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Comparison of Perioperative Outcomes Between Robotic and Laparoscopic Partial Nephrectomy: A Systematic Review and Meta-analysis

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Abstract

Context: Robotic partial nephrectomy (RPN) is rapidly increasing; however, the benefit of RPN over laparoscopic partial nephrectomy (LPN) is controversial.
Objective: To compare perioperative outcomes of RPN and LPN.
Evidence acquisition: We searched Ovid-Medline, Ovid-Embase, the Cochrane Library, KoreaMed, KMbase, KISS, RISS, and KisTi from their inception through August 2013. Two independent reviewers extracted data using a standardized form. Quality of the selected studies was assessed using the methodological index for nonrandomized studies.
Evidence synthesis: A total of 23 studies and 2240 patients were included. All studies were cohort studies with no randomization, and the methodological quality varied. There was no significant difference between the two groups regarding complications of Clavien-Dindo classification grades 1–2 ($p = 0.62$), Clavien-Dindo classification grades 3–5 ($p = 0.78$), change of serum creatinine ($p = 0.65$), operative time ($p = 0.35$), estimated blood loss ($p = 0.76$), and positive margins ($p = 0.75$). The RPN group had a significantly lower rate of conversion to open surgery ($p = 0.02$) and conversion to radical surgery ($p = 0.0006$), shorter warm ischemia time (WIT; $p = 0.005$), smaller change of estimated glomerular filtration rate (eGFR; $p = 0.03$), and shorter length of stay (LOS; $p = 0.004$).
Conclusions: This meta-analysis shows that RPN is associated with more favorable results than LPN in conversion rate to open or radical surgery, WIT, change of eGFR, and shorter LOS. To establish the safety and effectiveness outcomes of robotic surgery, well-designed randomized clinical studies with long-term follow-up are needed.
Patient summary: Robotic partial nephrectomy (PN) is more favorable than laparoscopic PN in terms of lower conversion rate to radical nephrectomy, a favorable renal function indexed estimated glomerular filtration rate, shorter length of hospital stay, and shorter warm ischemia time.

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1. Introduction

Partial nephrectomy (PN) is the gold standard for the treatment of small renal masses (<4 cm) [1,2]. Evolution has progressed from open radical nephrectomy through open PN to minimally invasive PN including laparoscopic PN (LPN) and robotic PN (RPN) [3]. However, the technical and ergonomic challenge of laparoscopic suturing has limited the dissemination of LPN [3]. Surgical robots were developed to facilitate minimally invasive surgery and to assist surgeons performing surgical procedures [4]. It has been reported that RPN can be performed successfully after a 25-case learning curve [3].

Evaluation of RPN is needed because it does not directly improve patient outcomes. Although some authors [5,6] reported that RPN provided equivalent perioperative outcomes with the added advantage of significantly shorter warm ischemia time (WIT) compared with LPN, the true benefit of RPN over LPN among previous comparison studies [3,5–11] is still controversial. In addition, the renal functional and oncologic advantages of RPN for patients with renal cancer are not well studied because of the lack of studies with which to perform meta-analyses. The numbers of papers on this subject have increased recently, so it appears to be the right time to perform meta-analyses of outcomes such as kidney function, estimated glomerular filtration rate (eGFR), and serum creatinine (sCr) for RPN versus LPN using statistical power even though there are no randomized studies. Although randomized controlled trials are powerful tools, they are limited by ethical issues, patient preferences, and the time and cost for intervention therapy, especially in robotic surgery. Consequently, our aim was to evaluate the perioperative outcomes of WIT, length of stay (LOS), estimated blood loss (EBL), changes of eGFR and sCr, conversion rate to radical surgery and open surgery, and positive surgical margin (PSM) rates of RPN versus LPN for patients with renal cancer, using recent research.

2. Evidence acquisition

2.1. *Search strategy*

We searched Ovid-Medline (1946–2013), Embase (inception –2013), and the Cochrane Central Register of Controlled Trials (in the Cochrane Library) on July 5, 2013. Korean databases (KoreaMed, KMbase, KISS, RISS, and KisTi) were also searched. Search terms combined patient-related terms (*kidney or renal neoplasm, kidney or renal cancer, kidney or renal carcinoma*) and intervention terms (*robotics, computer-assisted surgery, telerobot, remote operation, remote surgery, da Vinci*).

2.2. *Inclusion criteria and study eligibility*

We evaluated the records according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis statement. We defined study eligibility using the patient population, intervention, comparator, outcomes, and setting approach. Inclusion criteria were studies that focused on patients with kidney cancer and those that compared surgical and patient outcomes between RPN and LPN. Exclusion criteria were (1) studies that did not focus on patients with

