J Robotic Surg (2016) 10:27–31
DOI 10.1007/s11701-015-0554-8

ORIGINAL ARTICLE

Robot-assisted partial nephrectomy for complex renal masses

Michael W. Patton[1] · Daniel A. Salevitz[1] · Mark D. Tyson II.[1] · Paul E. Andrews[1] · Erin N. Ferrigni[1] · Rafael N. Nateras[1] · Erik P. Castle[1]

Received: 4 October 2015 / Accepted: 27 November 2015 / Published online: 24 December 2015

Abstract To determine whether the approach for partial nephrectomy is influenced by tumor complexity and if the introduction of robotic techniques has allowed us to treat more complex tumors minimally invasively. Data from 292 patients who underwent partial nephrectomy for renal masses from November 1999 to July 2013 at a tertiary referral center were retrospectively reviewed. Nephrometry scores and perioperative outcomes were stratified based on when robotic techniques were introduced. Mean follow-up time was 2.6 years. Preoperative RENAL nephrometry scores and perioperative outcomes were analyzed. Of the 292 patients, 31.5 % underwent robot-assisted partial nephrectomy, 46.2 % laparoscopic partial nephrectomy and 22.9 % open partial nephrectomy. Robot-assisted partial nephrectomy mean nephrometry score was significantly higher than laparoscopic and equivalent to open. Significant perioperative differences were estimated blood loss ($p = 0.0001$), length of stay ($p = 0.0001$) and Clavien score ($p = 0.0069$), all favoring robot-assisted partial nephrectomy. Limitations include retrospective design and single center data. Robot-assisted partial nephrectomy is a safe and effective surgical modality that allows for complex renal tumors that were previously reserved for open partial nephrectomy in the pure laparoscopic era to be managed with a minimally invasive approach.

Keywords Nephrectomy · Kidney neoplasms · Minimally invasive surgery

IRB approved protocol number: 13-002688.

✉ Michael W. Patton
patton.michael@mayo.edu

[1] Department of Urology, Mayo Clinic Hospital, 5779 E Mayo Blvd, Phoenix, AZ 85054, USA

Introduction

Partial nephrectomy is the preferred treatment for all renal masses <7 cm and for masses >7 cm when technically feasible [1]. As surgical technique and surgeon experience have evolved, increasingly complex tumors are being managed with partial nephrectomy (PN) [2]. When compared to radical nephrectomy, PN has been shown to have at least equivalent or better oncologic outcomes with improved long-term renal function and a lower incidence of subsequent chronic kidney disease [3–5]. Historically, open PN (OPN) has been the standard approach for small renal masses, but advancements in minimally invasive techniques have led to increasing utilization of laparoscopic and robot-assisted surgical approaches [6].

Laparoscopic PN (LPN) is associated with a shorter hospital stay, decreased postoperative pain and decreased transfusion requirements while maintaining equivalent oncologic outcomes as compared to OPN [7, 8]. Prior to the introduction of robot-assisted partial nephrectomy (RAPN), OPN was preferred over LPN for more complex masses, due in part to the steep learning curve and technical challenges of LPN [3]. Since its introduction in 2004, RAPN has been shown to be feasible and safe for small renal tumors and confers many of the same benefits of LPN with equivalent outcomes [9–11]. Proponents of RAPN suggest that RAPN may be able to overcome some of the issues facing LPN while maintaining the benefits of minimally invasive surgery. Though studies have compared practice patterns of surgeons and their utilization of different modalities, none have done so with regards to the complexity of the tumors resected [12]. The objective of this study is to determine how PN tumor complexity, based on RENAL nephrometry score, has changed over time and how the introduction of robotic surgery had affected this change [13].

Materials and methods

Data

We retrospectively reviewed the data of 608 patients who underwent PN performed at Mayo Clinic Arizona (MCA) from November 1999 to July 2013 from a prospectively maintained IRB approved registry. Our laparoscopic experience has been reported previously [14, 15]. We excluded 316 patients for reasons including: patients with solitary kidneys, multiple renal masses, a follow-up time of less than 90 days or incomplete data such as inadequate cross-sectional imaging.

