Review Article

Robotic partial nephrectomy: The current status

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ABSTRACT

Introduction: Since its introduction, robotic partial nephrectomy (RPN) has become increasingly popular, in part as a result of several advances in technique. The purpose of this paper is to review these techniques as well as the perioperative, functional, and oncologic outcomes after RPN and compare these outcomes to those after laparoscopic partial nephrectomy (LPN) and open partial nephrectomy (OPN).

Methods: A literature review was performed to identify papers and meta-analyses that compared outcomes after RPN to OPN or LPN. All meta-analyses were included in this review.

Results: Technical advances that have contributed to improved outcomes after RPN include the first-assistant sparing technique, the sliding clip technique, early unclamping, and selective arterial clamping. All five meta-analyses that compared LPN to RPN found that RPN was associated with a shorter warm ischemia time (WIT), but that there were no differences in estimated blood loss (EBL) or operative times. Those meta-analyses that compared intraoperative and postoperative complications, conversion to open or radical nephrectomy, length of stay (LOS), and postoperative estimated glomerular filtration rate (eGFR) either found no difference or favored RPN. Four meta-analyses compared RPN to OPN. All four found that EBL, LOS, and postoperative complications favor RPN. There were no significant differences in intraoperative complications, conversion to radical nephrectomy, or positive surgical margin rates. One meta-analysis found that eGFR was better after RPN. Operative time and WIT generally favored OPN.

Conclusions: Several techniques have been described to improve outcomes after RPN. We believe that the literature shows that RPN is as good if not better than both LPN and OPN and has become the preferred surgical approach.

INTRODUCTION

The first robotic partial nephrectomy (RPN) series was described in 2004,[1] and since its introduction, the popularity of RPN has increased dramatically.[2-4] Currently, RPN is more commonly performed than open partial nephrectomy (OPN).[4] One explanation for this rapid increase in popularity is the adoption of several new techniques, which help make the surgery easier and improve warm ischemia time (WIT) without compromising oncologic efficacy. However, the few meta-analyses comparing outcomes after robotic, laparoscopic, and open partial nephrectomies show mixed results.

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In this article, we review different robotic techniques, highlighting those that we have adopted at our high-volume center. We also summarize the data evaluating the impact of these techniques on perioperative outcomes. In addition, we compare the perioperative, functional, and oncologic outcomes after RPN to those after laparoscopic partial nephrectomy (LPN) and OPN to determine if the data supports the increased utilization of RPN compared to LPN or OPN.

METHODS

We performed a search of PubMed, Cochrane Library, and Google Scholar during June 2019 to identify all the relevant

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studies using the following keywords: "robotic partial nephrectomy," "open versus robotic partial nephrectomy," and "robotic versus laparoscopic partial nephrectomy." Three authors (ZGG, AT, and KKB) independently screened the search results to select studies most relevant to this review. All meta-analyses that compared outcomes between the robotic and open or laparoscopic approaches were included. Case reports, comments, editorials, letters, and papers not in English were excluded.

ROBOTIC PARTIAL NEPHRECTOMY AND REDUCING WARM ISCHEMIA TIME

First-assistant sparing technique

The senior author of this paper has previously described the first-assistant sparing technique (FAST).[5] Briefly, once the tumor has been exposed, but before hilar clamping, all sutures that are required for the renorrhaphy are placed intracorporeally. The sutures are tacked to the abdominal wall, above the kidney, for easy access. All bulldog clamps and the ultrasound probe are also placed intracorporeally. This allows the console surgeon to control the application of the bulldog clamps and sutures, without having to rely on the assistant. During the renorrhaphy, the needles are not cut until after all steps are completed and the bulldog clamps are removed. When compared to the standard technique, the FAST RPN has a significantly shorter WIT ($P = 0.049$) and total operative time ($P = 0.02$). In addition, on multivariate analysis, the FAST technique was a statistically significant, independent predictor of WIT ($P = 0.02$) and overall operative time ($P < 0.001$).[5]

