these results change the focus of research or clinical practice?

RaPN provided lower perioperative and postoperative complications and a favorable postoperative eGFR impact. Renal parenchyma, a pivotal role on renal function preservation, would be better preserved with robotic technologies. Further prospective randomized clinical studies with adequate follow-up is needed.

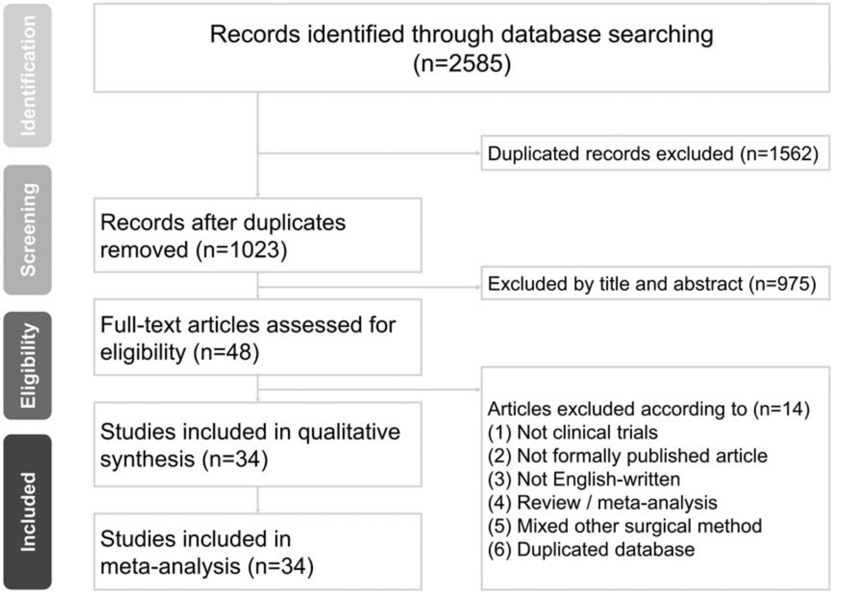


FIGURE 1 Flowchart of the selection strategy for the current meta-analysis

Random-effects meta-analysis models were applied with the Comprehensive Meta-Analysis software, version 3 (Biostat, Englewood, New Jersey) for the presumed heterogeneity among the recruited studies.[15] Effect sizes (ESs) of the analyses were investigated by odds ratio (OR) for binary data and Hedges' *g* for continuous data. The Cochrane Q statistic and I^2 statistic were used for evaluating heterogeneity among studies.[16,17] Funnel plots[18] and Egger's regression analysis[19] were used to assess publication bias. Besides, Duval and Tweedie's trim and fill test was used to adjust the ESs for data with significant publication bias.[20] The one study removal method for detecting outliers was used for sensitivity analyses.[21]

Meta-regression and/or subgroup analysis was used in datasets over five articles to assess for potential sources of heterogeneity among extracted variables including age, sex, BMI, ASA score, tumor size, RENAL nephrometry score,[22] and renal hilar control status. Two-tailed tests were used for all comparisons and a *P* value of <0.05 was considered statistically significant.

3 | RESULTS

3.1 | Study selection

Figure 1 shows the PRISMA flowchart for study selection in this systematic review. At eligibility stage, 48 studies entered the full-text evaluation, and 14 studies were excluded because eligibility criteria were not met. The reasons for exclusion included not formally published articles, duplicated database from our recruited studies, mixed with other surgical methods, not English-written articles, and not clinical trials.

Thirty-four eligible studies[9,23-55] included 60 808 patients who underwent PN, of whom 19 638 underwent RaPN with mean age 58.9 years and 41 170 underwent OPN with mean age 58.5 years. Table 1 presents the baseline patient demographics of all enrolled studies.

3.2 | Perioperative outcomes

3.2.1 | Main result

There were no differences in ischemic time (Hedges' g = 0.095, 95% confidence intervals (95% CI, −0.058 to 0.248, P = 0.248), intraoperative complication rate (OR = 0.792, 95%CI, 0.498-1.262, P = 0.327), and percentage of conversion to radical nephrectomy (OR = 1.171, 95% CI, 0.363-3.783, P = 0.792). In comparison with OPN, RaPN associated with decreased EBL (Hedges' g = −0.452, 95% CI, −0.546 to −0.358, P < 0.001, difference in means −104.295 c.c. 95% CI, −128.130 to −80.461) (Figure 2A) and blood transfusion rate (OR = 0.518, 95% CI, 0.427-0.628, P < 0.001) (Figure 2B) but longer operative time (Hedges' g = 0.264, 95% CI, 0.-0.406, P < 0.001, difference in means 14.557 min, 95% CI, 7.943-21.171) (Figure 2C).

3.2.2 | Heterogeneity, publication bias, sensitivity test, meta-regression, and subgroup meta-analysis

Significant heterogeneity (Q value = 83.366, df = 27, I^2 = 67.613%, P < 0.001) and publication bias (t value = 5.560, df = 26, P < 0.001) were noted in terms of EBL. The trim and fill test still favored RaPN after adjustment by publication bias (Hedges' g = −0.329, 95% CI, −0.420 to −0.238). The sensitive analysis revealed that the results of meta-analysis of EBL would not change after removing any recruited studies. Meta-regression analysis revealed that the Hedges' g on EBL was positively associated with percentage of patients with RENAL score ≥ 9 (k = 10, slope = 0.010, P = 0.003), which means difference of EBL between RaPN and OPN attenuated while tumor complexity increasing.

Significant heterogeneity (Q value = 30.326, df = 19, I^2 = 37.348%, P = 0.048) but not publication bias (t value = 0.373, df = 18, P = 0.713) was noted for blood transfusion rate. The sensitive analysis revealed that the results of meta-analysis of blood transfusion rate would not change after removing any recruited studies. Meta-regression analysis

TABLE 1 Studies and patient characteristics included in the meta-analysis for assessment of outcome for robotic-assisted partial nephrectomy (RaPN) and open partial nephrectomy (OPN)