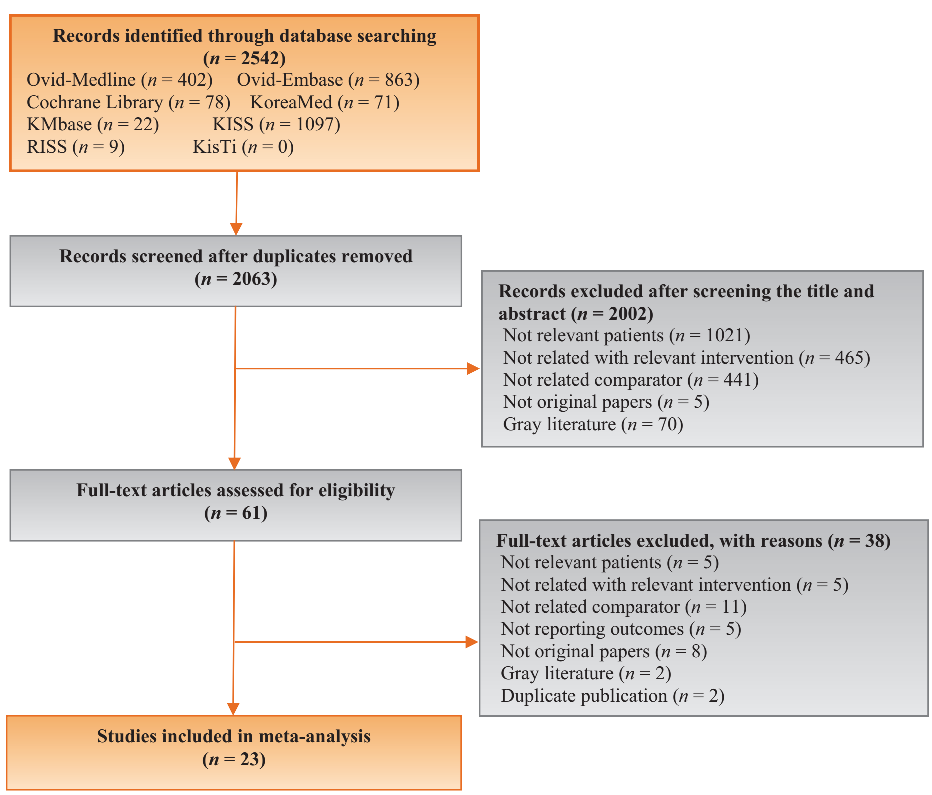

Fig. 1 – Flowchart of study selection process.

Table 1 – Demographics of included studies

Study	Study design	Level of evidence*	Surgical approach/ Clamp method		No. of surgeons	No. of patients		Follow up duration**		Mean age, yr		Tumor size, cm	
			RPN	LPN		RPN $n = 1152$	LPN $n = 1088$	RPN	LPN	RPN	LPN	RPN	LPN
Alemozaffar et al [20]	Retro	2b	Unclear/total clamp	Unclear/total clamp	Single	25	25	NR	NR	56	53	2.5	3.3
Chaste et al [21]	Retro	4	Transperitoneal/total clamp	Transperitoneal/total clamp	Single	54	44	NR	NR	60	63	3.5	3.1
Masson-Lecomte et al [8]	Pro	2b	Transperitoneal/selective clamp	Transperitoneal/selective clamp	8	220	45	9.3 (7.9)	23.1 (24.9)	59	63	3.1	3.0
Williams et al [22]	Pro	2b	Transperitoneal/total clamp/ with or without early unclamp	Transperitoneal/total clamp with delayed unclamp	Single	27	59	NR	NR	56	55	2.5	3.1
Ellison et al [23]	Retro	2b	Transperitoneal or retroperitoneal/unclamped mixed	Transperitoneal or retroperitoneal/unclamped mixed	RPN: 5; LPN: single	108	108	NR	NR	59	56	2.9	2.7
Hyams et al [24]	Retro	4	Unclear	Unclear	Single	20	20	NR	NR	52	59	3.0	3.2
Long et al [9]	Retro	2b	Unclear	Unclear	RPN: 3 LPN: 2	199	182	8.3 (10)	18.3 (17.9)	59	60	3.8	4.0
Lucas et al [25]	Retro	2b	Unclear	Unclear	Single	27	15	9.4 (7.6)	25.8 (20.2)	62	49	2.4	2.2
Cho et al [26]	Retro	4	Transperitoneal/selective clamp	Transperitoneal	NR	10	10	NR	NR	63	56	2.7	2.8
Lavery et al [10]	Retro	4	Transperitoneal/total clamp	Transperitoneal/total clamp	Single	20	18	NR	NR	55	54	2.5	2.3
Pierorazio et al [3]	Retro	2b	Transperitoneal/selective clamp	Transperitoneal/selective clamp	Single	48	102	NR	NR	62	56	2.2	2.5
Seo et al [27]	Retro	4	Transperitoneal/total clamp	Transperitoneal/total clamp	Single	13	14	NR	NR	54	54	2.7	2.0
Boger et al [15]	Retro	4	Transperitoneal/unclear	Transperitoneal/unclear	2	13	46	NR	NR	NR	NR	4.8	5.8
Choi et al [28]	Pro	2b	Transperitoneal/total clamp	Transperitoneal/total clamp	Single	13	31	NR	NR	56	51	2.8	2.3
DeLong et al [29]	Retro	4	Transperitoneal/total clamp	Transperitoneal/total clamp	Single	13	15	6.3 (1–17)	9 (4–14)	60	54	2.6	2.8
Haber et al [30]	Retro	2b	Transperitoneal/early/ conventional/unclamped mixed	Transperitoneal/early/ conventional/unclamped mixed	Single	75	75	NR	NR	63	60	2.8	2.5
Wu et al [31]	Retro	2b	Transperitoneal/unclamped	Transperitoneal/total clamp	3	42	36	7.8 (1–18.9)	25.8 (0.5–71.5)	56	58	2.7	2
Benway et al [32]	Retro	4	Transperitoneal/unclear	Transperitoneal/unclear	3	129	118	NR	NR	59	59	2.9	2.6
Jeong et al [33]	Retro	4	Transperitoneal/total clamp	Transperitoneal/total clamp	Single	31	26	NR	NR	53	59	3.4	2.4
Kaouk et al [34]	Pro	4	Single-port transperitoneal or retroperitoneal	Single-port transperitoneal or retroperitoneal	NR	2	5	NR	NR	58	69	2.0	2.1
Kural et al [35]	Unclear	4	Transperitoneal/total clamp	Transperitoneal/total clamp	NR	11	20	7.54 (3–14)	38 (19–66)	51	59	3.2	3.1
Wang et al [36]	Retro	4	Unknown	Unknown	Single	40	62	NR	NR	61	58	2.5	2.4
Aron et al [37]	Retro	2b	Transperitoneal/unclamped or early unclamped	Transperitoneal/unclamped or early unclamped	NR	12	12	7.4 (5.2)	8.5 (5.6)	64	61	2.4	2.9

