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Robot-Assisted Partial Nephrectomy: Evaluation of Learning Curve for an Experienced Renal Surgeon

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Abstract

Purpose: The learning curve for robot-assisted partial nephrectomy (RAPN) has not been extensively studied. We therefore evaluated the learning curve of RAPN for a fellowship-trained laparoscopic surgeon with extensive prior experience with laparoscopic partial nephrectomy (LPN). We also examined the potential effect of tumor size on the learning curve.

Patients and Methods: We prospectively evaluated 38 consecutive patients undergoing RAPN by a single surgeon (S.B.B.). Sixteen patients had tumors <2 cm, and 22 patients had tumors >2 cm. Warm ischemia times and overall operative times were recorded as indices of learning progression.

Results: Average operative time for tumors <2 cm was 131.9 minutes (115.3–148.5 minutes) and for tumors >2 cm was 145.8 minutes (131.1–160.5 minutes). The difference between the operative times for tumors <2 and >2 cm was not statistically significant ($p = 0.23$). Average warm ischemia time for tumors <2 cm was 21 minutes (16.9–25.1 minutes) and for tumors >2 cm was 24.7 minutes (21.3–28.1 minutes). This difference was also not statistically significant ($p = 0.20$). Defined by the overall operative time, the learning curve for RAPN was 16 cases, and by ischemic time, the learning curve was 26 cases. Tumor size did not have an effect on the learning curve.

Conclusions: The learning curve for RAPN is short for surgeons already experienced with LPN. The learning curve for portions performed under warm ischemia is slightly longer, implying that the critical portions of the procedure require more experience to become facile. Tumor size does not appear to have a significant impact on the learning curve for surgeons experienced with LPN.

Introduction

Laparoscopic partial nephrectomy (LPN) is a challenging procedure that requires considerable skill and expertise. The technical difficulty of intracorporeal suturing, combined with the necessity of minimizing ischemic times, threatens to restrict the procedure to the domain of very highly experienced laparoscopic surgeons.[1] Even for skilled laparoscopic surgeons, the learning curve with respect to the operative time for LPN is estimated to be in the range of 100–150 cases.[2]

Robot-assisted partial nephrectomy (RAPN) decreases the difficulty of intracorporeal suturing by providing six degrees of freedom at the distal end of the instruments, magnified stereoscopic vision, movement scale-down, and decreased tremor.[3,4] However, the learning curve of RAPN in the hands of an experienced laparoscopic surgeon has not been extensively evaluated.

The overall operative time is one index by which a surgeon's progress may be measured; however, as the critical portions of partial nephrectomy are often performed under the duress of warm ischemia, evaluating a surgeon's improvement under warm ischemia may also serve as a useful metric to evaluate the learning curve of RAPN.

The aim of our present investigation is to evaluate the learning curve of RAPN for a fellowship-trained laparoscopic

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surgeon with extensive prior experience with LPN. We also sought to evaluate the potential effect of tumor size on the learning curve.

Patients and Methods

Patient selection

After obtaining Institutional Review Board's approval, prospective collection and retrospective analysis of data for the initial 38 patients undergoing RAPN between June 2007 and June 2008 by a single surgeon at our institution was performed. Of these initial 38 patients, 16 patients had tumors <2 cm, whereas 22 patients had tumors >2 cm.

All procedures were performed by a single fellowship-trained surgeon (S.B.B.), who had extensive prior experience with LPN, having performed over 200 pure laparoscopic partial nephrectomies throughout his experience as a fellow and as a member of the faculty at our institution. All procedures were performed using the da Vinci S Surgical System (Intuitive Surgical, Sunnyvale, CA) and were performed using standard robotic technique, which is described elsewhere.[5,6]

Briefly, after reflecting the colon and identifying the tumor with intraoperative ultrasound, the hilum was dissected to identify the renal vasculature, which was controlled with bulldog clamps. The tumor was excised sharply, and the cortex was coagulated with electrocautery for hemostasis. In the event of large, open venous channels or collecting system entry, repair was performed using a 2-0 polyglactin suture and LapraTy (Ethicon, Cincinnati, OH) clips. Renorrhaphy was initially performed using assistant-placed LapraTy clips, though after the 13th procedure, all reconstruction was accomplished with a sliding-clip renorrhaphy, which has previously been described elsewhere.[7]

To evaluate the learning curve for RAPN, we used a protocol similar to those previously described for the evaluation of the learning curve of robotic prostatectomy.[8,9] Each of the 38 patients was assigned a consecutive case number without regard to laterality or tumor size. For each case, we recorded the overall operative time as well as the warm ischemia time. Operative time was defined as the time from first incision to the completion of skin closure, and included docking and undocking of the robot. Warm ischemia time was defined as the time from initial vascular clamping until the removal of the final arterial clamp.