Study	Study Design	Study Origin	Study Period	SQ	LE	No. of Patients		Mean Age, Year		Mean BMI		Mean Tumor Size, cm		Mean RENAL Score	
						RaPN	OPN	RaPN	OPN	RaPN	OPN	RaPN	OPN	RaPN	OPN
Lee, S	Retro	Korean	2003-2010	7	3	69	234	53.48	54.35	25.5	24.49	2.37	2.58	...	...
Stroup, SP	Retro	US	2003-2011	6	3	31	153	61	56	27.7	28.9	2.0*	4.2*	8	6.7
Yu, H	Retro	US	2008	6	3	445	3049	...	...	...	...	...	...	...	...
Ficarra, V	Retro, MP	Multiple	2008-2011	8	3	200	200	62.4	62.4	...	...	2.8*	3.5*	...	...
Alemozaffar, M	Retro	US	2008-2010	8	3	25	25	55.9	61.9	27.5	30.1	2.5	3.3	6.08	7
Masson-Lecomte, A	Pro	France	2008-2010	8	2	42	58	61.7	60.8	26.9	26.5	2.8	3.1	...	...
Zagar, H[†]	Retro	US	2007-2013	8	3	40	85	61.3	61.5	30	31.7	2.5* 4.15*	3.5* 4.3*	6* 9.5*	7* 10*
Vittori, G	Retro	Italy	2010-2011	7	3	105	198	62.3	63.8	25.7*	26.2*	2.8	3.5	...	...
Webb, CM	Retro	Egypt	2005-2011	7	3	14	21	60.5	53.6	...	...	2.99	4.22	...	...
Porpiglia, F	Retro	Italy	2009-2012	8	3	95	133	57.3	62.3	25.8*	26*	5*	5*	...	...
Takagi, T	Retro	Japan	2012-2014	7	3	100	179	58	57	24	24	2.8	4.2	...	...
Kara, O	Retro	US	2011-2016	8	3	87	56	58.3	61.1	29*	29.5*	2.8*	3.1*	9*	9*
Mearini, L	Retro	Italy	2006-2015	8	3	31	80	67.6	63	27.8	26.7	3.05	3.54	...	...
Patton, MW	Retro	US	1999-2013	8	3	90	37	63	65	29*	29*	...	...	...	...
Malkoc E	Retro	US	2011-2015	8	3	177	60	54.9	55.9	33.4*	34.1*	2.5*	2.8*	7*	7*
Lucas, SM	Retro	US	2004-2010	7	3	27	54	62.1	57.6	31.4*	29.6*	2.4*	2.3*	6*	6*
Simhan, J	Retro	US	2007-2010	7	3	91	190	...	...	...	...	...	...	...	...
Laydner, H	Retro	US	20092010	7	3	145	133	59	61	30	28	2.6	4	7	8
Ghani, KR	Retro	US	2008-2010	6	3	9095	25461	57.82	58.33	...	...	...	...	...	...
Luciani, LG	Pro	US	2005-2016	8	2	110	73	61	63	...	...	3.6	3.6	...	...
Wu, Z	Retro, PS	China	2009-2013	7	3	51	94	53	52	24.8*	25.1*	...	...	...	...
Mano, R	Retro	US	2011	7	3	63	190	57	59	29.1*	29*	2.6*	3*	...	...
Peyroneet, B	Retro	France	2006-2014	7	3	937	863	69.6	57.5	26.6	26.5	3.29	3.99	6.8	6.7
Wang, Y	retro, MP	China	2007-2014	8	3	190	190	61.8	59.8	25.4	24.6	3.8	3.6	8.4	8.2
Pak, J	Retro	US	2009-2012	6	3	1531	2959	59	60	...	...	...	...	...	...
Malkoc E	Retro	US	2009-2015	8	3	54	56	61.7	61.5	30.4*	27.9*	7.3*	7.9*	10*	9*
Oh, JJ	Retro, PS	Korea	2003-2015	7	3	317	385	52.13	54.88	24.73	24.55	2.168	2.305	...	...
Lee, C	Retro, PS	Korea	2007-2013	7	3	114	289	52.9	53.3	25.4	25	2.5	2.7	...	...
Klaasen, Z	Retro	US	2006-2012	7	3	35	23	56	62	32.8	28.9	3.6	3.8	7.4	9.0
Tabayoyong, W	Retro	US	2010-2011	6	3	4812	5094	...	...	...	...	...	...	...	...

(Continues)

TABLE 1 (Continued)

Study	Study Design	Study Origin	Study Period	SQ	LE	No. of Patients		Mean Age, Year		Mean BMI		Mean Tumor Size, cm		Mean RENAL Score	
						RaPN	OPN	RaPN	OPN	RaPN	OPN	RaPN	OPN	RaPN	OPN
Miyake, H	Retro	Japan	2012-2014	8	3	16	15	63.3	64.2	24.9	24.4	3	3.2	⋯	⋯
Hamilton, ZA	Retro	US	2002-2015	8	3	302	426	67.4	66.8	29.8	30.1	3.4	4.5	7.6	8.7
Tan, J	Retro	Australia	2010-2016	8	3	145	55	57.68	64.64	27.9*	27.43*	3*	3*	⋯	⋯
Borghesi, M.	Retro	Italy	2011-2015	7	3	52	52	61*	61*	26*	26*	3*	3*	6*	6*

Data presented as mean if not specific marked. Abbreviations: BMI, body mass index; LE, level of evidence MP, match paired; Multiple, multiple countries; PS, propensity score matching; Pro, prospective study; Retro, retrospective study; SQ, score of quality US, United States.

*data presented as median.

†Zagar et al divided the participants into simple (RENAL score 4-8) and complex (RENAL score 9-12) groups for comparison.

revealed that the OR on blood transfusion rate is inversely associated with mean female proportion (k = 18, slope = −0.044, P = 0.038), which means the advantage of RaPN increased in female patients.

Significant heterogeneity (Q value = 196.327, df = 27, I^2 = 86.247%, P < 0.001) but not publication bias (t value = 1.661, df = 26, P = 0.109) was noted for operative time. No confounding factors associated with operative time differences were found with meta-regression. The sensitive analysis revealed that the results of meta-analysis of operative time would not change after removing any recruited studies.

Significant heterogeneity (Q value = 30.702, df = 15, I^2 = 51.143%, P = 0.010) without publication bias (t value = 0.544, df = 14, P = 0.595) was noted for intraoperative complication rate. However, intraoperative complication rate favored RaPN rather than OPN after removing Lee et al[23] (OR = 0.678, 95% CI, 0.603-0.762, P < 0.001). Meta-regression analysis revealed that the OR of intraoperative complication rate is inversely associated with renal hilar control rate in RaPN groups (k = 11, slope = −0.025, P = 0.003), which means the advantage of RaPN increased with renal hilar control rate in RaPN group.

3.3 | Postoperative outcomes

3.3.1 | Main result

Figure 3A to C tabulated the postoperative outcomes of included studies. In comparison with OPN, RaPN was associated with decreased overall postoperative complication rate (OR = 0.578, 95% CI, 0.514-0.649, P < 0.001), decreased readmission rate (OR = 0.660, 95% CI, 0.524-0.832, P < 0.001), and shorter hospital stay (Hedges' g = −0.492, 95% CI, −0.588 to −0.396, P < 0.001, difference in means −1.781 d, 95% CI, −2.221 to −1.341).