LPN = laparoscopic partial nephrectomy; NR = not reported; Pro = prospective cohort; Retro = retrospective cohort; RPN = robotic partial nephrectomy.
* Level of evidence by the Oxford Centre for Evidence-based Medicine.
** Measures of central tendency for follow-up duration were used with mean or median, and variation was used with standard deviation or range.

kidney cancer, (2) studies that included patients with solitary kidneys or bilateral nephrectomy, (3) studies in which robot-assisted surgery was not performed, (4) studies in which LPN was not performed as a comparator, (5) nonprimary studies (eg, review articles, letters, commentaries, systematic research reviews, meta-analyses), and (6) gray literature (eg, abstract only, thesis).

When two or more studies were reported in an overlapping time period by the same institution and/or authors, the most recently published report that included the largest number of patients was used. Articles in any language were included. We identified 2542 potentially relevant articles but excluded 2002 on examining the titles and abstracts based on exclusion criteria. The full text of 61 articles was evaluated, and 38 articles were excluded because 5 included nonrelevant patients, 5 included nonrelevant interventions, 11 included nonrelated comparators, 5 did not report outcomes, 8 were not original papers, 2 were gray literature, and 2 were reported in an overlapping time period by the same institution and/or authors. Finally, 23 articles were selected yielding 2240 patients (Fig. 1).

The methodological index for nonrandomized studies (MINORS) [12] was used to evaluate the quality of the research because all of the studies were observational. MINORS involves 12 items: a stated aim of the study; inclusion of consecutive patients; prospective data collection; end points appropriate to the study aim; unbiased evaluation of end points; a follow-up period appropriate to the major end point; loss to follow-up not >5%; a control group having the gold standard intervention; contemporary groups; baseline equivalence of groups; prospective calculation of the sample size; and statistical analyses adapted to the study design and scored as 0 (not reported), 1 (reported but inadequate), or 2 (reported and

