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Transition From Laparoscopic to Robotic Partial Nephrectomy: the Learning Curve for an Experienced Laparoscopic Surgeon

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ABSTRACT

Background: The complexity of laparoscopic partial nephrectomy (LPN) has prompted many laparoscopic surgeons to adopt robotic partial nephrectomy (RPN) for the treatment of small renal masses. We assessed the learning curve for an experienced laparoscopic surgeon during the transition from LPN to RPN.

Methods: We compared perioperative outcomes of the first 20 patients who underwent RPN to the last 18 patients who underwent LPN by the same surgeon (MAP). Surgical technique was consistent across platforms. The learning curve was defined as the number of cases required to consistently perform RPN with shorter average operative times (OT) and warm ischemia times (WIT), as compared to the last 18 LPN. A line of best fit aided graphical interpretation of the learning curve on a scatter diagram of OT versus procedure date.

Results: The 2 groups had comparable preoperative demographics and tumor histopathology. No patients in either group had a positive surgical margin. There was a downward trend in both OT and WIT during the RPN learning curve. After the first 5 RPN cases, the average OT reached the average OT of the last 18 LPN cases. The average OT of the first 5 RPN patients was 242.8 minutes, compared with the average OT of the last 15 RPN patients of 171.3 minutes ($P=0.011$).

Conclusion: The transition from LPN to RPN is rapid in an experienced laparoscopic surgeon. There were no significant differences in WIT, estimated blood loss, or length of hospital stay between LPN and RPN. RPN achieved a similar OT as LPN after 5 procedures.

Key Words: Neoplasm, Renal, Laparoscopy, Robotics, Partial nephrectomy, Learning curve.

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INTRODUCTION

The complexity of laparoscopic partial nephrectomy (LPN) has prompted many laparoscopic surgeons to adopt robotic partial nephrectomy (RPN) for the treatment of small renal masses. The LPN was described in 1993, and the technique became popular over the next 2 decades, achieving safe and effective results that were equivalent to the "gold standard" of open partial nephrectomy.[1-3] However, the laparoscopic procedure is technically challenging even for experienced surgeons. RPN has emerged in the last 5 years as a potential minimally invasive alternative to LPN.[4-6] Several recent reports indicate that the articulating, wristed robotic instruments increase the ease of tumor resection and facilitate intracorporeal suturing, decreasing warm ischemia time.[4,7-11]

Few studies have directly compared laparoscopic with robotic partial nephrectomy.[12-17] While direct evaluation of surgical learning curves has been systematically studied in other urologic surgeries, such as radical prostatectomy, it has not been studied in as great detail for partial nephrectomy.[18-20] We compare one experienced laparoscopic surgeon's initial clinical experience with RPN to his immediate prior experience with LPN and use these data to assess the learning curve of the transition between the procedures.

MATERIALS AND METHODS

Between April 2005 and July 2009, partial nephrectomies were performed on 40 patients for enhancing renal masses by an experienced minimally invasive surgeon (MP). The surgeon was fellowship trained in laparoscopy and is experienced with over 100 LPNs; thus, he was beyond his laparoscopic learning curve at the beginning of this study. The surgeon also had a baseline level of experience with robotic surgery, conducting over 100 robotic prostatectomies and 15 pyeloplasties during fellowship training and the first 3 years of clinical practice. Patients were offered all treatment options including watchful waiting, tumor ablative techniques, open surgery, and radical vs partial nephrectomy and chose PN. RPN was initiated in October 2007 and became the exclusive approach for partial nephrectomy by mid-2008. After excluding one LPN that was converted to a laparoscopic radical nephrectomy and one RPN was converted to a hand-assisted laparoscopic radical nephrectomy, we retrospectively reviewed the perioperative outcomes of the first 20 patients who underwent RPN and the last 18 patients who underwent LPN.

All patients had preoperative laboratory measurements and either CT or MR imaging available for review. Glomerular filtration rate (GFR) was calculated using the Modification of Diet in Renal Disease (MDRD) formula. Tumors were classified using the R.E.N.A.L. Nephrometry scoring system for quantitating the salient anatomy of the masses. The R.E.N.A.L. Nephrometry Score consists of (R)adius (tumor size as maximal diameter), (E)xophytic/endophytic properties of the tumor, (N)earness of tumor deepest portion to the collecting system or sinus, (A)nterior (a)/posterior (p) descriptor and the (L)ocation relative to the polar line.[21] Sufficient data were available to quantitate a nephrometry score in 14 of the LPN and 13 of the RPN patients. A single reader determined all nephrometry scores. Operative time was measured from first incision until skin closure in both robotic and laparoscopic series; robotic console time was not recorded.