The data for operative and warm ischemia time were stratified by tumor size >2 and <2 cm. As the majority of tumors treated in this early experience were clinical stage T1a tumors, we chose this arbitrary size division to cleanly stratify our patients into two easily evaluable groups, so that the potential impact of the tumor size on the learning curve could be summarily evaluated. We defined the endpoint of the learning curve as the number of cases after which minimal variation of warm ischemia times and overall operative times was observed, as identified by a leveling of the slope of the curve.

Data analysis

The data for operative time and warm ischemia time as a function of case number were modeled via polynomial regression. A Student's *t*-test was used to analyze the difference between the mean operative time and mean ischemia time for tumor sizes <2 cm and tumor sizes >2 cm.

Results

Clinical parameters

The average age of the patients was 62 years (range 41–83 years). Tumors of all sizes were addressed throughout the series, and there was no significant migration of tumor size over the course of the experience. For patients with tumors <2 cm, the average tumor size was 1.45 cm (range 0.3–2.0 cm). For patients with tumors >2 cm, the average tumor size was 3.3 cm (range 2.1–5.5 cm). The average length of stay for all the patients was 2.5 days (range 1–7 days), and the average intraoperative blood loss was 135 mL (range 25–500 mL). In all, 25% of the patients with tumors <2 cm and 76% of the patients with tumors >2 cm required pelvicaliceal repair, a difference that was statistically significant ($p = 0.001$).

Operative time

The average operative time for tumors <2 cm was 131.9 minutes (range 69–214 minutes) and for tumors >2 cm was 145.8 minutes (range 96–219 minutes); this difference was not statistically significant ($p = 0.23$). As defined by the total operative time, the learning curve for RAPN was 16 cases and was independent of the tumor size. Figure 1 shows the operative time as a function of case number for tumor size <2 and >2 cm.

Warm ischemia time

Three of the 16 patients with tumors <2 cm and 3 of the 22 patients with tumors >2 cm did not require clamping of the renal vasculature and were thus excluded from this subset analysis. The average warm ischemia time for tumors <2 cm was 21 minutes (range 11–35 minutes), and for tumors >2 cm, the average ischemic time was 24.7 minutes (range 13–40 minutes); this difference was not statistically significant ($p = 0.20$). The learning curve for RAPN in terms of warm ischemia time was 26 cases, which was also independent of the tumor size. Figure 2 shows warm ischemia time as a function of case number for tumor size <2 and >2 cm.

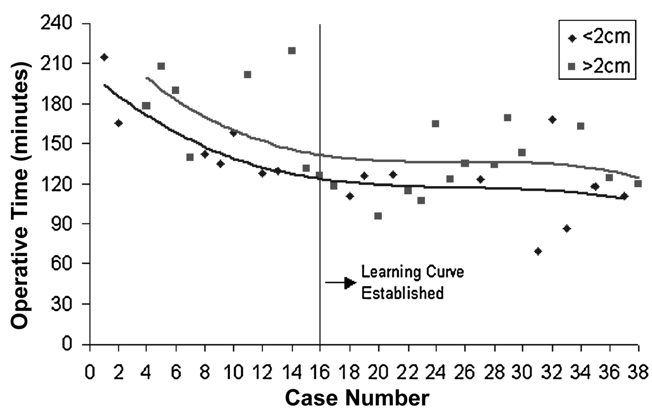

FIG. 1. Operative time in minutes as a function of case number for tumor sizes <2 and >2 cm.