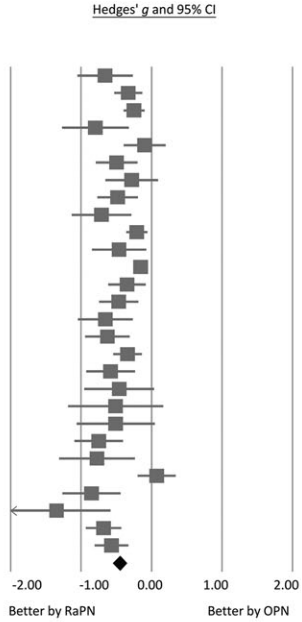
3.3.2 | Heterogeneity, publication bias, sensitivity test, meta-regression, and subgroup meta-analysis

Nonsignificant heterogeneity (Q value = 29.253, df = 25, I^2 = 14.538%, P = 0.253) but significant publication bias (t value = 2.257, df = 24, P = 0.033) was noted for the postoperative complication rate. The trim and fill test still favored RaPN after adjustment by publication bias (OR = 0.617, 95% CI, 0.540-0.705). The sensitivity test revealed that the difference between RaPN and OPN would not change after removal of any single study. No confounding factors associated with PSM rate differences were found with meta-regression. RaPN associated with both decreased major (Clavien classification ≥3; OR = 0.599, 95% CI, 0.435-0.825, P = 0.002) and minor (Clavien classification 1-2; OR = 0.600, 95% CI, 0.498-0.725, P < 0.001) complication rates in subgroup meta-analysis.

Nonsignificant heterogeneity (Q value = 5.061, df = 5, I^2 = 1.210%, P = 0.408) but significant publication bias (t value = 3.640, df = 4, P = 0.022) was noted for the readmission rate. The trim and fill test revealed that difference in readmission between groups became into nonsignificant after adjustment to publication bias (OR = 0.661, 95% CI, 0.433-1.007). The sensitivity test revealed same result after

Study name	Hedges' g	Lower limit	Upper limit	p-Value	Relative weight
Borghesi, M. (2018)	-0.660	-1.052	-0.268	0.001	3.02
Ficarra, V. (2014)	-0.331	-0.528	-0.134	0.001	4.97
Hamilton, Z.A. (2018)	-0.248	-0.396	-0.100	0.001	5.49
Lucas, S.M. (2012)	-0.798	-1.272	-0.324	0.001	2.43
Luciani, L.G. (2017)	-0.099	-0.394	0.196	0.509	3.91
Malkoc, E. (2017) BJUI	-0.496	-0.791	-0.201	0.001	3.91
Malkoc, E. (2017) WJU	-0.282	-0.655	0.091	0.139	3.18
Mano, R. (2015)	-0.483	-0.770	-0.195	0.001	3.99
Mearini, L. (2016)	-0.711	-1.133	-0.288	0.001	2.78
Oh, J.J. (2016)	-0.209	-0.358	-0.060	0.006	5.48
Patton, M.W. (2016)	-0.461	-0.846	-0.077	0.019	3.08
Peyronnet, B. (2016)	-0.155	-0.248	-0.063	0.001	5.98
Porpiglia, F. (2016)	-0.348	-0.612	-0.083	0.010	4.23
Simhan, J. (2012) RENAL7-9	-0.467	-0.744	-0.189	0.001	4.09
Stroup, S.P. (2012)	-0.656	-1.046	-0.266	0.001	3.03
Tan, J.L. (2017)	-0.627	-0.942	-0.311	0.000	3.71
Wang, Y. (2017)	-0.340	-0.542	-0.137	0.001	4.91
Wu, Z. (2014) EBL	-0.581	-0.927	-0.236	0.001	3.42
Zargar, H. (2014) RENAL 4-8	-0.459	-0.954	0.035	0.069	2.30
Zargar, H. (2014) RENAL 9-12	-0.510	-1.184	0.164	0.138	1.49
Alemozaffar, M. (2013)	-0.508	-1.063	0.047	0.073	1.98
Kara, O. (2016)	-0.750	-1.096	-0.405	0.000	3.42
Klaassen, Z. (2014)	-0.774	-1.312	-0.236	0.005	2.06
Lee, S. (2011)	0.072	-0.196	0.340	0.599	4.19
Masson-Lecomte, A. (2013)	-0.853	-1.265	-0.442	0.000	2.87
Miyake, H. (2015)	-1.348	-2.112	-0.584	0.001	1.22
Takagi, T. (2016)	-0.681	-0.932	-0.431	0.000	4.38
Minervini, A. (2014)	-0.568	-0.809	-0.328	0.000	4.49
Overall	**-0.452**	**-0.546**	**-0.358**	**0.000**	**100.00**

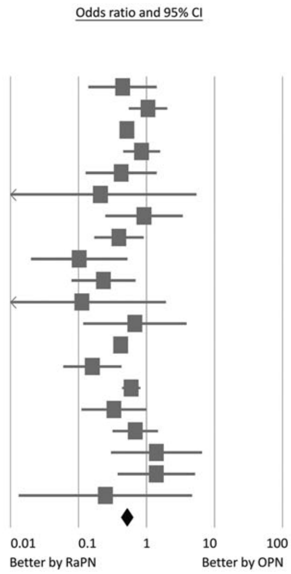
Statistics for each study



(A) Estimate blood loss

Study name	Odds ratio	Lower limit	Upper limit	p-Value	Relative weight
Borghesi, M. (2018)	0.447	0.141	1.413	0.170	2.52
Ficarra, V. (2014)	1.056	0.553	2.015	0.869	6.48
Ghani, K.R. (2014)	0.518	0.470	0.570	0.000	22.22
Hamilton, Z.A. (2018)	0.848	0.455	1.579	0.603	6.85
Kara, O. (2016)	0.427	0.128	1.418	0.165	2.33
Klaassen, Z. (2014)	0.211	0.008	5.415	0.348	0.35
Lee, S. (2011)	0.921	0.250	3.401	0.902	2.00
Luciani, L.G. (2017)	0.396	0.172	0.911	0.029	4.37
Malkoc, E. (2017) BJUI	0.103	0.020	0.525	0.006	1.33
Malkoc, E. (2017) WJU	0.234	0.079	0.691	0.009	2.81
Mano, R. (2015)	0.112	0.007	1.927	0.132	0.45
Masson-Lecomte, A. (2013)	0.675	0.118	3.869	0.659	1.17
Pak, J.S. (2017)	0.419	0.331	0.530	0.000	17.41
Patton, M.W. (2016)	0.160	0.060	0.429	0.000	3.31
Peyronnet, B. (2016)	0.598	0.440	0.814	0.001	14.74
Minervini, A. (2014)	0.334	0.111	1.000	0.050	2.74
Wang, Y. (2017)	0.686	0.318	1.479	0.336	4.99
Wu, Z. (2014)	1.406	0.302	6.542	0.664	1.48
Zargar, H. (2014) RENAL 4-8	1.400	0.379	5.168	0.614	2.00
Zargar, H. (2014) RENAL 9-12	0.249	0.013	4.670	0.353	0.43
Overall	**0.518**	**0.427**	**0.628**	**0.000**	**100.00**