Sliding clip technique

The sliding clip technique for renorrhaphy has been utilized in the laparoscopic and robotic settings. As described by Benway *et al*., all sutures that will be used in the renorrhaphy are prepared before beginning the procedure.[6] A knot is tied at the end of a 15 cm 0 or 1 polyglactin suture. Above the knot, a Lapra-Ty (Ethicon, Cincinnati, OH, USA) clip is placed, and above that, a 10-mm Hem-o-Lock (Teleflex, Research Triangle Park, NC) clip is placed. During the renorrhaphy, after the suture is placed through both sides of the capsule, the assistant places another Hem-o-Lock on the needle end of the suture. To tighten the renorrhaphy, the clips are cinched down to the capsule. A Lapra-Ty clip is then placed by the assistant, above the Hem-o-Lock on the needle end, to secure the closure. Benway *et al*. found that the sliding clip technique shortened average WIT by almost 8 min ($P = 0.0029$).[6]

Early unclamping

Early unclamping (EU) was initially described for LPN by Nguyen and Gill.[7] With the EU technique, the only steps performed while on clamp are the dissection of the tumor from the kidney and the initial closure of the base of the resection. Oversewing arterial bleeders and the sliding clip renorrhaphy, are performed while the kidney is perfused. Gill *et al*. found that with EU, the average WIT was 14 min versus 31 min ($P < 0.0001$) with conventional technique, and there was no significant increase in the estimated blood loss (EBL) or the incidence of postoperative complications.[7] When applied to RPN, EU has been shown to decrease WIT from 27 min to 16 min, without a significant increase in blood loss.[8] On a multivariate analysis, EU was predictive of shorter WIT ($ß = –0.34$; $P < 0.001$) but not of EBL.[9]

Select clamping and off clamp techniques

To further preserve global renal function, efforts have been made to avoid clamping the hilar vessels. During selective arterial clamping, the hilum and renal artery are identified and branching vessels are carefully dissected. Only branching vessels supplying the tumor are clamped. The off-clamp technique avoids any preemptive control of the renal blood supply to further minimize ischemia to healthy parenchyma. A propensity-score matched comparison of renal function after standard and off-clamp partial nephrectomy found that patients who underwent an off-clamp procedure experienced a significantly smaller decrease in their estimated glomerulus filtration rate (eGFR). Patients who underwent a standard procedure had on average a 6% decrease in eGFR, whereas off-clamp patients had on average a 1.6% increase (standard deviation of 2.7%; $P = 0.008$).[10] However, Paulucci *et al*. performed a propensity-score matched analysis of renal function outcomes after selective arterial clamping and standard RPN and found no significant difference in renal function at 7 months.[11]

Efforts to better delineate the association between the various clamping techniques and renal functional outcomes are underway. A recent meta-analysis that compared outcomes after off-clamp and conventional RPN found no significant differences in EBL or eGFR at 3 months.[12] However, because most studies of off-clamp RPN have been retrospective, the studies included in the meta-analysis were at a high risk for selection bias and did not account for confounding variables, such as the amount of functional parenchyma spared. Therefore, the authors concluded that it was not possible to determine whether or not off-clamp procedures were associated with superior renal functional outcomes. A recently published randomized controlled trial (RCT) compared forty off-clamp RPNs to forty on-clamp RPNs. At 3 months postoperatively, there was no significant difference in renal function, determined by the percent change in eGFR and the change in split renal function.[13] In addition, currently, the CLOCK study (CLamp vs. Off Clamp Kidney during Partial Nephrectomy clinicaltrial.gov NCT02287987) is underway with the primary purpose of comparing renal outcomes after traditional and off-clamp RPN.[14] Together, these RCTs may help identify which patients, if any, would benefit from an off-clamp procedure.

OUTCOMES AFTER ROBOTIC PARTIAL NEPHRECTOMY

Peri-operative outcomes of laparoscopic partial nephrectomy versus robotic partial nephrectomy