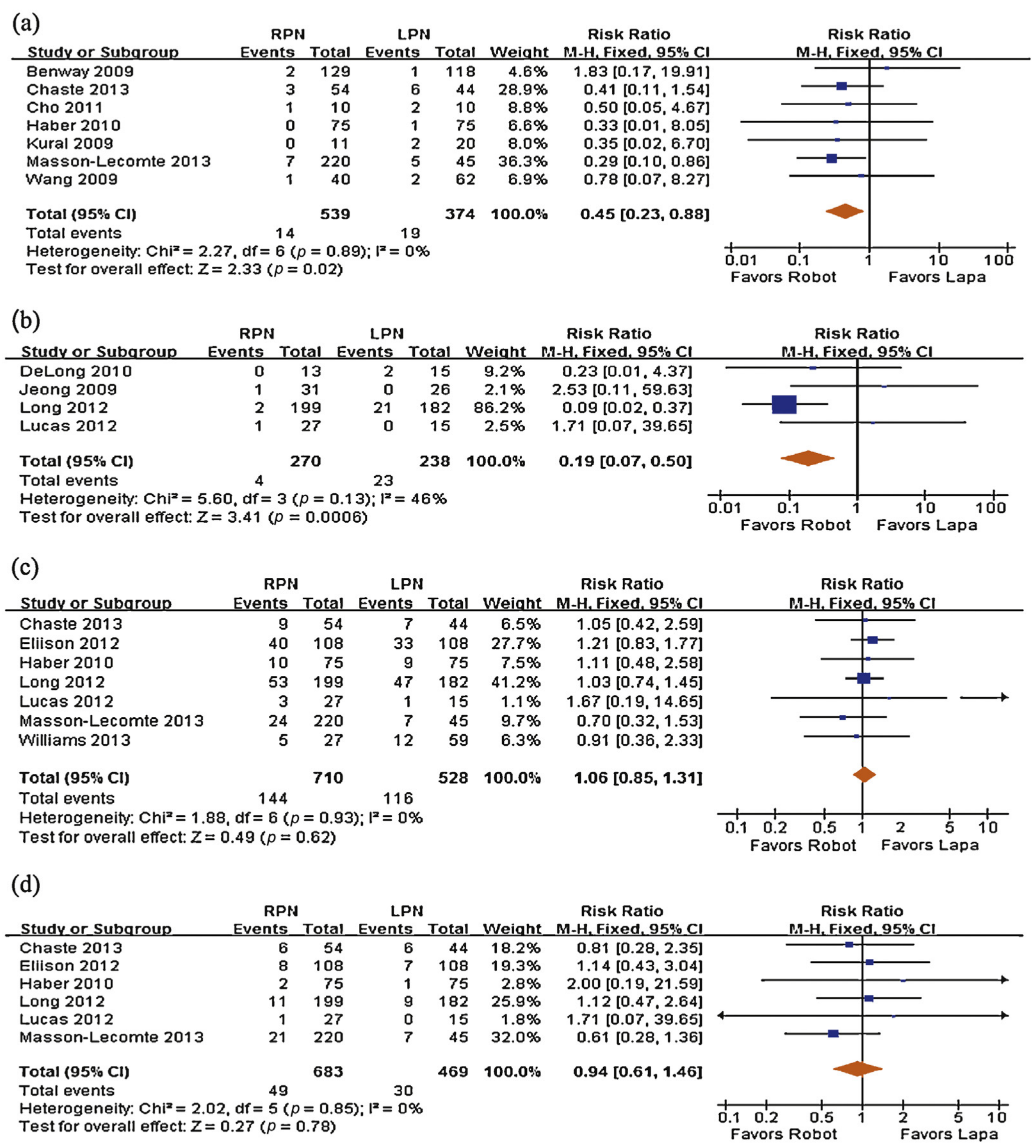

Fig. 2 – Safety outcomes of meta-analysis: (a) convert to open surgery; (b) convert to radical surgery; (c) Clavien-Dindo classification grades 1–2; (d) Clavien-Dindo classification grades 3–5.
CI = confidence interval; IV = inverse variance; LPN = laparoscopic partial nephrectomy; M-H = Mantel-Haenszel; RPN = robot-assisted partial nephrectomy; SD = standard deviation.

adequate). The maximum score for comparative studies is 24 points.

Two independent researchers (J.E.C. and J.H.Y.) performed the quality assessment and data extraction using a piloted form including the first author, publication year, country of origin, study setting and design, number of surgeons, funding sources, number of eligible patients, mean age, sex ratio, renal complexity score when available, body mass index, robot-assisted and laparoscopic technique, safety outcomes, effectiveness outcomes, and additional clinical data. Disagreements between the reviewers were resolved by discussion with all authors or in consultation with clinical specialists.

2.3. Data analysis

Meta-analysis was conducted using RevMan v.5.2 (Cochrane Collaboration, Oxford, UK) and Comprehensive Meta Analysis v.2.0 (Biostat, Englewood, NJ, USA). The Cochrane Q statistic and I^2 statistic were used to assess statistical heterogeneity. For continuous data measured on the same scale, the weighted mean difference (WMD) was estimated. The standardized mean difference (SMD) was estimated when different outcome scales were used. Relative risk (RR) was calculated for binary data, and RR and 95% confidence intervals (CIs) were used for dichotomous variables. Heterogeneity was analyzed using a chi-square test with $n - 1$ degrees of freedom. A p value of 0.05 was used for statistical significance with the I^2 test [13]. I^2 values of 25%, 50%, and 90% corresponded to low, moderate, and high levels of heterogeneity, respectively. A fixed-effects model was used unless there was statistically significant high heterogeneity (eg, $I^2 > 90\%$) between studies. A random-effects model was used if heterogeneity existed. To assess the risk of publication bias, we used a funnel plot and the Egger test for outcomes when at least 10 statistically significant studies were included in the meta-analysis. A public health statistics expert reviewed the statistical analyses.

3. Evidence synthesis

Table 1 shows the characteristics of the included studies. Three were prospective cohort studies, and 20 were retrospective cohort studies with no randomization. Included studies were of varying methodological quality. Among the 2240 patients, the mean ages of the RPN group (1152 patients) ranged from 51 to 64 yr; the mean ages of the LPN group (1088 patients) ranged from 49 to 69 yr (Table 1). The MINORS sum scores ranged from 6 to 14, and the mean score of all the included studies was 10.4. Although the maximum score of MINORS is 24, no article scored ≥15. The articles with low scores were evaluated in terms of *unbiased evaluation of end points, follow-up period appropriate to the major end point, loss to follow-up not exceeding 5%, prospective calculation of the sample size*, and *baseline equivalence of groups*.

3.1. Safety outcomes

Table 1 and Figure 2 depict the demographics of the studies including number of patients, age, size of tumor, and results

Table 2 – Safety results of robotic partial nephrectomy versus laparoscopic partial nephrectomy

Study	No. of patients		Conversion rate to open surgery		Conversion ratio to radical surgery		Complication CD 1–2, n		Complication CD 3–5, n	
	RPN (n = 1152)	LPN (n = 1088)	RPN	LPN	RPN	LPN	RPN	LPN	RPN	LPN
Alemozaffar et al [20]	25	25	–	–	–	–	–	–	–	–
Chaste et al [21]	54	44	3	6	–	–	9	7	6	6
Masson-Lecomte et al [8]	220	45	7	5	–	–	24	7	21	7
Williams et al [22]	27	59	–	–	–	–	5	12	–	–
Ellison et al [23]	108	108	–	–	–	–	40	33	8	7
Hyams et al [24]	20	20	–	–	–	–	–	–	–	–
Long et al [9]	199	182	–	–	2	21	53	47	11	9
Lucas et al [25]	27	15	–	–	1	0	3	1	1	0
Cho et al [26]	10	10	1	2	–	–	–	–	–	–
Lavery et al [10]	20	18	–	–	–	–	–	–	–	–
Pierorazio et al [3]	48	102	–	–	–	–	–	–	–	–
Seo et al [27]	13	14	–	–	–	–	–	–	–	–
Boger et al [15]	13	46	–	–	–	–	–	–	–	–
Choi et al [28]	13	31	–	–	–	–	–	–	–	–
DeLong et al [29]	13	15	–	–	0	2	–	–	–	–
Haber et al [30]	75	75	0	1	–	–	10	9	2	1
Wu et al [31]	42	36	–	–	–	–	–	–	–	–
Benway et al [32]	129	118	2	1	–	–	–	–	–	–
Jeong et al [33]	31	26	–	–	1	0	–	–	–	–
Kaouk et al [34]	2	5	–	–	–	–	–	–	–	–
Kural et al [35]	11	20	0	2	–	–	–	–	–	–
Wang et al [36]	40	62	1	2	–	–	–	–	–	–
Aron et al [37]	12	12	–	–	–	–	–	–	–	–