Statistical analysis was performed with SPSS version 17.0 and Microsoft Excel. Comparisons between groups were calculated using the chi-square and Student *t* test for categorical and continuous variables, respectively. Significance was defined as $P<.05$, and all tests were 2-tailed. Lines of best fit were modeled on plots of warm ischemia time and operative time as a function of case number. Linear, quadratic, and cubic lines of best fit were fitted to the graphs; the line with the highest r^2 value was selected as representative and included as a figure.

LPN Technique

The LPN technique was standardized in all cases and similar to previously described techniques.[22-24] The patient was placed in the 60-degree flank position, and a 3-trocar approach was used on left-sided masses and a 4-trocar approach was used on right-sided ones. Both renal artery and vein were dissected, perinephric fat was excised, and the tumor was visualized. Intraoperative ultrasound was always utilized to aid in identifying tumor boundaries. The renal artery was clamped with a bulldog clamp and the tumor was excised under warm ischemia. If a collecting system defect was created, this was closed with a running 2-0 absorbable suture. Overall hemostasis and closure of the renal defect was accomplished with simple interrupted 0 Vicryl sutures and a hemostatic matrix (FloSeal, Baxter, Deerfield, IL). Oxidized cellulose (Surgicel, Ethicon EndoSurgery, Cincinnati, OH) was used as a bolster with the renorrhaphy sutures. The patients were discharged when they were able to tolerate a regular diet and bowel function had returned.

RPN Technique

The RPN technique was similar to the laparoscopic approach and used previously described techniques.[11,25] A 3-arm approach was used with the da Vinci S HD system (Intuitive Surgical, Sunnyvale, CA). The patients were placed in the 60-degree flank position. Pneumoperitoneum was achieved by standard transperitoneal Veress needle access. A standard 12-mm umbilical port, two 8-mm robotic ports, and a 12-mm assistant port were placed. The assistant port was placed in either the corresponding upper or lower abdominal quadrant, depending on the location of the tumor. The remaining portion of the procedure was identical to the laparoscopic technique described above.

Learning Curve

We adapted the definition of learning curve as defined by previous studies on the adoption of robotic radical prostatectomy.[18-20] We thus defined the learning curve as the number of cases required to consistently perform RPN with equal or shorter average operative times (OT) and warm ischemia times (WIT) than the average of the last 18 LPN. This is consistent with other robotic partial nephrectomy studies that have defined the learning curve by similar perioperative measures.[11]

RESULTS

Baseline, Perioperative, and Histopathologic Data

Baseline patient demographics are listed in **Table 1**. The 2 groups had comparable preoperative demographics. The mean age of patients was 54 years in the LPN group and 55 years in the RPN group. The groups were statistically comparable in terms of sex, race, and BMI, although the RPN group had a significantly higher American Society of Anesthesiologists (ASA) score. Nephrometry scores were similar in the 2 groups, with a mean score of 6.6 in the LPN patients and 6.2 in the RPN patients, $P=.57$. There were no significant trends noted in nephrometry scores during the robotic learning curve. Tumor location and side were similar and evenly distributed in both groups. Mean baseline creatinine was significantly higher in the

Table 1.
Patient Demographics

	LPN[a]	RPN[a]	P
N	18	20	
Age (mean±SD)	53.6 ±11.1	55.4 ±11.1	.62
Sex			.18
Male	14 (78%)	11 (55%)	
Female	4 (22%)	9 (45%)	
Race			.69
White	13 (72%)	12 (60%)	
African American	2 (11%)	4 (20%)	
Other	3 (17%)	4 (20%)	
BMI (kg/m^2) (mean±SD)	29.3 ±5.1	30.1 ±5.8	.59
ASA Score (mean±SD)	2.1 ±0.6	2.5 ±0.5	.04
Tumor Size (mm) (range)	2.3 (0.1–4.4)	2.5 (1.2–4.3)	.44
Tumor Side			.79
Right	11 (61%)	11 (55%)	
Left	6 (33%)	9 (45%)	
Preoperative Creatinine (mg/dL) (range)	1.1 (0.7–1.7)	0.9 (0.5–1.3)	.04
Preoperative Hemoglobin (g/dL) (range)	14.7 (11.9–17)	13.4 (10.1–15.6)	.02
Preoperative GFR[b] (mL/min/1.73 m^2) (range)	81.5 (44.4–127.9)	92.5 (58.3–151.0)	.23
Tumor Location			.56
Upper pole	4 (22%)	8 (40%)	
Middle	5 (27%)	5 (25%)	
Lower pole	7 (39%)	6 (30%)	
Nephrometry Score	6.6	6.2	.57

[a]LPN=laparoscopic partial nephrectomy; RPN=robotic partial nephrectomy.