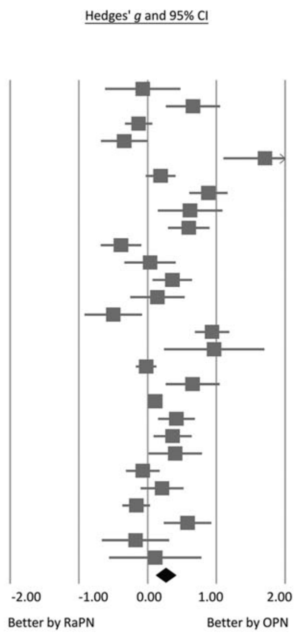
Statistics for each study



(B) Blood transfusion rate

Study name	Hedges' g	Lower limit	Upper limit	p-Value	Relative weight
Alemozaffar, M. (2013)	-0.071	-0.617	0.475	0.799	2.74
Borghesi, M. (2018)	0.660	0.268	1.052	0.001	3.41
Ficarra, V. (2014)	-0.131	-0.327	0.065	0.190	4.22
Kara, O. (2016)	-0.340	-0.676	-0.004	0.047	3.65
Klaassen, Z. (2014)	1.709	1.104	2.314	0.000	2.51
Lee, C. (2016)	0.189	-0.028	0.406	0.088	4.15
Lee, S. (2011)	0.884	0.607	1.161	0.000	3.91
Lucas, S.M. (2012)	0.616	0.149	1.084	0.010	3.07
Luciani, L.G. (2017)	0.598	0.297	0.899	0.000	3.81
Malkoc, E. (2017) BJUI	-0.387	-0.681	-0.093	0.010	3.84
Malkoc, E. (2017) WJU	0.036	-0.335	0.407	0.850	3.50
Mano, R. (2015)	0.359	0.073	0.644	0.014	3.87
Masson-Lecomte, A. (2013)	0.142	-0.253	0.536	0.481	3.39
Mearini, L. (2016)	-0.500	-0.917	-0.083	0.019	3.29
Minervini, A. (2014)	0.937	0.690	1.185	0.000	4.03
Miyake, H. (2015)	0.968	0.241	1.696	0.009	2.09
Oh, J.J. (2016)	-0.022	-0.170	0.127	0.772	4.37
Patton, M.W. (2016)	0.654	0.265	1.043	0.001	3.42
Peyronnet, B. (2016)	0.110	0.017	0.202	0.020	4.50
Porpiglia, F. (2016)	0.419	0.153	0.684	0.002	3.96
Simhan, J. (2012) RENAL7-9	0.363	0.087	0.640	0.010	3.91
Stroup, S.P. (2012)	0.402	0.015	0.788	0.042	3.43
Takagi, T. (2016)	-0.071	-0.315	0.173	0.567	4.04
Tan, J.L. (2017)	0.210	-0.099	0.520	0.183	3.77
Wang, Y. (2017)	-0.165	-0.366	0.036	0.108	4.21
Wu, Z. (2014)	0.581	0.236	0.927	0.001	3.61
Zargar, H. (2014) RENAL 4-8	-0.176	-0.665	0.313	0.480	2.98
Zargar, H. (2014) RENAL 9-12	0.110	-0.559	0.778	0.748	2.28
Overall	**0.264**	**0.121**	**0.406**	**0.000**	**100.00**

Statistics for each study



(C) Operative time

FIGURE 2 Forest plots of significantly different perioperative outcomes for robotic-assisted partial nephrectomy versus open partial nephrectomy

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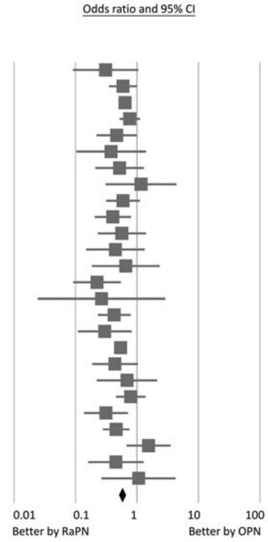
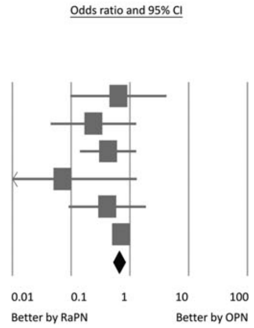
Study name	Odds ratio	Lower limit	Upper limit	p-Value	Relative weight
Borghesi, M. (2018)	0.311	0.092	1.050	0.060	0.90
Ficarra, V. (2014)	0.594	0.352	1.003	0.051	4.39
Ghani, K.R. (2014)	0.644	0.609	0.681	0.000	33.17
Hamilton, Z.A. (2018)	0.766	0.520	1.127	0.176	7.28
Kara, O. (2016)	0.470	0.221	0.998	0.049	2.25
Klaassen, Z. (2014)	0.381	0.104	1.395	0.145	0.79
Lee, S. (2011)	0.524	0.211	1.301	0.164	1.58
Lucas, S.M. (2012)	1.168	0.310	4.397	0.819	0.76
Luciani, L.G. (2017)	0.595	0.318	1.114	0.105	3.17
Malkoc, E. (2017) BJUI	0.406	0.206	0.798	0.009	2.75
Malkoc, E. (2017) WJU	0.568	0.231	1.396	0.218	1.61
Mano, R. (2015)	0.447	0.149	1.340	0.151	1.10
Masson-Lecomte, A. (2013)	0.658	0.184	2.348	0.519	0.82
Minervini, A. (2014)	0.225	0.092	0.549	0.001	1.64
Miyake, H. (2015)	0.267	0.025	2.902	0.278	0.24
Oh, J.J. (2016)	0.428	0.232	0.791	0.007	3.30
Patton, M.W. (2016)	0.300	0.110	0.816	0.018	1.31
Peyronnet, B. (2016)	0.545	0.436	0.681	0.000	15.58
Porpiglia, F. (2016)	0.440	0.188	1.031	0.059	1.79
Stroup, S.P. (2012)	0.691	0.223	2.139	0.522	1.04
Takagi, T. (2016)	0.792	0.458	1.370	0.405	4.03
Tan, J.L. (2017)	0.313	0.138	0.710	0.005	1.92
Wang, Y. (2017)	0.460	0.279	0.759	0.002	4.73
Wu, Z. (2014)	1.550	0.682	3.518	0.295	1.92
Zargar, H. (2014) RENAL 4-8	0.455	0.161	1.285	0.137	1.23
Zargar, H. (2014) RENAL 9-12	1.067	0.268	4.253	0.927	0.70
Overall	**0.578**	**0.514**	**0.649**	**0.000**	**100.00**



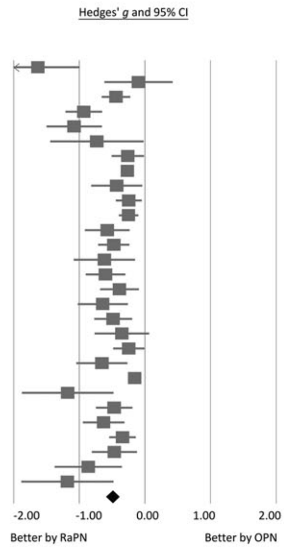
(A) Postoperative complication rate

Study name	Odds ratio	Lower limit	Upper limit	p-Value	Relative weight
Alemozaffar, M. (2013)	0.638	0.097	4.188	0.639	1.51
Kara, O. (2016)	0.240	0.045	1.283	0.095	1.90
Malkoc, E. (2017) BJUI	0.426	0.142	1.282	0.129	4.36
Malkoc, E. (2017) WJU	0.071	0.004	1.298	0.074	0.64
Mano, R. (2015)	0.412	0.091	1.866	0.250	2.34
Pak, J.S. (2017)	0.709	0.575	0.875	0.001	89.27
Overall	**0.660**	**0.524**	**0.832**	**0.000**	**100.00**