Study population, definitions, and statistics

RENAL nephrometry scores were calculated for the remaining 291 patients from cross-sectional imaging done <1 month prior to their surgery. The subjects were stratified into two groups: group 1 included 109 patients who underwent OPN ($n = 30$) or LPN ($n = 79$) prior to the introduction of robotic surgery to MCA in late 2007, and group 2 included 182 patients who underwent OPN ($n = 37$), LPN ($n = 55$) or RAPN ($n = 90$) after this time. Patient demographics (gender, age), clinical data [BMI, American Society of Anesthesiologists (ASA) score, history of diabetes or hypertension], perioperative outcomes (estimated blood loss, surgery time, units of blood transfused and length of stay) and post-surgery complications (Clavien classification score) were analyzed. Change in estimated glomerular filtration rate (eGFR) was assessed based on preoperative and most recent creatinine values using the chronic kidney disease epidemiology collaboration (CKD-EPI) equation, due to its increased accuracy over the modification of diet in renal disease equation, especially with eGFR's ≥60 mL/min/1.73 m^2 [16, 17].

Data are presented as median [interquartile range (IQR)] or frequency (percentage) for continuous and categorical variables, respectively. For group 1, continuous variables were compared using the Student t test for normally distributed data or the Mann–Whitney U test as appropriate, and categorical variables were compared using Fisher's exact test. For group 2, continuous variables were compared across the three approaches using ANOVA for normally distributed data or Kruskal–Wallis test as appropriate, and categorical variables were compared using Pearson Chi-square test. For all data, a two-sided p value of 0.05 was considered statistically significant. Statistical analyses were performed using STATA 12®.

Results

Demographic characteristics are summarized in Table 1. No significant differences existed between approaches in either the pre-robotic era (PRE) or robotic era (RE) for any of the demographics data analyzed including gender, age, ASA score, comorbidities, BMI or pre-surgery eGFR. In the PRE, significantly more LPN patients had previous abdominal surgery, while there were no significant differences in the RE. OPN in both groups did have the highest percentage of patients with diabetes (PRE: 27.6 %, RE 27 %) and the lowest preoperative eGFR (PRE: 61.2, RE 75.9) though these differences were not statistically significant. In the PRE, OPN had significantly higher RENAL nephrometry scores compared to LPN ($p = 0.009$), and OPN had the only case with a RENAL nephrometry score ≥10. Table 2 summarizes RENAL nephrometry in the RE. In the RE, RAPN and OPN were significantly more complex than LPN ($p = 0.007$ and $p = 0.002$, respectively) but OPN and RAPN did not differ significantly ($p = 0.14$). Additionally, nine out of the ten highly complex tumors (RENAL score ≥10) resected in the RE, were performed via RAPN.

Table 3 summarizes perioperative outcomes. In the PRE, estimated blood loss (EBL), transfusion rate, length of stay (LOS) and Clavien scores were significantly higher in OPN compared to LPN ($p < 0.001$) with no significant difference in surgery time ($p = 0.096$). In the RE group, significant differences existed for EBL, transfusion rate, surgery time, LOS ($p < 0.001$) and Clavien scores ($p = 0.044$). There was significantly less blood loss in LPN (median 100 mL) compared to both RAPN (median 150 mL; $p = 0.046$) and OPN (median 250 mL; $p < 0.001$), and significantly less blood loss in RAPN compared to OPN ($p = 0.019$). RAPN had a significantly longer median surgery time (196 min) compared to both LPN (151 min; $p < 0.001$) and OPN (147 min; $p < 0.001$). Transfusion rate and LOS were both significantly higher in OPN compared to both LPN ($p < 0.001$) and RAPN ($p < 0.001$) with no significant differences between LPN and RAPN ($p = 0.53$ and $p = 0.17$, respectively). Clavien scores were significantly higher in OPN compared to RAPN ($p = 0.013$). In the PRE, OPN had a significantly lower eGFR compared to LPN ($p = 0.015$), but change in eGFR was not significantly different between the groups. In the RE, there was a significant difference in change of eGFR between the three approaches: LPN eGFR change was significantly less than OPN ($p = 0.0097$) and RAPN was less than OPN though not significantly so ($p = 0.056$).