All meta-analyses currently published have found significantly shorter WITs with RPN compared to LPN.[15-18] Earlier meta-analyses found no differences in operative time, EBL, length of stay (LOS), complications, or positive surgical margin (PSM) rate.[15,16] A meta-analysis by Choi *et al*. from 2015, that included 23 studies and 2240 patients, was the first to show that RPN was associated with a lower conversion rate to both open surgery ($P = 0.02$) and radical nephrectomy ($P = 0.0006$), shorter LOS ($P = 0.004$), and improved renal functional outcomes ($P = 0.03$).[17] These findings have been confirmed on subsequent meta-analyses. The following year, Leow *et al*. performed a meta-analysis of 25 studies that included 2681 RPNs and 2238 LPNs. They found that despite the fact that RPNs were performed on larger masses ($P = 0.001$) with higher nephrometry scores ($P = 0.002$) than LPNs, patients who underwent robotic surgery were 16% less likely to have a complication ($P = 0.007$) and 29% less likely to have a major complication (defined as Clavien III or higher) ($P = 0.023$). There were no statistically significant differences in EBL, operative time, or LOS. WIT was an average of 4 min shorter with RPN ($P < 0.001$). A sub-analysis of patients with nephrometry scores ≥7 found that RPN was associated with shorter operative times ($P = 0.011$) and shorter WITs ($P = 0.04$) without a significant difference in major or minor complications.[18] The most recent meta-analysis by Cacciamani *et al*. from 2018 compared 3824 LPN and 4289 RPN patients. RPN was associated with shorter WITs ($P < 0.0001$), lower conversion rates to both OPN ($P = 0.03$) and radical nephrectomy ($P = < 0.00001$), fewer transfusions ($P = 0.009$), intraoperative complications ($P < 0.00001$), and major postoperative complications ($P = 0.0006$).[19] A comparison of the findings of meta-analyses comparing perioperative outcomes after RPN and LPN can be found in Table 1.

Peri-operative outcomes of open partial nephrectomy versus robotic partial nephrectomy

Cacciamani *et al*. also compared 4675 OPNs and 4431 RPNs. The authors found that while OPN had significantly shorter operative times ($P = 0.0004$) and WITs ($P = 0.02$), it was also associated with a significantly higher EBL ($P < 0.00001$) and transfusion rate ($P < 0.0001$), a greater incidence of postoperative complications ($P < 0.0001$), and longer LOS ($P = 0.001$). Previous meta-analyses have found similar results.[19-22] A full comparison of meta-analyses comparing OPN and RPN can be found in Table 2.

Functional outcomes

The primary benefit of a partial nephrectomy, compared to a radical nephrectomy, is the preservation of renal function. Several studies have assessed functional outcomes after RPN with favorable results. A retrospective review of 670 patients who underwent RPN for small renal masses found that at 9–12 month follow-up, eGFR only decreased by 9%, and just 15% of patients had upstaging of their chronic kidney disease (CKD) score.[23] Khalifeh *et al*. reviewed 134 patients who underwent RPN with a minimum of 2 years of follow-up. They found an average eGFR decrease of 8% and a 20% incidence of upstaging of CKD score. No patients required dialysis.[24] Finally, Andrade *et al*. found that with a median follow-up of 47 months, eGFR decreased by 19%, with a 19% CKD upstaging rate without any patient developing dialysis requirements.[25]

Renal functional outcomes after RPN have been compared to those after LPN. Meta-analyses comparing robotic to laparoscopic surgery showed that functional outcomes were as good as, and perhaps slightly better than, those after laparoscopic surgery.[17,18] Cacciamani *et al*. found

Table 1: Results of comparisons of laparoscopic and robotic partial nephrectomy

Meta-analysis	EBL	Operative time	WIT	LOS	Intraoperative complications	Postoperative complications	eGFR	PSM	Conversion to radical	Conversion to open
Aboumarzouk 2012	NSD	NSD	RPN	NSD	N/A	NSD	N/A	NSD	N/A	N/A
Zhang 2013	NSD	NSD	RPN	NSD	N/A	NSD	N/A	NSD	N/A	N/A
Choi 2015	NSD	NSD	RPN	RPN	N/A	NSD	RPN	NSD	RPN	RPN
Leow 2016	NSD	NSD	RPN	NSD	N/A	RPN	NSD	RPN	NSD	RPN
Cacciamani 2018	NSD	NSD	RPN	NSD	RPN	RPN	RPN	RPN	RPN	RPN