CD = Clavien-Dindo classification grade; LPN = laparoscopic partial nephrectomy; RPN = robotic partial nephrectomy.

of safety outcomes. In terms of safety, there were no differences in operative outcomes including complications of Clavien-Dindo classification grades 1–2 ($p = 0.62$; RR: 1.06; 95% CI, 0.85–1.31) and Clavien-Dindo classification grades 3–5 ($p = 0.78$; RR: 0.94; 95% CI, 0.61–1.46). The RPN group had a significantly lower rate of conversion to open surgery ($p = 0.02$; RR: 0.45; 95% CI, 0.23–0.88) and conversion to radical surgery ($p = 0.0006$; RR: 0.19; 95% CI, 0.07–0.50) than the LPN group (Fig. 2).

3.2. *Effectiveness outcomes*

Table 2, Table 3 and Figure 3 show the effectiveness outcomes of the included studies. In terms of effectiveness, there were no significant differences between the two groups regarding change of sCr ($p = 0.65$; SMD: −0.06; 95% CI, −0.31 to 0.19), operative time ($p = 0.35$; WMD: 8.77; 95% CI, −9.56 to 27.1), EBL ($p = 0.76$; WMD: 5.72; 95% CI, −31.43 to 42.87), or PSMs ($p = 0.75$; RR: 1.09; 95% CI, 0.64–1.84). The RPN group had significantly shorter WIT ($p = 0.005$; WMD: −2.97; 95% CI, −5.05 to −0.89), smaller change of eGFR ($p = 0.03$; SMD: −0.18; 95% CI, −0.34 to −0.02), and shorter LOS ($p = 0.004$; WMD: −0.21; 95% CI, −0.36 to −0.07) (Fig. 3). There were moderate to high heterogeneity in WIT ($I^2 = 62\%$), operative time ($I^2 = 91\%$), and EBL ($I^2 = 52\%$), but subgroup analysis was not possible due to the lack of data. The funnel plot did not show significant asymmetry for WIT (Egger test $p = 0.82$) (Fig. 4a) and LOS (Egger test $p = 0.46$) (Fig. 4b).