Table 1 Demographics

Pre-robotic era	Lap ($n = 79$)	Robot	Open ($n = 30$)	p value
Gender				0.82
Male	53 (67.1 %)		19 (63.3 %)	
Female	26 (32.9 %)		11 (36.7 %)	
Age (years)	70 (61–79)		69 (57–74)	0.35
ASA	3 (2–3)		3 (2–3)	0.22
1–2	38 (48.7 %)		10 (33 %)	
3–4	40 (51.3 %)		20 (66 %)	
Comorbidities				
Diabetes	9 (11.4 %)		8 (27.6 %)	0.07
Hypertension	38 (48 %)		12 (41 %)	0.535
Previous abdominal surgery	36 (45.6 %)		5 (16.6 %)	**0.007**
BMI	28 (24–32)		27 (24–30)	0.5044
Pre CKD-EPI	74.8 (60.2–86.5)		61.2 (44.6–84.7)	0.09
RENAL score	6 (4–7)		7 (5–8)	**0.009**
Low (4–6)	55 (69.6 %)		13 (43.3 %)	
Intermediate (7–9)	24 (30.4 %)		16 (53.3 %)	
High (10–12)	0		1 (3.3 %)	
Robotic era	**Lap ($n = 55$)**	**Robot ($n = 90$)**	**Open ($n = 37$)**	
Gender				0.46
Male	38 (69 %)	58 (64.4 %)	9 (24.3 %)	
Female	17 (31 %)	32 (35.6 %)	28 (75.7 %)	
Age (years)	67 (59–73)	63 (56–70)	65 (60–70)	0.33
ASA	3 (2–3)	2 (2–3)	3 (2–3)	
1–2	25 (45.5 %)	47 (52.2 %)	16 (43.2 %)	
3–4	30 (54.5 %)	43 (47.8 %)	21 (56.8 %)	
Comorbidities				
Diabetes	6 (10.9 %)	16 (17.8 %)	10 (27 %)	0.137
Hypertension	32 (58.2 %)	50 (55.5 %)	19 (51.4 %)	0.811
Previous abdominal surgery	21 (38.2 %)	39 (43.3 %)	13 (38.9 %)	0.796
BMI	31 (27–35)	29 (26–33)	29 (26–34)	0.24
Pre CKD-EPI	80 (61–95.5)	81.2 (66.2–94.5)	75.9 (62.1–93.8)	0.63

ASA American society of anesthesiologists, *BMI* body mass index

Statistically significant p values

Table 2 RENAL nephrometry scores in the robotic era

RENAL score	Lap	Robot	Open
Low (4–6)	33 (60 %)	35 (38.9 %)	10 (27 %)
Intermediate (7–9)	21 (38.2 %)	46 (51.1 %)	27 (73 %)
High (10–12)	1 (1.8 %)	9 (10 %)	0
Complexity comparison			
Robot vs laparoscopic		$\mathbf{p = 0.002}$	
Open vs laparoscopic		$\mathbf{p = 0.007}$	
Robot vs open		$p = 0.14$	

Statistically significant p values

Discussion

RAPN has become a well-established approach for renal masses and an approach that is increasingly utilized by surgeons. One question is whether or not it provides a significant advantage over conventional laparoscopic techniques especially when cost containment is a concern. Conventional wisdom has always been that there may be certain complex tumors that are easier to perform through an open incision. Surgeon skill and experience also play a role and have been difficult to control for in attempts in comparative effectiveness analyses. Another concern has been that nephron-sparing surgery has not been adequately utilized in complex tumor cases with a default to laparoscopic radical nephrectomy [18]. In this retrospective analysis, we demonstrated that RAPN can safely and effectively be utilized for even the most complex renal masses that would have previously been reserved for OPN in the pre-robotic era.

In the PRE, the only significant differences in demographics between LPN and OPN groups were the incidence of previous abdominal surgery (greater in the LPN group)