[b]GFR (glomerular filtration rate) calculated using the Modification of Diet in Renal Disease (MDRD) formula.

LPN group at 1.06mg/dL compared to 0.88mg/dL for RPN (P=.04). However, calculated GFR was not statistically different.

Operative and postoperative data are listed in **Table 2**. There were no significant differences in average length of hospital stay, complications, or change in renal function. The mean OT and WIT in the last 18 LPN were 179.7 minutes (range, 132 to 223) and 24.7 minutes (range, 18 to 34). The mean OT and WIT in the first 20 RPN were similar at 189.2 minutes (range, 111 to 294) and 22.7 (range, 12 to 40) minutes (P=0.24), respectively. EBL was similar in both groups. Hand-assistance was utilized in 5 LPN patients and 0 of the RPN. Pathological data are listed in **Table 3**. Mean tumor size was 2.26cm (range, 0.1 to 4.4) in the LPN group and 2.47cm (range, 1.2 to 4.3) in the RPN group, P=.44. LPN and RPN had similar distributions of tumor type, stage, and Fuhrman grade. There were no positive surgical margins in either group.

Complications were not significantly different between LPN and RPN. There were 2 complications in the LPN group, and 3 complications in the RPN group. There were no intraoperative complications. In the LPN group, one patient had postoperative pneumonia and one patient had a renal pseudoaneurysm. In the RPN group, one patient had postoperative respiratory distress requiring a prolonged intubation, one patient experienced a pulmonary embolism 2 days postoperative, and one patient had a postoperative bleed requiring a transfusion.

Table 2.
Operative and Postoperative Data

	LPN	RPN	P
N	18	20	
Operative Time (minutes) (range)	179.7 (132–223)	189.2 (111–294)	.54
Warm Ischemia Time (minutes) (range)	24.7 (18–34)	22.7 (12–40)	.32
Estimated Blood Loss (mL) (range)	139.7 (25–300)	93.3 (20–350)	.07
Hospital Stay (days) (range)	2.9 (1–5)	2.6 (1–5)	.23
Postoperative Creatinine (mg/dL) (range)	1.2 (0.8–1.8)	1.0 (0.1–1.6)	.06
Postoperative Hemoglobin (g/dL) (range)	13.2 (10.3–15.5)	12.3 (9.5–14.7)	.45
Postoperative GFR (mL/min/1.73 m^2) (range)	72.3 (31.6–108.3)	68.5 (5.3–106.7)	.60
Intraoperative Complications	0	0	
Postoperative Complications	2 (11%)	3 (15%)	1.00
Respiratory	1	1	
Vascular	1	2	
Transfusions	1	0	.47

[a]LPN=laparoscopic partial nephrectomy; RPN=robotic partial nephrectomy.

[b]GFR (glomerular filtration rate) calculated using the Modification of Diet in Renal Disease (MDRD) formula.

Learning Curve

There was a downward trend in both OT and WIT during the RPN learning curve. **Figure 1** shows the learning curve as a function of OT by RPN procedure date as a cubic line of best fit (r^2=0.32). With r^2 of 0.18 and 0.30 in linear and quadratic lines, respectively, this was the best fitting of the modeled lines. After the first 5 RPN cases, the average OT reached the average OT of the last 18 LPN cases. The average OT of the first 5 RPN patients was 243 (range, 180 to 294) minutes, compared with the average OT of the last 15 RPN patients of 171 (range, 111 to 260) minutes (P=0.01) **(Figure 1)**. WIT and EBL showed no significant differences from the average LPN values after 5 RPN procedures **(Table 2)**.