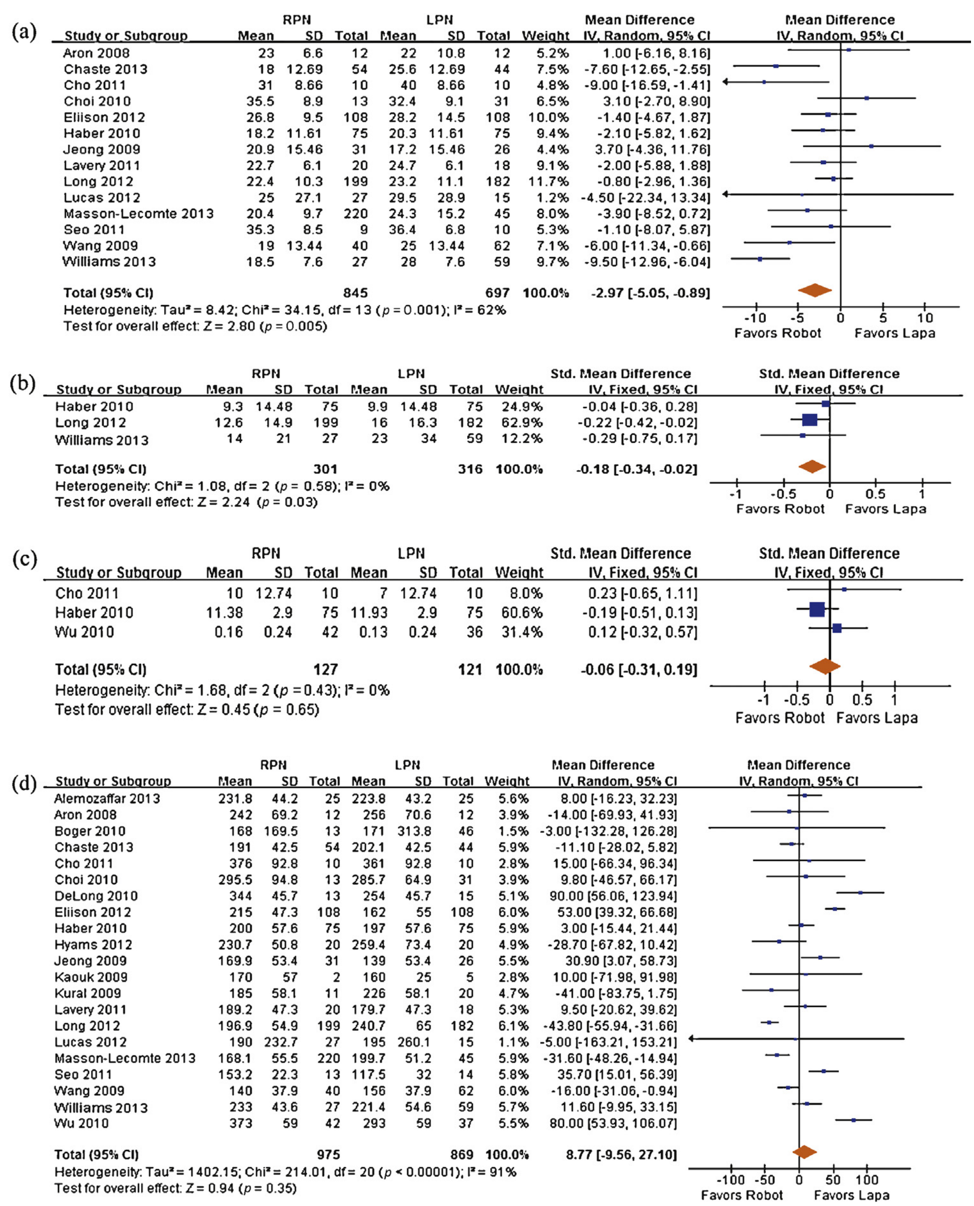

Fig. 3 – Effectiveness outcomes of meta-analysis: (a) warm ischemia time; (b) change of estimated glomerular filtration rate; (c) change of serum creatinine; (d) operative time; (e) estimated blood loss; (f) length of stay; (g) positive surgical margins.
CI = confidence interval; IV = inverse variance; LPN = laparoscopic partial nephrectomy; M-H = Mantel-Haenszel; RPN = robot-assisted partial nephrectomy; SD = standard deviation.

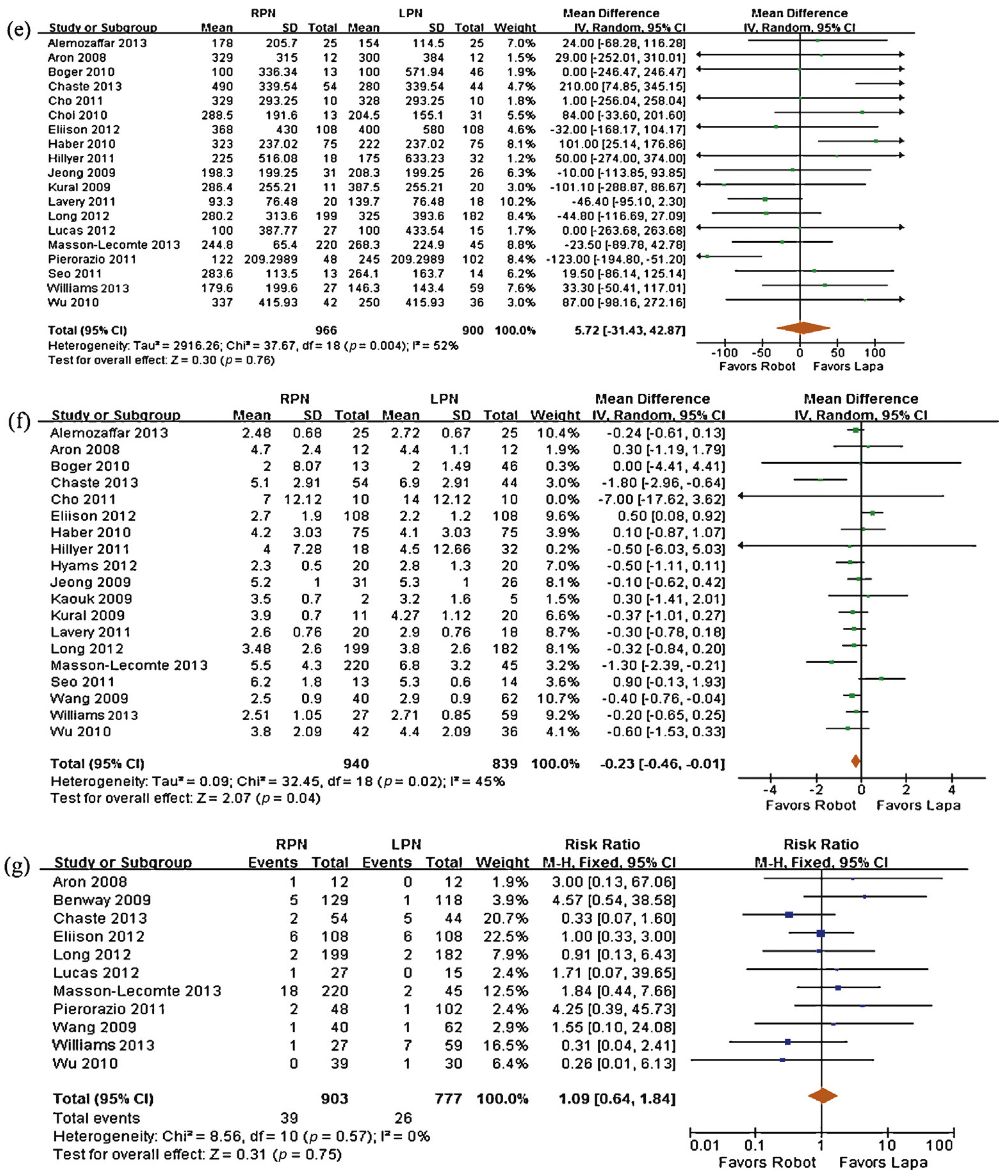

Fig. 3. (*Continued*)

3.3. *Discussion*

The results of the meta-analysis of 2240 patients showed that RPN had (1) a lower conversion rate to open surgery and radical nephrectomy, (2) a favorable eGFR impact and positive results on renal function, (3) reduction in LOS, and (4) shorter WIT compared with LPN. This result differs from past meta-analyses of RPN for kidney cancer patients.