Table 3 Perioperative outcomes

Pre-robotic era	Lap ($n = 79$)	Robot ($n = 0$)	Open ($n = 30$)	p value
EBL (mL)	100 (50–150)		475 (150–1000)	**<0.001**
Surgery time (m)	148 (123–183)		138 (101–168)	0.096
Transfused	6 (7.6 %)		11 (36.7 %)	**<0.001**
Length of stay	2 (2–3)		4 (4–8)	**<0.001**
Clavien				**<0.001**
1–2	1 (1.2 %)		10 (33 %)	
3–4	3 (3.8 %)		3 (10 %)	
Follow-up (days)	1275 (654–1915)		1552 (467–2591)	0.61
5 year+	25 (31.6 %)		11 (36.6 %)	
Latest eGFR	69.6 (54–85.6)		55 (23–73)	**0.015**
Change in eGFR	−0.37 (−11.9–8.7)		−9.45 (−22.06–6.77)	0.09
Robotic era	Lap ($n = 55$)	Robot ($n = 90$)	Open ($n = 37$)	p value
EBL (mL)	100 (100–200)	150 (100–300)	250 (150–400)	**<0.001**
Surgery time (m)	151 (136–179)	196 (163–226)	147 (116–168)	**<0.001**
Transfused	3 (5.5 %)	8 (8.9 %)	14 (37.8 %)	**<0.001**
LOS	2 (2–3)	2 (2–3)	4 (3–5)	**<0.001**
Clavien				**0.044**
1–2	7 (12.7 %)	7 (7.8 %)	7 (18.9 %)	
3–4	2 (3.6 %)	2 (2.2 %)	3 (8.1 %)	
Follow-up	581 (249–749)	479 (156–834)	756 (419–1284)	
3 year+	2	17	14	
5 year+	0	1	3	
Latest eGFR	72 (59.2–92)	76 (59.6–92.3)	64 (49.8–73.4)	**0.0073**
Change in eGFR	−0.25 (−5.29–13.13)	−0.66 (−7–12.65)	−3.6 (−15.8–8.8)	**0.03**

EBL estimated blood loss, *eGFR* estimated glomerular filtration rate, *LOS* length of stay

Statistically significant p values

and the complexity of the tumor, as assessed by RENAL nephrometry score, with the more complex tumors being performed with OPN. The complexity of tumors resected via LPN increased from the PRE to the RE, likely reflecting increased experience and comfort with the approach. In fact, LPN included one out of the ten RENAL scores ≥10 in the robotic era. Still, the complexity of LPN in the robotic era was still significantly lower than both RAPN and OPN. This reinforces the argument that RAPN may enable surgeons to overcome both the steep learning curve of LPN and the limitations of LPN instrumentation with RAPN, allowing surgeons to undertake more complex cases with a minimally invasive approach.

In the robotic era, RAPN was utilized for tumors of similar complexity to OPN with significantly improved perioperative outcomes including lower EBL, transfusion rate, hospital stay and postoperative complication rate. Change in eGFR was also better in RAPN nearing significance ($p = 0.056$). While we do not suggest that RAPN allows for better preservation of renal function, it certainly does not result in worse functional outcomes. In fact, the only data point where OPN was superior to RAPN, as expected, was surgical time. Interestingly, though RENAL nephrometry scores were not significantly different between OPN and RAPN, RAPN was utilized nine out of ten times for RENAL scores ≥10, while none of the RENAL scores for OPN were ≥10. With the superior perioperative outcomes after RARP in mind, this is further evidence that RAPN can be safely utilized for nephron-sparing surgery on highly complex renal masses.

While the short-term benefits of minimally invasive surgery are demonstrated in the pre-robotic era with respect to estimated blood loss, length of stay, transfusion rate and complications, it would be easy to attribute much of this to a potential selection bias that existed with respect to tumor complexity. Clearly patients with more complex tumors and possibly more “need” for nephron-sparing due to comorbidities were being steered towards open surgery. This would explain the differences in perioperative outcomes. This has always been an issue when comparing minimally invasive approaches to open surgery for partial nephrectomy. However, when the robotic approach was introduced at MCA, the tumor complexity was essentially controlled for and still there were statistically significant short-term benefits with respect to estimated blood loss, transfusion rates, length of stay and complications. Surely, if something beyond a larger incision was influencing these factors such as complexity one would expect a difference in nephrometry scores between open and minimally invasive approaches, but that was not the case.

The limitations of the current study include its retrospective design and single center data. Although the surgeons included in this study have been performing laparoscopic surgery since 1999, differences in experience and comfort between surgeons may have influenced different utilization rates of the modalities. In addition, outcomes may have been influenced by surgeon technique and experience rather than the approach itself. Another limitation was our inability to match LPN, OPN or RAPN due to the size of the cohort, though the analysis showed no significant differences in demographic data between the three modalities. Despite these limitations, the bottom line is that the complex tumors that previously were managed with open partial nephrectomy techniques are now regularly being managed with the robotic approach. Most importantly, the robot-assisted approach may now help close the gap that has long existed between nephron-sparing surgery and radical nephrectomy, in so much as facilitating the use of partial nephrectomy.