NSD=No significant difference, RPN=favors robotic partial nephrectomy, N/A=Not assessed in the meta-analysis, EBL=Estimated blood loss, WIT=Warm ischemia time, LOS=Length of stay, eGFR=Estimated glomerulus filtration rate, PSM=Positive surgical margin

Table 2: Results of comparisons of open and robotic partial nephrectomy

Meta-analysis	EBL	Operative time	WIT	LOS	Intraoperative complications	Postoperative Complications	eGFR	PSM	Conversion to radical
Wu 2014	RPN	Open	NSD	RPN	NSD	RPN	NSD	NSD	NSD
Shen 2016	RPN	Open	Open	RPN	NSD	RPN	NSD	NSD	NSD
Xia 2017	RPN	NSD	NSD	RPN	NSD	RPN	NSD	NSD	N/A
Cacciamani 2018	RPN	Open	Open	RPN	NSD	RPN	RPN	NSD	NSD

NSD=No significant difference, RPN=favors robotic partial nephrectomy, Open=favors open nephrectomy, N/A=Not assessed in the meta-analysis, EBL=Estimated blood loss, WIT=Warm ischemia time, LOS=Length of stay, eGFR=Estimated glomerulus filtration rate, PSM=Positive surgical margin

that eGFR changed significantly less postoperatively in the RPN group ($P = 0.02$). However, a sensitivity analysis considering only studies that were comparing RPN and LPN for complex renal masses, found no difference in postoperative GFRs between the two groups.[19] Another study found that although patients who underwent RPN had higher postoperative eGFRs than those who underwent LPN, on multivariate analysis, surgical technique (laparoscopic vs. robotic) was not predictive of postoperative renal function at around 1 year.[26]

A matched-pair analysis comparing OPN to RPN for complex renal masses (defined as masses with a R.E.N.A.L. score ≥7) found that at a median follow-up of over 2 years, there was no significant difference in eGFR.[27] However, on meta-analysis, eGFR changed significantly less after RPN ($P = 0.005$).[19]

Oncologic outcomes

Andrade *et al*. examined 5-year oncologic outcomes after 115 RPNs in 110 patients.[25] Median tumor size was 2.6 cm, median R.E.N.A.L. score was 7, and the median Charlson Comorbidity Index (CCI) was 4. The 5-year overall survival, cancer-free survival, and cancer-specific survival rates were 91.1%, 97.8%, and 97.8%, respectively, at a median follow-up of 61.9 months. Two patients (1.8%) developed metastases during the study period (and subsequently died at 23 and 48 months after surgery). On univariable logistic regression, age-adjusted CCI was the only factor associated with a higher risk of overall mortality ($P = 0.006$).

Early meta-analyses comparing outcomes after LPN and RPN found no difference in the incidence of PSMs. However, the two most recent studies, by Leow *et al*. and Cacciamani *et al*., found a lower incidence of PSMs with RPN. This may be because the prior studies were under powered. Leow *et al*. found that patients who underwent LPN were 1.9 times more likely to have a PSM than patients who underwent RPN ($P < 0.001$). Overall survival and cancer-specific survival were not assessed. Cacciamani *et al*. also found that a PSM was twice as likely with LPN ($P < 0.0001$).

The only meta-analysis that compared recurrence rates or cancer-specific survival was by Cacciamani *et al*. When comparing RPN and LPN, they found no significant difference in recurrence or cancer-specific survival, during follow-up periods that ranged from 3 to 27 months. When comparing RPN and OPN, they found that OPN was associated with a 4.45 increase in the odds of overall mortality ($P < 0.0001$). The odds of recurrence were 5.1 times lower in the RPN group, although this difference was not significant ($P = 0.15$). A sensitivity analysis comparing studies with similar renal scores showed that both mortality and recurrence rates were still significantly lower after RPN.[19]

CONCLUSIONS

Over the past 14 years, changes in surgical technique have improved perioperative outcomes after RPN including operative time and WIT. When comparing RPN to LPN, RPN is consistently associated with a shorter WIT. There are no perioperative outcomes that favor LPN. Compared to OPN, RPN is associated with a lower EBL, shorter LOS, and fewer postoperative complications. However, WIT and operative time generally favor OPN. Taken together, we believe that RPN is as good if not better than both LPN and OPN and has become the preferred surgical approach.

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