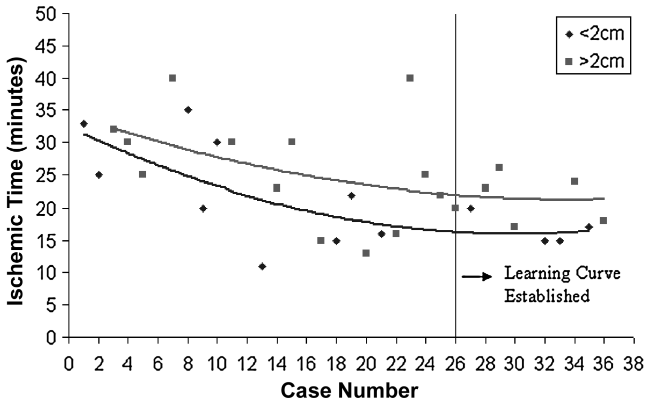

FIG. 2. Ischemic time in minutes as a function of case number for tumor sizes <2 and >2 cm.

Outcomes and complications

Estimated blood loss was equivalent for patients with tumors <2 and >2 cm (130.9 vs. 136.4 mL, respectively, $p = 0.9$). No patients required intraoperative or immediate postoperative blood transfusion. However, two patients with tumors >2 cm received transfusions: one for a drift in hematocrit in a patient with baseline anemia and cardiac impairment and the other for a perirenal hematoma, which required transfusion 2 weeks postoperatively. No patients with tumors <2 cm required transfusion.

One patient with a tumor >2 cm, the 26th patient in our experience, developed a prolonged urine leak for 6 weeks postoperatively, which was managed with ureteral stenting and percutaneous drainage of the urinoma. One patient with an operative time of 190 minutes experienced a postoperative deep venous thrombosis with pulmonary embolus, and one patient with an operative time of 118 minutes suffered a myocardial infarction. One patient late in the experience was readmitted for hypertensive crisis after noncompliance with her antihypertensive medication regimen. In addition, one patient with a tumor <2 cm was later admitted for urinary retention.

The serum creatinine for all the patients on the postoperative day 1 rose by a mean of 0.23 mg/dL (range 0.18–0.28 mg/dL).

Tumor pathology

Pathological analysis revealed 15 patients with clear renal-cell carcinoma (RCC), 6 with papillary RCC, 2 with chromophobe RCC, and 1 with mixed RCC. In addition, there were six angiomyolipomas, two oncocytomas, one metanephric adenoma, one schwannoma, and four benign renal cysts. Margins were negative in 37 out of the 38 patients. The sole positive margin was in one patient with 2.1 cm papillary RCC, which occurred in the second-to-last case evaluated in this study.

Discussion

For an experienced laparoscopic surgeon, the learning curve for RAPN is slight and can be surpassed in roughly two dozen cases. This foreshortened learning curve may be attributable to the decreased difficulty of intracorporeal suturing and increased spatial resolution afforded by the da Vinci S Surgical System.[3,4]

In our study, the learning curve in terms of the total operative time was 16 cases, and for portions of the case performed under warm ischemia, the learning curve was slightly longer, 26 cases. Tumor size did not appear to have a significant impact on the learning curve, nor did it have an impact on the intraoperative blood loss. We found this particularly interesting, because tumors >2 cm required calyceal repair in 76% of the procedures, compared with only 25% of the procedures for tumors <2 cm, indicating that the larger tumors were also generally more endophytic and conceivably more complex than the smaller tumors. However, the relatively small size of our study might have rendered our data underpowered to demonstrate a true effect if one exists.

It is interesting that the learning curve is steeper for portions of the case performed under ischemic conditions. This implies that mastery of some of the more critical portions of RAPN may require more experience than the less critical portions of the procedure. Therefore, we cannot simply define the learning curve in terms of the total operative time, as other critical aspects of the case must also be considered.

The foreshortened learning curve apparent in our series of RAPN compares favorably to the previously reported experiences with LPN. In one large series, Link et al[2] evaluated the learning curve for LPN in over 230 cases. Although they were able to demonstrate that the total operative time improved with increasing surgeon experience, they were unable to identify a learning curve for warm ischemia time. However, it is possible that the learning curve for LPN with respect to the ischemia time was so prolonged that mastery was not attainable even after 200 cases. In our experience with RAPN, both total operative time and warm ischemia time decreased within 26 cases, thus lending support to the notion that the learning curve for RAPN is far less steep than that for LPN.