DISCUSSION

Our results demonstrate that the transition from LPN to RPN is feasible and rapid in an experienced laparoscopic surgeon. As in prior studies, there were no significant differences in operative time, warm ischemia time, estimated blood loss, or length of hospital stay between LPN and RPN after the first 5 cases. Our data confirm prior reports on the topic, which have demonstrated that RPN is comparable, if not superior, to LPN in terms of perioperative outcomes.[12-17]

We were interested in developing a learning curve for RPN to aid surgeons who are contemplating transitioning from LPN to RPN. The robotic partial nephrectomy is almost identical to the laparoscopic procedure; indeed, it is a form of assisted laparoscopy. Much of the difficulty of the LPN is related to the intracorporeal suturing required to close defects in the collecting system, obtain hemostasis, and perform renorrhaphy. Developing a system for preparing the sutures and readying them for timely use after completing the excision of the mass is a significant component of the laparoscopic learning curve, which can be transferred to the robotic platform with minimal modification. Additionally, the articulating, wristed robotic arms facilitate intracorporeal suturing as well as precise mass excision at obscure angles. As such, we hypothesized that the learning curve would be short for a surgeon experienced in LPN.

Evaluation of surgical learning curves has been extensively studied in radical prostatectomy.[18-20,26-28] Various definitions for the learning curve have been utilized, including perioperative measures, surgeon comfort, and oncological outcomes. Fewer studies have assessed the learning curve in robotic partial nephrectomy. Given similar baseline tumor characteristics, operative time can be viewed as a surrogate for the overall efficiency of the surgeon. As such, we chose to use it as one of our metrics in assessing the learning curve. Our other metric, the length of WIT, is highly correlated with postoperative renal function.[29] It is thus the most important surgeon-

Table 3. Pathologic Data			
	LPN[a]	RPN[a]	P
N	18	20	
Malignant	14	15	1.0
Clear Cell RCC	8	10	
Papillary RCC	4	2	
Other RCC	2	3	
Benign	4	5	1.0
Oncocytoma	4	1	
Angiomyolipoma	0	3	
Other	0	1	
RCC[a] Stage			.08
pT1a	9	14	
pT1b	4	1	
pT2	1	0	
Fuhrman Grade			.70
I	4	6	
II	9	9	
III	1	0	
IV	0	0	
Positive Margin	0	0	1.0
Pathologic Tumor Size (cm) (range)	3.14 (1.3–16.0)	2.1 (0.5–4.1)	.27

[a]LPN=laparoscopic partial nephrectomy; RPN=robotic partial nephrectomy; RCC=renal cell carcinoma.

dependent outcome of partial nephrectomy. Furthermore, it is a surrogate for the efficiency of the tumor dissection and renorrhaphy, making it an obvious choice for our other learning curve metric. Because the surgeon was fellowship trained in laparoscopy and experienced with over 100 LPNs, he was beyond his laparoscopic learning curve at the beginning of this study. Thus the average time it took to perform his prior 20 LPNs is a good indicator of the time required to perform the procedure. For these reasons, we defined the learning curve as the time it took to perform RPN, in terms of both OT and WIT, at less than the average time it took him to perform LPN.

With this definition, the learning curve was 5 cases. After the initial 5 RPN procedures, OT and WIT became comparable with the average LPN OT and WIT. The same metrics were used in a recent study assessing the learning curve of RPN, although their definitions were slightly different. In that study, the learning curve was defined as

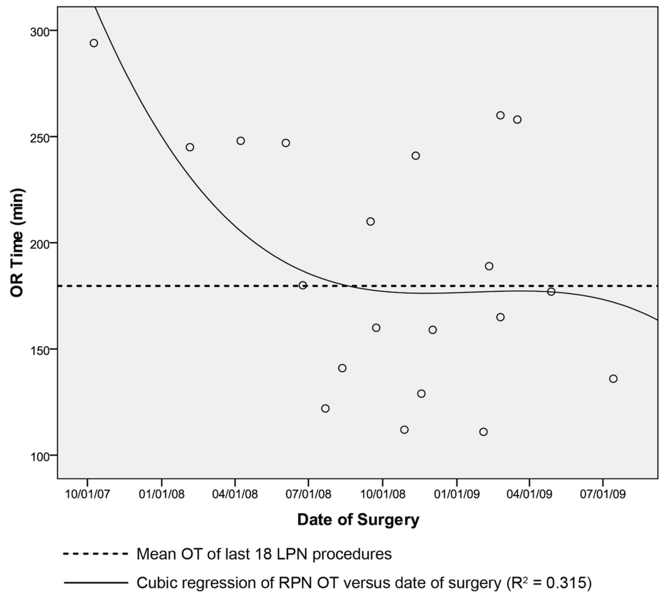

Figure 1. Robotic partial nephrectomy learning curve: OR time versus date of surgery.