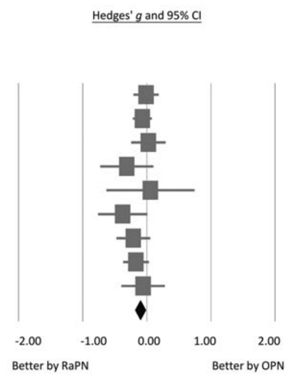
(B) Re-admission rate

Study name	Hedges' g	Lower limit	Upper limit	p-Value	Relative weight
Alemozaffar, M. (2013)	-1.628	-2.260	-0.996	0.000	1.65
Klaassen, Z. (2014)	-0.096	-0.615	0.424	0.718	2.16
Lee, C. (2016)	-0.439	-0.658	-0.221	0.000	4.51
Lee, S. (2011)	-0.930	-1.208	-0.652	0.000	3.94
Masson-Lecomte, A. (2013)	-1.078	-1.499	-0.656	0.000	2.75
Miyake, H. (2015)	-0.730	-1.440	-0.021	0.044	1.39
Takagi, T. (2016)	-0.259	-0.504	-0.014	0.038	4.25
Yu, H.Y. (2012)	-0.265	-0.365	-0.166	0.000	5.54
Borghesi, M. (2018)	-0.428	-0.814	-0.042	0.030	3.01
Ficarra, V. (2014)	-0.246	-0.443	-0.050	0.014	4.72
Hamilton, Z.A. (2018)	-0.248	-0.396	-0.100	0.001	5.17
Kara, O. (2016)	-0.573	-0.913	-0.232	0.001	3.38
Laydner, H. (2013)	-0.473	-0.711	-0.235	0.000	4.32
Lucas, S.M. (2012)	-0.616	-1.084	-0.149	0.010	2.45
Luciani, L.G. (2017)	-0.598	-0.899	-0.297	0.000	3.73
Malkoc, E. (2017) BJUI	-0.387	-0.681	-0.093	0.010	3.79
Malkoc, E. (2017) WJU	-0.641	-1.021	-0.260	0.001	3.05
Mano, R. (2015)	-0.483	-0.770	-0.195	0.001	3.85
Mearini, L. (2016)	-0.350	-0.764	0.065	0.098	2.80
Minervini, A. (2014)	-0.246	-0.483	-0.009	0.042	4.33
Patton, M.W. (2016)	-0.654	-1.043	-0.265	0.001	2.99
Peyronnet, B. (2016)	-0.155	-0.248	-0.063	0.001	5.58
Simhan, J. (2012) RENAL 10-12	-1.175	-1.872	-0.478	0.001	1.43
Simhan, J. (2012) RENAL7-9	-0.467	-0.744	-0.189	0.001	3.94
Tan, J.L. (2017)	-0.627	-0.942	-0.311	0.000	3.60
Wang, Y. (2017)	-0.340	-0.542	-0.137	0.001	4.67
Wu, Z. (2014)	-0.465	-0.809	-0.122	0.008	3.35
Zargar, H. (2014) RENAL 4-8	-0.861	-1.372	-0.350	0.001	2.20
Zargar, H. (2014) RENAL 9-12	-1.180	-1.880	-0.480	0.001	1.42
Overall	**-0.492**	**-0.588**	**-0.396**	**0.000**	**100.00**



(C) Length of hospital stay

Study name	Hedges' g	Lower limit	Upper limit	p-Value	Relative weight
Ficarra, V. (2014)	-0.010	-0.205	0.186	0.923	17.56
Hamilton, Z.A. (2018)	-0.069	-0.216	0.079	0.362	30.96
Lee, S. (2011)	0.026	-0.242	0.294	0.850	9.37
Mearini, L. (2016)	-0.310	-0.724	0.104	0.142	3.92
Miyake, H. (2015)	0.057	-0.629	0.743	0.870	1.43
Patton, M.W. (2016)	-0.374	-0.758	0.009	0.055	4.58
Porpiglia, F. (2016)	-0.209	-0.472	0.054	0.120	9.71
Wang, Y. (2017)	-0.169	-0.370	0.032	0.100	16.63
Wu, Z. (2014)	-0.057	-0.396	0.283	0.744	5.84
Overall	**-0.101**	**-0.183**	**-0.019**	**0.016**	**100.00**



(D) eGFR change

FIGURE 3 Forest plots of significantly different postoperative and functional outcomes for robotic-assisted partial nephrectomy versus open partial nephrectomy removal of any single study. No confounding factors associated with readmission rate differences were found with meta-regression.

Significant heterogeneity (*Q* value = 101.336, *df* = 28, I^2 = 72.369%, *P* < 0.001) and publication bias (*t* value = 6.543, *df* = 27, *P* < 0.001) were noted for the hospital stay. The trim and fill test revealed unchanged result after adjustment for publication bias (Hedges' *g* = −0.343, 95% CI, −0.443 to −0.244). The difference between RaPN and OPN would not change after removal of any single study. No confounding factors associated with length of hospital stay differences were found with meta-regression.

3.4 | Oncological outcomes

3.4.1 | Main result

There was no significant difference between RaPN and OPN in PSM (OR = 0.926, 95% CI, 0.657-1.304, *P* = 0.660) and tumor recurrence rates (OR = 0.328, 95% CI, 0.078-1.381, *P* = 0.129).

3.4.2 | Heterogeneity, publication bias, sensitivity test, meta-regression, and subgroup meta-analysis

Significant heterogeneity (*Q* value = 45.977, *df* = 24, I^2 = 47.800%, *P* = 0.004) and publication bias (*t* value = 2.921, *df* = 23, *P* = 0.008) were noted for PSM. The trim and fill test revealed similar result after adjustment for publication bias (OR = 0.943, 95% CI, 0.673-1.322). The sensitivity test revealed same result after removal of any single studies. Subgroup analysis revealed that the PSM favored RaPN group when patient BMI was less than 28 (OR = 0.663, 95% CI, 0.488-0.900, *P* = 0.008).

Significant heterogeneity (*Q* value = 9.070, *df* = 3, I^2 = 66.925%, *P* = 0.028) but not publication bias (*t* value = 0.849, *df* = 2, *P* = 0.485) was noted for tumor recurrence rates. However, via sensitivity test, the tumor recurrence rates favored RaPN rather than OPN after removing Malkoc et al[47] (OR = 0.213, 95% CI, 0.051-0.884, *P* = 0.033).

3.5 | Functional outcomes

3.5.1 | Main result

RaPN group had decreased eGFR change (Hedges' *g* = −0.101, 95% CI, −0.183 to −0.019, *P* = 0.016; difference in means: −0.522, 95% CI, −1.270 to 0.226) (Figure 3D).