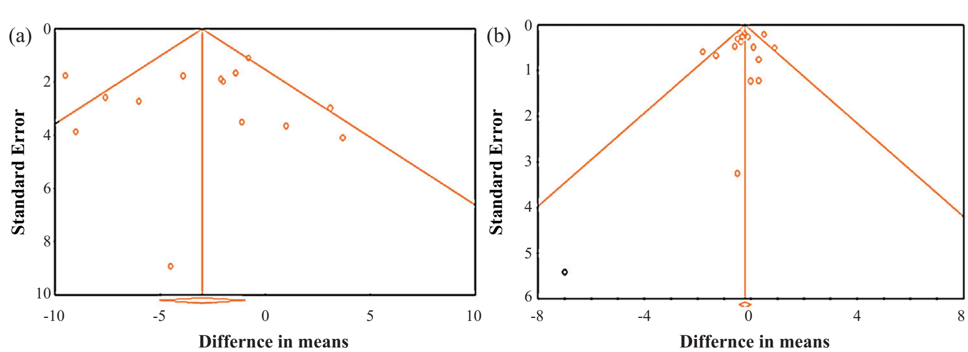

Fig. 4 – Funnel plot for (a) warm ischemia time and (b) length of stay.

Table 3 – Effectiveness results of robotic partial nephrectomy versus laparoscopic partial nephrectomy

Study	No. of patients		Mean WIT, min		eGFR, ml/min per 1.73 m^2		sCr, mg/dl		Mean operative time, min		Mean EBL, ml		Mean LOS, d		PSM, *n*	
	RPN (*n* = 1152)	LPN (*n* = 1088)	RPN	LPN	RPN	LPN	RPN	LPN	RPN	LPN	RPN	LPN	RPN	LPN	RPN	LPN
Alemozaffar et al [20]	25	25	–	–	–	–	–	–	232	224	178	154	2.5	2.7	–	–
Chaste et al [21]	54	44	18	25.6	–	–	–	–	191	202	490	280	5.1	6.9	2	5
Masson-Lecomte et al [8]	220	45	20.4	24.3	–	–	–	–	168	200	245	268	5.5	6.8	18	2
Williams et al [22]	27	59	18.5	28	14	23	–	–	–	–	–	–	–	–	–	–
Ellison et al [23]	108	108	26.8	28.2	–	–	–	–	215	162	368	400	2.7	2.2	6	6
Hyams et al [24]	20	20	–	–	–	–	–	–	231	259			2.3	2.8	–	–
Long et al [9]	199	182	22.4	23.2	12.6	16	–	–	197	241	280	325	3.5	3.8	2	2
Lucas et al [25]	27	15	25	29.5	–	–	–	–	190	195	100	100	2.0	3.0	1	0
Cho et al [26]	10	10	31	40	–	–	10	7	376	361	329	328	7.0	14	–	–
Lavery et al [10]	20	18	22.7	24.7	–	–	–	–	189	180	93	140	2.6	2.9	0	0
Pierorazio et al [3]	48	102	–	–	–	–	–	–	–	–	–	–	–	–	2	1
Seo et al [27]	13	14	35.3	36.4	–	–	–	–	153	118	284	264	6.2	5.3	0	0
Boger et al [15]	13	46	–	–	–	–	–	–	168	171	100	100	2.0	2.0	–	–
Choi et al [28]	13	31	35.5	32.4	–	–	–	–	296	286	289	205	–	–	–	–
DeLong et al [29]	13	15	–	–	–	–	–	–	344	254	100	150	2.0	2.0	–	–
Haber et al [30]	75	75	18.2	20.3	9.3	9.9	11.4	12	200	197	323	222	4.2	4.1	0	0
Wu et al [31]	42	36	–	–	–	–	0.16	0.13	373	293	337	250	3.8	4.4	0	1
Benway et al [32]	129	118	19.7	28.4	–	–	–	–	189	174	155	196	2.4	2.7	–	–
Jeong et al [33]	31	26	20.9	17.2	–	–	–	–	170	139	198	208	5.2	5.3	–	–
Kaouk et al [34]	2	5	–	–	–	–	–	–	170	160	100	420	3.5	3.2	–	–
Kural et al [35]	11	20	–	–	–	–	–	–	185	226	286	388	3.9	4.3	5	1
Wang et al [36]	40	62	19	25	–	–	–	–	140	156	136	173	2.5	2.9	1	1
Aron et al [37]	12	12	23	22	–	–	–	–	242	256	329	300	4.7	4.4	1	–

EBL = estimated blood loss; eGFR = estimated glomerular filtration rate; LOS = length of stay; LPN = laparoscopic partial nephrectomy; PSM = positive surgical margin; RPN = robotic partial nephrectomy; sCr = serum creatinine; WIT = warm ischemia time.

Aboumarzouk et al [14] and Zhang et al [5] previously conducted systematic reviews to compare the perioperative outcomes of RPN and LPN, and no differences were noted between groups in terms of operative times, EBL, conversion rates, PSM rate, LOS, and complications. The RPN group had significantly shorter WIT than the LPN group in the two systematic reviews [5,14]. Each study included seven articles, and the number of patients was small; therefore, the data might not satisfy normality assumptions for the fixed-effects and random-effects models that were used. Precise comparison with the outcomes of the meta-analysis was not performed previously.