the number of cases required to reach a plateau, which occurred at 19 cases for OT and 26 cases for WIT.[11]

Few studies have directly compared laparoscopic with robotic partial nephrectomy.[12-16] Most studies have been in case series with less than 15 RPN procedures, and have shown no substantial advantage to RPN over LPN. The 2 largest studies were done by Benway et al[12] in 2009 and Haber et al in 2010[17] in which 118 and 186 laparoscopic and 129 and 75 robotic partial nephrectomies were compared, respectively. Both studies showed comparable outcomes between RPN and LPN. Haber et al[17] showed no differences in blood loss, warm ischemia time, or hospital stay. Benway et al[12] showed decreased blood loss by 41mL, decreased warm ischemia time by 30%, and decreased hospital stay by 0.3 days in the RPN group. They also found that the robotic approach appeared to benefit experienced laparoscopic surgeons the most.[12] This last point is relevant to our study, and is likely the reason our learning curve is substantially shorter than those previously reported. Safety of these procedures must also be addressed. Our complication rates for LPN and RPN were 11% and 15%, respectively. These rates are consistent with reported complication rates of 10% to 15% in other large studies.[12,17]

Another notable aspect of our study is that it is one of the first studies of robotic partial nephrectomy procedures to utilize the nephrometry score.[21] This new, standardized tool will be helpful in the future for comparing tumor severity between groups of patients and across studies at different institutions. We are hopeful that this will be a standard feature of future publications in the field of partial nephrectomy, as it provides an easier way of comparing the degree of difficulty of the various procedures. Our study did not demonstrate any difference in nephrometry scores between tumors treated laparoscopically or robotically. Furthermore, there was no trend toward more difficult tumors being attempted as the robotic learning curve progressed. This further reinforces the concept that experienced laparoscopic surgeons can easily transition to robotics. In the future, we expect robotics may allow increasingly difficult tumors to be managed via a minimally invasive approach.[30]

This study must be viewed in light of its limitations. This study was retrospective and unpaired, which can introduce selection bias into the study population. Because the groups were comparable in terms of demographics, tumor size, and nephrometry scores, the LPN and RPN groups are likely similar, although one cannot completely exclude confounding variables or otherwise unknown biases. This bias is minimized by the fact that our institution made a complete switch to RPN from LPN, so following a brief transition period, patient and tumor characteristics were not factors in selecting the treatment course. Two patients were excluded from the study, one from the RPN requiring a secondary procedure and one LPN converted to laparoscopic radical nephrectomy. The ultimate nature of these operations was fundamentally different from the originally intended approach, and we feel that including these patients would have artificially affected the RPN and LPN data. Also, 5 patients in the LPN group underwent hand-assisted LPN. These patients could potentially underestimate OT and EBL or overestimate LOS. Inherent to a sequential case series study of a new procedure performed by one surgeon is the progression of experience through time. Naturally, a surgeon will become more comfortable with a procedure after repeated attempts and measurements of performance will improve. As discussed above, the surgeon had sufficient laparoscopic experience that he was beyond the laparoscopic learning curve, and unlikely to improve substantially within the studied time period. Similarly, the surgeon had a baseline level of experience with robotics, so the learning curve associated with familiarization with the platform was already passed. These limitations could be overcome by a prospective, randomized, multi-institutional trial with robotically naïve surgeons; however, it is unlikely that this will happen in the near future.

RPN itself has fallen under some recent criticism for its disadvantages.[31] There is a high cost to purchase, maintain, and operate the robot, although no critical analyses of the costs of RPN vs LPN have been published to date. RPN also requires a skilled bedside assistant to perform advanced maneuvers and to handle potential emergencies, as the surgeon is unscrubbed and away from the bedside while at the console. Such complications have not occurred thus far during our experience.

RPN is growing in popularity as a treatment option for small renal masses. The early adopters of RPN were surgeons with significant experience with LPN. However, as surgeons less experienced with LPN begin to adopt RPN, further studies like this one would be informative.

CONCLUSION

The learning curve for an experienced laparoscopic surgeon to adopt RPN from LPN is rapid, on the order of 5 cases. Patients do not have significantly worse outcomes during the learning curve phase.

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