3.5.2 | Heterogeneity, publication bias, sensitivity test, meta-regression, and subgroup meta-analysis

Nonsignificant heterogeneity (*Q* value = 6.174, *df* = 8, I^2 < 0.001%, *P* = 0.628) and publication bias (*t* value = 0.878, *df* = 7, *P* = 0.409) were noted for eGFR change. The difference in eGFR change turned out to be nonsignificant after removal of the dataset by Wang et al[45] (Hedges' *g* = −0.087, 95% CI, −0.177 to 0.003, *P* = 0.057). No confounding factors associated with eGFR change differences were found with meta-regression.

4 | DISCUSSION

Utilization of robotic technique for renal masses has rapid increased over time; the role of RaPN versus standard OPN is still debated.[9] The present meta-analysis of a large-pooled sample revealed that RaPN had decreased blood loss, blood transfusion, postoperative complication rate, and length of stay (LOS) when compared with OPN. No difference was noted with ischemic time, conversion rate, PSM, and recurrence rate. RaPN had decreased readmission rate and a favorable postoperative eGFR impact.

Wu et al,[13] Shen et al,[56] and Xia et al[57] previously conducted meta-analyses on this topic. Wu et al[13] pooled 8 studies with 3418 patients, Shen et al[56] pooled 16 studies with 3024 patients, and Xia et al[57] pooled 19 studies with 3551 patients. In our present study, we pooled 34 articles with 60 808 patients and for presumed heterogeneity between studies, random-effect model was applied for our analyses. Meta-regression analyses and sensitivity tests were used to clarify the impact of possible confounding factors for heterogeneity and the outliers of studies to achieve updated and comprehensive analyses.

Decreased EBL was found in RaPN group rather than OPN in the present meta-analysis, consistent with prior literatures.[56,57] With wide application of robotic platform, RaPN even had a decreased EBL for complex renal masses such as endophytic and hilar ones.[34,52] However, our meta-regression analysis revealed that when tumor complexity highly increased (RENAL score ≥ 9), the advantage of RaPN in terms of EBL was significant reduced, confirming results for renal mass over 7 cm was reported by Malkoc et al.[47] Accordingly, RaPN associated with lower blood transfusion rate. The superiority of RaPN was strengthened in female patients in meta-regression analysis. Our finding supported that RaPN may reduce overtransfusion in women secondary to liberal transfusion strategy and nonsex specific transfusion threshold.[58]

Decreased postoperative complications was found in RaPN group when compared with OPN in our pooled analysis. Both major (Clavien ≥3, *P* = 0.006) and minor (Clavien 1-2, *P* < 0.001) postoperative complications were both reduced in RaPN. Vittori et al reported that RaPN associated with decreased overall postoperative complications[30] (*P* = 0.009). They also demonstrated that OPN was the only independent factor associated with Clavien 3 to 4 surgical complications, compatible with our findings.

Although intraoperative complication rate was similar between RaPN and OPN groups in our pooled analysis, RaPN would have a decreased intraoperative complication rate if we removed Lee's study,[23] Lee's study enrolled patients in 2003 to 2010, which involved the period of initial application of robotic technique, and thus underestimated the superiority of contemporary RaPN. Recent epidemiological data had found decreased intraoperative complications of RaPN compared with OPN (OR = 0.69, 95% CI, 0.52-0.93, *P* = 0.014).[9] Further meta-regression analysis revealed that the advantage of RaPN increased with renal hilar control. Compared with hilar control, off-clamp RaPN associated with higher blood loss, possible leading to compromised visualization of surgical filed and intraoperative complications.[59]

Renal function preservation after PN is confounded by complex perioperative variables, including ischemic time, remaining renal parenchymal, surgical technique, blood loss, and contralateral renal function. Ischemic time is frequently used as a surrogate of renal function however ischemic time showed no difference between RaPN and OPN in our analysis. Interestingly, we found that RaPN group had minor postoperative eGFR decline compared with OPN. It could be deduced that RaPN is favorable in renal function preservation due to factors other than renal pedicle control. Takagi et al revealed that RaPN tended to preserve more normal parenchyma than OPN[33] (84% versus 79%, P = 0.0504). RaPN also provided narrower peritumoral surgical margin than OPN due to improved vision with 3D capabilities.[48] These evidences suggested that renal parenchyma, a pivotal role on renal function preservation, would be better preserved with robotic technologies. However, it was not possible to perform a pooled analysis of parenchyma preservation as a confounding factor of renal function due to limited study numbers.

PSM, as an indicator of local oncological control, remains a controversial surrogate for long-term recurrence and metastasis.[60,61] Pooled analysis for long-term oncological comparison is not available. Our present study found no significant difference with PSM between RaPN and OPN. In subgroup analysis, we found that in patients with BMI < 28, RaPN associated with a decreased PSM rate. Malkoc et al reported no significant PSM difference in obese patients who underwent RaPN compared with OPN[40] (4% versus 3.4%, P = 0.82). Others revealed no difference in PSM in obese patients undergoing RaPN compared with nonobese ones[62] (3.5% versus 2.8%, P = 0.383). PSM of PN is rare, without collating large series together, the difference is likely diluted. Our analysis supported that abundance of perirenal fat in obese patients may hinder renal tumor dissection with RaPN. Incidence of tumor recurrence was very rare in our analysis, and the result may be interfered easily with few extreme outliers. It could explain the result of tumor recurrence rate turns to favoring RaPN after removal of the study with only three recurrence patients.[47]

The only advantage of OPN that we found was less operative time. Masson-Lecomte et al, however, revealed that the difference in operative time was insignificant between RaPN and OPN after excluding robotic setup and docking times.[28] Recent studies have found shorter operative times in RaPN patients compared with OPN patients with experienced surgical teams.[35,37] Additionally, studies found that OPN was less expensive, especially when accounting for operating room costs.[39,45] Our meta-analysis with limited study numbers and inconsistent accounting methods was unable to study cost-effectiveness. Further prospective and large scale cost-effective studies should be undertaken to compare these two techniques.

4.1 | Limitation

Our analysis has a number of limitations. First, the majority of studies were retrospective, nonrandomized comparisons, except two prospectively derived studies. Second, there was significant variation for EBL, transfusion rate, intraoperative complications, operative time, PSM, recurrence rates, and hospital stay. Although conducting meta-regression and subgroup analyses to identify confounding factors and outlier studies for heterogeneities, other factors such size of series, surgeon experience, varied approaches of renal hilar control, and varied methods for measuring clinical variables still contribute to the study heterogeneity. Third, there was publication bias in regard with EBL, postoperative complication rate, hospital stay, PSM, and readmission rates. Trim and fill test only revealed significant change on readmission rate; readmission rate was strongly influenced by publication bias. Finally, most studies reported insufficient and varied follow-up period, and thus our pooled analyses evaluating long-term oncologic and functional outcomes were limited.