In this study, we included 23 articles and 2240 patients to satisfy normality. Similar to previous studies, LOS and WIT showed a significant decrease, and PSM rate was not significantly different. However, our results notably revealed a lower conversion rate to open surgery and radical surgery and a favorable eGFR in the RPN group in contrast to those reported in previous systematic reviews.

On the robotic platform, using three-dimensional magnified vision and delicate movements of the instrument with 7 degrees of freedom, dissection of the renal pedicle and tumor resection are better performed with robotic assistance. Using this robotic assistance, renal pedicle injury could decrease and inaccessible tumors could be resected, ensuring a lower rate of radical conversion and open conversion. The RPN group revealed a low WIT and a favorable post-RPN eGFR rate. Renal function was previously thought to depend on the duration of WIT. A significant decrease in eGFR with WIT >30 min was shown, and every minute >30 min was harmful for the preservation of renal function [13]. It could be deduced that RPN is favorable versus LPN in preserving renal function due to decreased WIT. We attribute this result to the 7 degrees of freedom of the robotic instrument for tumor dissection and the faster suturing technique on the robotic platform.

We found significant differences in postoperative change in eGFR but not in postoperative changes in sCr, although the direction of the effect was similar. Included studies and the number of patients in the meta-analysis for a change in eGFR and sCr were different. The number of patients included in eGFR was approximately 300 for each group compared with about 100 for each group in sCr. Long et al [9] reported the only change in eGFR was that the percentage of the eGFR decrease was higher in the LPN group of 182 patients compared with the RPN group of 199 patients. They also reported that the significant difference was shown in the moderate complexity tumor group but not in the high complexity tumor group [9].

Froghi et al [6] performed a systematic review to compare LPN and RPN for small renal masses <4 cm. They included six articles and found no significant differences regarding EBL, WIT, LOS, or overall postoperative complication rates between the groups. We did not restrict our inclusion criteria to small renal masses, but the mean tumor sizes in the included studies were <4 cm, except in the study by Boger et al [15] that reported the mean tumor size was 4.8 cm for RPN and 5.8 cm for LPN. Statistical significance was not reported. Bi et al [7] performed a systematic review for renal tumors >4 cm and reported that the combined conversion rate was 7.0%, but they could not compare results between RPN and LPN owing to the data shortage.

There is little evidence about the difference in the results of RPN and LPN meta-analysis according to tumor size. The treatment of renal tumors >4 cm may be challenging in minimally invasive surgery. Deklaj et al investigated the feasibility of LPN in the preservation of renal function in a T1b renal tumor and reported the mean tumor size as 4.8 cm [16]. This study also revealed the wide application of LPN in renal masses >4 cm. However, mass excision with a straight instrument and renorrhaphy in a restricted time leading to a steep learning curve have limited the widespread use of LPN. Since it was first introduced for renal masses in 2004, RPN has been performed on renal tumors >4 cm in some large centers, and recently, a meta-analysis of RPN for renal tumors >4 cm investigated the feasibility and safety of RPN [7,17,18]. Although few cases of tumors >4 cm were analyzed in our meta-analysis, we analyzed not only T1a cases but also large-volume T1b cases.

This study has some limitations. First, the evidence quality was low because there were no prospective randomized controlled studies. Second, there was great heterogeneity, particularly in terms of WIT, operative time, and EBL. Therefore, this result should be applied carefully in clinical practice. We especially attempted to consider the renal tumor complexity reported with the RENAL nephrometry score and/or PADUA and differences in surgical procedure such as the approach method, whether non-ischemic PN was used, and what kind of clamping method was applied because the surgical procedure could influence the outcomes of postoperative renal function. Unfortunately, although some papers reported the renal mass complexity score and information about the surgical procedure in detail, some papers did not. Even when the papers did report these data, the form of data varied according to the study, and there was not enough for subgroup analysis. Recent research has reported a relationship between renal function and clamp technique, finding no statistically significant differences regarding the functional outcome among clamp techniques after 6 mo of RPN [19].

Third, many studies in our review reported an insufficient follow-up period; therefore, most data were unsuitable to evaluate oncologic outcomes such as recurrence, metastasis, and mortality. Fourth, we were not able to determine whether surgeon learning curves affected the end results because the included studies did not report comparisons between initial and subsequent RPN experiences. There was insufficient information on surgeons' experience to perform a sensitivity analysis exploring the impact of the learning curve on end results and selection bias.

4. Conclusions

This meta-analysis showed that RPN is associated with more favorable results than LPN in terms of lower conversion rate to open surgery and radical nephrectomy, favorable eGFR, shorter WIT, and shorter LOS. The result should be applied carefully in clinical practice because of the low quality of evidence. To establish robust safety and effectiveness outcomes of robotic surgery, well-designed randomized clinical studies with long-term follow-up periods are needed.

Author contributions: Seon Heui Lee had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Rha, Lee.
Acquisition of data: Choi, You.
Analysis and interpretation of data: Choi, Lee.
Drafting of the manuscript: Choi, Kim.
Critical revision of the manuscript for important intellectual content: Lee, Rha.
Statistical analysis: You, Lee.
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Administrative, technical, or material support: You, Kim.
Supervision: Rha, Kim.
Other (specify): Choi.

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