Conclusions

Robot-assisted surgery has facilitated the minimally invasive treatment of complex renal masses in our practice. This approach appears to be safe with preservation of the benefits of minimally invasive surgery for even the most complex of tumor.

Acknowledgments We would like to thank Desert Mountain's C.A.R.E (Cancer Awareness Through Research and Education) organization for its generous support of the genitourinary research program at Mayo Clinic, Scottsdale, Arizona. The authors would also like to acknowledge the support provided by the Gloria A. and Thomas J. Dutson, Jr. Kidney Research Endowment.

Compliance with ethical standards

Conflict of interest Authors Patton, Salevitz, Tyson, Andrews, Ferrigni, Nateras and Castle declare that they have no conflict of interest.

References

1. Ljungberg B, Bensalah K, Bex A et al (2013) Guidelines on renal cell carcinoma, renal cell carcinoma: update march 2013. European Association of Urology, Milan
2. Patard JJ, Pantuck AJ, Crepel M et al (2007) Morbidity and clinical outcome of nephron-sparing surgery in relation to tumour size and indication. Eur Urol 52:148–154
3. Campbell SC, Novick AC, Belldegrun A et al (2009) Guideline for management of the clinical T1 renal mass. J Urol 182:1271–1279
4. Patard JJ, Shvarts O, Lam JS et al (2004) Safety and efficacy of partial nephrectomy for all T1 tumors based on an international multicenter experience. J Urol 171:2181–2185
5. Huang WC, Levey AS, Serio AM et al (2006) Chronic kidney disease after nephrectomy in patients with renal cortical tumours: a retrospective cohort study. Lancet Oncol 7:735–740
6. Minervini A, Siena G, Carini M (2011) Robotic-assisted partial nephrectomy: the next gold standard for the treatment of intracapsular renal tumors. Expert Rev Anticancer Ther 11:1779–1782
7. Gill IS, Kavoussi LR, Lane BR et al (2007) Comparison of 1800 laparoscopic and open partial nephrectomies for single renal tumors. J Urol 178:41–46
8. Lane BR, Gill IS (2007) 5-Year outcomes of laparoscopic partial nephrectomy. J Urol 177:70–74 (**discussion 74**)
9. Aboumarzouk OM, Stein RJ, Eyraud R et al (2012) Robotic versus laparoscopic and partial nephrectomy: a systematic review and meta-analysis. Eur Urol 62(6):1023–1033
10. Froghi S, Ahmed K, Khan MS et al (2013) Evaluation of robotic and laparoscopic partial nephrectomy for small renal tumours (T1a). BJU Int 112:E322–E333
11. Petros F, Sukumar S, Haber GP et al (2012) Multi Institutional analysis of robot- and assisted partial nephrectomy for renal tumors >4 cm versus <4 cm in 445 consecutive patients. J Endourol 26:642–646
12. Ghani KR, Sukumar S, Sammon JD et al (2013) 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 191(4):907–912. doi:10.1016/j.juro.2013.10.099
13. Kutikov A, Uzzo RG (2009) The RENAL nephrometry score: a comprehensive standardized system for quantitating renal tumor size, location and depth. J Urol 182(3):844–853
14. Simon SD, Castle EP, Ferrigni RG et al (2004) Complications of laparoscopic nephrectomy: the Mayo Clinic experience. J Urol 171(4):1447–1450
15. Desai PJ, Andrews PE, Ferrigni RG et al (2008) Laparoscopic partial nephrectomy at the Mayo Clinic Arizona: follow-up surveillance of positive margin disease. Urology 71(2):283–286
16. Levey SA, Stevens LA, Schmid CH et al (2009) CKD-EPI (chronic kidney disease epidemiology collaboration); a new equation to estimate glomerular filtration rate. Ann Intern Med 150(9):604–612
17. Stevens LA, Schmid CH, Greene T et al (2010) Comparative performance of the CKD epidemiology collaboration (CKD-EPI) and the modification of diet in renal disease (MDRD) study equations for estimating GFR levels above 60 mL/min/1.73 m^2. Am J Kidney Dis 56(3):486–495 (**ISSN 0272-6386**)
18. Hollenbeck BK, Taub DA, Miller DC et al (2006) National utilization trends of partial nephrectomy for renal cell carcinoma: a case of underutilization? Urology 67:254–259