5 | CONCLUSION

This meta-analysis showed that compared with OPN, RaPN is associated with decreased blood loss, blood transfusion and complication rates, longer operative time, shorter hospital stay, lower readmission rate, and minor eGFR change. Some advantages of RaPN was strengthen in nonobese patients and/or with renal hilar control but attenuated in patients with highly complex renal tumor. However, these results should be applied with caution in clinical practice due to suboptimal quality of evidence and study heterogeneity. Further prospective randomized clinical studies with adequate follow-up is needed not only to validate our results but also to establish robust safety and efficacy evidence of robotic renal surgery.

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CONFLICTS OF INTEREST

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REFERENCES

1. Huang WC, Levey AS, Serio AM, et al. Chronic kidney disease after nephrectomy in patients with renal cortical tumours: a retrospective cohort study. *Lancet Oncol*. 2006;7(9):735-740.
2. Ljungberg B, Bensalah K, Canfield S, et al. EAU guidelines on renal cell carcinoma: 2014 update. *Eur Urol*. 2015;67(5):913-924.
3. Miller DC, Schonlau M, Litwin MS, Lai J, Saigal CS. Urologic diseases in America P. Renal and cardiovascular morbidity after partial or radical nephrectomy. *Cancer*. 2008;112(3):511-520.
4. Patard JJ, Shvarts O, Lam JS, et al. Safety and efficacy of partial nephrectomy for all T1 tumors based on an international multicenter experience. *J Urol*. 2004;171(6 Pt 1):2181-2185. quiz 2435
5. Patard JJ, Pantuck AJ, Crepel M, et al. Morbidity and clinical outcome of nephron-sparing surgery in relation to tumour size and indication. *Eur Urol*. 2007;52(1):148-154.
6. Minervini A, Siena G, Carini M. Robotic-assisted partial nephrectomy: the next gold standard for the treatment of intracapsular renal tumors. *Expert Rev Anticancer Ther*. 2011;11(12):1779-1782.

7. Gettman MT, Blute ML, Chow GK, Neururer R, Bartsch G, Peschel R. Robotic-assisted laparoscopic partial nephrectomy: technique and initial clinical experience with DaVinci robotic system. *Urology*. 2004;64(5):914-918.
8. Pierorazio PM, Patel HD, Feng T, Yohannan J, Hyams ES, Allaf ME. Robotic-assisted versus traditional laparoscopic partial nephrectomy: comparison of outcomes and evaluation of learning curve. *Urology*. 2011;78(4):813-819.
9. Ghani KR, Sukumar S, Sammon JD, Rogers CG, Trinh QD, Menon M. Practice patterns and outcomes of open and minimally invasive partial nephrectomy since the introduction of robotic partial nephrectomy: results from the nationwide inpatient sample. *J Urol*. 2014; 191(4):907-912.
10. Dulabon LM, Kaouk JH, Haber GP, et al. Multi-institutional analysis of robotic partial nephrectomy for hilar versus nonhilar lesions in 446 consecutive cases. *Eur Urol*. 2011;59(3):325-330.
11. Gong Y, Du C, Josephson DY, Wilson TG, Nelson R. Four-arm robotic partial nephrectomy for complex renal cell carcinoma. *World J Urol*. 2010;28(1):111-115.
12. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med*. 2009;6(7). e1000100
13. Wu Z, Li M, Liu B, et al. Robotic versus open partial nephrectomy: a systematic review and meta-analysis. *PloS one*. 2014;9(4):e94878.
14. Seveso M, Grizzi F, Bozzini G, Mandressi A, Guazzoni G, Taverna G. Open partial nephrectomy: ancient art or currently available technique? *Int Urol Nephrol*. 2015;47(12):1923-1932.
15. Borenstein M, Hedges LV, Higgins JP, Rothstein HR. A basic introduction to fixed-effect and random-effects models for meta-analysis. *Res Synth Methods*. 2010;1(2):97-111.
16. Borenstein M, Higgins JP, Hedges LV, Rothstein HR. Basics of meta-analysis: I(2) is not an absolute measure of heterogeneity. *Res Synth Methods*. 2017;8(1):5-18.
17. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327(7414):557-560.
18. Higgins JP, Green S. Recommendations on testing for funnel plot asymmetry. In: Higgins JP, Green S, eds. *Cochrane Handbook for Systematic Reviews of Interventions*. Cochrane Library; 2011.
19. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 1997;315(7109):629-634.
20. Duval S, Tweedie R. Trim and fill: a simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. *Biometrics*. 2000;56(2):455-463.
21. Tobias A. Assessing the influence of a single study in meta-analysis. *Stata Tech Bull*. 1999;47:15-17.
22. Kutikov A, Uzzo RG. The R.E.N.A.L. nephrometry score: a comprehensive standardized system for quantitating renal tumor size, location and depth. *J Urol*. 2009;182(3):844-853.
23. Lee S, Oh J, Hong SK, Lee SE, Byun SS. Open versus robot-assisted partial nephrectomy: effect on clinical outcome. *J Endourol*. 2011;25(7):1181-1185.
24. Stroup SP, Palazzi K, Kopp RP, et al. RENAL nephrometry score is associated with operative approach for partial nephrectomy and urine leak. *Urology*. 2012;80(1):151-156.
25. Yu HY, Hevelone ND, Lipsitz SR, Kowalczyk KJ, Hu JC. Use, costs and comparative effectiveness of robotic assisted, laparoscopic and open urological surgery. *J Urol*. 2012;187(4):1392-1398.
26. Ficarra V, Minervini A, Antonelli A, et al. A multicentre matched-pair analysis comparing robot-assisted versus open partial nephrectomy. *BJU Int*. 2014;113(6):936-941.
27. Alemozaffar M, Chang SL, Kacker R, Sun M, DeWolf WC, Wagner AA. Comparing costs of robotic, laparoscopic, and open partial nephrectomy. *J Endourol*. 2013;27(5):560-565.
28. Masson-Lecomte A, Yates DR, Hupertan V, et al. 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*. 2013;31(6):924-929.
29. Zargar H, Bhayani S, Allaf ME, et al. Comparison of perioperative outcomes of robot-assisted partial nephrectomy and open partial nephrectomy in patients with a solitary kidney. *J Endourol*. 2014; 28(10):1224-1230.
30. Minervini A, Vittori G, Antonelli A, et al. Open versus robotic-assisted partial nephrectomy: a multicenter comparison study of perioperative results and complications. *World J Urol*. 2014;32(1):287-293.
31. Webb CM, Kamel M, Eltahawy E, et al. A comparative study of open, laparoscopic and robotic partial nephrectomy in obese patients. *Urol Ann*. 2015;7(2):231-234.
32. Porpiglia F, Mari A, Bertolo R, et al. Partial nephrectomy in clinical T1b renal tumors: multicenter comparative study of open, laparoscopic and robot-assisted approach (the RECORd project). *Urology*. 2016; 89:45-51.
33. Takagi T, Kondo T, Tachibana H, et al. A propensity score-matched comparison of surgical precision obtained by using volumetric analysis between robot-assisted laparoscopic and open partial nephrectomy for T1 renal cell carcinoma: a retrospective non-randomized observational study of initial outcomes. *Int Urol Nephrol*. 2016;48(10):1585-1591.
34. Kara O, Maurice MJ, Malkoc E, et al. Comparison of robot-assisted and open partial nephrectomy for completely endophytic renal tumours: a single centre experience. *BJU Int*. 2016;118(6):946-951.
35. Mearini L, Nunzi E, Vianello A, Di Biase M, Porena M. Margin and complication rates in clampless partial nephrectomy: a comparison of open, laparoscopic and robotic surgeries. *J Robot Surg*. 2016;10(2):135-144.
36. Patton MW, Salevitz DA, Tyson MD 2nd, et al. Robot-assisted partial nephrectomy for complex renal masses. *J Robot Surg*. 2016; 10(1):27-31.
37. Lucas SM, Mellon MJ, Erntsberger L, Sundaram CP. A comparison of robotic, laparoscopic and open partial nephrectomy. *JSLS*. 2012; 16(4):581-587.
38. Simhan J, Smaldone MC, Tsai KJ, et al. Perioperative outcomes of robotic and open partial nephrectomy for moderately and highly complex renal lesions. *J Urol*. 2012;187(6):2000-2004.
39. Laydner H, Isac W, Autorino R, et al. Single institutional cost analysis of 325 robotic, laparoscopic, and open partial nephrectomies. *Urology*. 2013;81(3):533-538.
40. Malkoc E, Maurice MJ, Kara O, et al. Robot-assisted approach improves surgical outcomes in obese patients undergoing partial nephrectomy. *BJU Int*. 2017;119(2):283-288.
41. Luciani LG, Chiodini S, Mattevi D, et al. Robotic-assisted partial nephrectomy provides better operative outcomes as compared to the laparoscopic and open approaches: results from a prospective cohort study. *J Robot Surg*. 2017;11(3):333-339.
42. Wu Z, Li M, Qu L, et al. A propensity-score matched comparison of perioperative and early renal functional outcomes of robotic versus open partial nephrectomy. *PloS one*. 2014;9(4):e94195.
43. Mano R, Schulman A, Hakimi AA, et al. Cost comparison of open and robotic partial nephrectomy using a short postoperative pathway. *Urology*. 2015;85(3):596-603.
44. Peyronnet B, Seisen T, Oger E, et al. Comparison of 1800 robotic and open partial nephrectomies for renal tumors. *Ann Surg Oncol*. 2016;23(13):4277-4283.
45. Wang Y, Shao J, Ma X, Du Q, Gong H, Zhang X. Robotic and open partial nephrectomy for complex renal tumors: a matched-pair comparison with a long-term follow-up. *World J Urol*. 2017;35(1):73-80.
46. Pak JS, Lee JJ, Bilal K, Finkelstein M, Palese MA. Utilization trends and outcomes up to 3 months of open, laparoscopic, and robotic partial nephrectomy. *J Robot Surg*. 2017;11(2):223-229.