Our study focused on the learning curve for an experienced fellowship-trained laparoscopic surgeon. However, recent data suggest that the learning curve for RAPN performed by a laparoscopic-naive, yet experienced open surgeon may be foreshortened as well. Deane et al[10] compared outcomes of partial nephrectomy in a series of 11 patients who underwent LPN by experienced laparoscopic surgeons and 10 patients who underwent RAPN by an experienced open surgeon. Within 10 cases, the outcomes of RAPN performed by the experienced open surgeon were comparable to LPN performed by the experienced laparoscopic surgeons, suggesting that the learning curve can be foreshortened even for surgeons with limited laparoscopic experience.

There have been at least 14 studies that detail experiences with RAPN.[1,3,5,10–20] Our experience with RAPN is comparable to other studies with respect to warm ischemia time, length of hospital stay, and perioperative complications. Mean ischemic time from the literature ranges from 18 to 31 minutes, whereas ischemic time in our series averaged 21 minutes for tumors <2 cm and 24.7 minutes for tumors >2 cm. The mean length of hospital stay previously reported in the literature ranges from 1.9 to 4.3 days, whereas in our study the average hospital stay was 2.5 days. Our postoperative complications, including urinary retention and prolonged urine leak, have also been previously reported in other series.[3,12]

In addition, our average operative time and intraoperative blood loss are consistent with those reported in other series. Mean operative times from the literature range from 83 to 279 minutes, whereas in our series, the mean operative time was 132 minutes for tumors <2 cm and 146 minutes for tumors >2 cm. The estimated blood loss in previous series ranges from 92 to 329 mL, whereas in our study the blood loss averaged 135 mL (range 50–500 mL).

There are a few potential shortcomings of the present analysis which warrant discussion. First, the arbitrary cutoff of 2 cm in our analysis is likely of no practical significance in terms of the oncologic outcome. However, the difference in the need for calyceal repair between the two groups suggests a greater tumor complexity for those masses >2 cm, as calyceal repair has been shown in prior reports to serve as an objective indicator of a predominantly endophytic or central tumor.[21,22] Therefore, this distinction, although arbitrary, serves to illustrate that the tumor size and complexity likely have little bearing upon technical proficiency, a notion supported by a recent multiinstitutional analysis of RAPN.[15]

Further, there are a few potentially confounding variables that could not be controlled in the analysis. As not every renal mass is amenable to a robot-assisted nephron-sparing approach, the surgeon did perform multiple laparoscopic and robot-assisted radical nephrectomies during the present experience. These procedures, especially the robot-assisted radical procedures, may have surreptitiously advanced the learning curve outside of the parameters of this analysis. Further, the surgeon also performed a substantial number of robot-assisted laparoscopic prostatectomies during the experience, which may have also contributed in some manner to an increasing proficiency with the robotic system. However, eliminating radical nephrectomy and robot-assisted prostatectomy altogether during the period of study would not have been practical.

In addition, beginning with the 13th procedure in the series, a shift in the reconstructive technique toward sliding-clip renorrhaphy occurred. This technique has been credited in one recent analysis with a drastic reduction in warm ischemic times,[16] which may have affected the interpretation of the learning curve. However, the converse may also be argued, that the relatively slight learning curve noted in the present experience was capable of affecting the perceived advantage of sliding-clip renorrhaphy. That said, as continuous refinement of technique can and should be considered part and parcel of a surgeon's learning curve for a particular procedure, this shift in the reconstructive technique is an essential and perhaps indelible facet of the present experience.

Conclusions

In the hands of an experienced laparoscopic surgeon, the learning curve for RAPN is slight and can be surpassed in less than two dozen cases. Mastery of the critical portions of the case, which are often performed under ischemic conditions, appears to require additional experience beyond which can be observed by measuring the total operative time alone. Tumor size does not appear to have a significant impact on the learning curve.

Disclosure Statement

Bhayani: Consultant, Intuitive Surgical Corp., Sunnyvale, CA.

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Abbreviations Used

LPN = laparoscopic partial nephrectomy
RAPN = robot-assisted partial nephrectomy
RCC = renal-cell carcinoma