47. Malkoc E, Ramirez D, Kara O, et al. Robotic and open partial nephrectomy for localized renal tumors larger than 7 cm: a single-center experience. *World J Urol*. 2017;35(5):781-787.

48. Oh JJ, Lee JK, Kim K, Byun SS, Lee SE, Hong SK. Comparison of the width of peritumoral surgical margin in open and robotic partial nephrectomy: a propensity score matched analysis. *PloS one*. 2016;11(6):e0158027.

49. Lee C, Kwon T, Yoo S, et al. Comparison of renal function between robot-assisted and open partial nephrectomy as determined by Tc 99m-DTPA renal scintigraphy. *J Korean Med Sci*. 2016;31(5):743-749.

50. Klaassen Z, Kohut RM Jr, Patel D, Terris MK, Madi R. A single surgeon's experience with open, laparoscopic, and robotic partial nephrectomy. *Int Sch Res Notices*. 2014;2014. 430914. https://doi.org/10.1155/2014/430914

51. Tabayoyong W, Abouassaly R, Kiechle JE, et al. Variation in surgical margin status by surgical approach among patients undergoing partial nephrectomy for small renal masses. *J Urol*. 2015;194(6):1548-1553.

52. Miyake H, Hinata N, Imai S, Furukawa J, Tanaka K, Fujisawa M. Partial nephrectomy for hilar tumors: comparison of conventional open and robot-assisted approaches. *Int J Clin Oncol*. 2015;20(4):808-813.

53. Hamilton ZA, Uzzo RG, Larcher A, et al. Comparison of functional outcomes of robotic and open partial nephrectomy in patients with pre-existing chronic kidney disease: a multicenter study. *World J Urol*. 2018;36(8):1255-1262.

54. Tan JL, Frydenberg M, Grummet J, et al. Comparison of perioperative, renal and oncologic outcomes in robotic-assisted versus open partial nephrectomy. *ANZ J Surg*. 2018;88(3):E194-E199.

55. Borghesi M, Schiavina R, Chessa F, et al. Retroperitoneal robot-assisted versus open partial nephrectomy for cT1 renal tumors: a matched-pair comparison of perioperative and early oncological outcomes. *Clin Genitourin Cancer*. 2018;16(2):e391-e396.

56. Shen Z, Xie L, Xie W, et al. The comparison of perioperative outcomes of robot-assisted and open partial nephrectomy: a systematic review and meta-analysis. *World J Surg Oncol*. 2016;14(1):220.

57. Xia L, Wang X, Xu T, Guzzo TJ. Systematic review and meta-analysis of comparative studies reporting perioperative outcomes of robot-assisted partial nephrectomy versus open partial nephrectomy. *J Endourol*. 2017;31(9):893-909.

58. Gombotz H, Schreier G, Neubauer S, Kastner P, Hofmann A. Gender disparities in red blood cell transfusion in elective surgery: a post hoc multicentre cohort study. *BMJ Open*. 2016;6(12):e012210.

59. Cacciamani GE, Medina LG, Gill TS, et al. Impact of renal hilar control on outcomes of robotic partial nephrectomy: systematic review and cumulative meta-analysis. *Eur Urol Focus*. 2018. pii: S2405–4569(18)30013–0. https://doi.org/10.1016/j.euf.2018.01.012

60. Khalifeh A, Kaouk JH, Bhayani S, et al. Positive surgical margins in robot-assisted partial nephrectomy: a multi-institutional analysis of oncologic outcomes (leave no tumor behind). *J Urol*. 2013;190(5):1674-1679.

61. Ani I, Finelli A, Alibhai SM, Timilshina N, Fleshner N, Abouassaly R. Prevalence and impact on survival of positive surgical margins in partial nephrectomy for renal cell carcinoma: a population-based study. *BJU Int*. 2013;111(8):E300-E305.

62. Abdullah N, Dalela D, Barod R, et al. Robotic partial nephrectomy for renal tumours in obese patients: perioperative outcomes in a multi-institutional analysis. *Can Urol Assoc J*. 2015;9(11–12):E859-E862.

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