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Robot-Assisted Partial Nephrectomy: An International Experience

Brian M. Benway[a,*], *Sam B. Bhayani*[a], *Craig G. Rogers*[b], *James R. Porter*[c], *Nicolò M. Buffi*[d], *Robert S. Figenshau*[a], *Alexandre Mottrie*[e]

[a] *Division of Urologic Surgery, Department of Surgery, Washington University School of Medicine, Saint Louis, MO, USA*
[b] *Vattikuti Urology Institute, Henry Ford Hospital, Detroit, MI, USA*
[c] *Swedish Urology Group, Seattle, WA, USA*
[d] *Department of Urology, Vita-Salute University, San Raffaele–Turro Hospital, Milan, Italy*
[e] *Department of Urology, Onze Lieve Vrouwziekenhuis, Aalst, Belgium*

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Abstract

Background: Robot-assisted partial nephrectomy (RAPN) is emerging as a viable approach for nephron-sparing surgery (NSS), though many reports to date have been limited by evaluation of a relatively small number of patients.

Objective: We present the largest multicenter RAPN experience to date, culling data from four high-volume centers, with focus upon functional and oncologic outcomes.

Design, setting, and participants: A retrospective chart review was performed for 183 patients who underwent RAPN at four centers between 2006 and 2008.

Surgical procedure: RAPN was performed using methods outlined in the supplemental video material. Though operative technique was similar across all institutions, there were minor variations in trocar placement and hilar control.

Measurements: Perioperative parameters, including operative time, warm ischemic time, blood loss, and perioperative complications were recorded. In addition, we reviewed functional and oncologic outcomes.

Results and limitations: Mean age at treatment was 59.3 yr. Mean tumor size was 2.87 cm. Mean total operative time was 210 min while mean ischemic time was 23.9 min. Calyceal repair was required in 52.1% of procedures. Mean estimated blood loss was 131.5 ml. Sixty-nine percent of excised tumors were malignant, of which 2.7% exhibited positive surgical margins. The incidence of major complications was 8.2%. At up to 26 mo follow-up, there have been no documented recurrences and no significant change in serum creatinine (1.03 vs 1.04 mg/dl, $p = 0.84$) or estimated glomerular filtration rate (eGFR) from baseline (82.2 vs 79.4 mg/ml per square meter, $p = 0.74$). The study is limited by its retrospective nature, and the outcomes are likely influenced by the robust prior laparoscopic renal experience of each of the surgeons included in this study.

Conclusions: RAPN is a safe and efficacious approach for NSS, offering short ischemic times, as well as perioperative morbidity equivalent to other standard approaches. Moreover, RAPN is capable of providing patients with excellent functional and oncologic outcomes.

* Corresponding author. Division of Urologic Surgery, Department of Surgery, Washington University School of Medicine, Saint Louis, MO 63110, USA. Tel. +1 314 747 0888; Fax: +1 314 454 2876.
E-mail address: benwayb@wudosis.wustl.edu (B.M. Benway).

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1. Introduction

Since its introduction in 2004 by Gettman and colleagues [1], robot-assisted partial nephrectomy (RAPN) using the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA, USA) has been steadily gaining acceptance as a viable alternative to both open and laparoscopic partial nephrectomy for patients with small renal masses amenable to nephron-sparing surgery (NSS) [2].

However, given the relative immaturity of the global RAPN experience, reports to date have often included series composed of only a handful of patients and with limited follow-up, suggesting a critical need for larger series composed of data from multiple high-volume centers. In this paper we describe the largest RAPN experience to date, culling data from four centers in both Europe and the United States.

2. Methods

2.1. *Patient demographics*

Across our four institutions, a retrospective chart review was performed for a total of 183 patients who underwent RAPN between September 2006 and December 2008. Five patients had multiple tumors that were treated simultaneously, for a total of 191 tumors addressed with RAPN during the course of the study. Two patients had a functional solitary kidney. The individual databases were merged using a common template, and de-identified with respect to patient, institution, and surgeon. As all institutions are teaching centers, qualified residents and fellows performed portions of the procedure when appropriate; however, the bulk of the procedures were performed by the attending surgeon.

As patient selection for robot-assisted NSS is based upon multiple factors, including the size and complexity of the renal mass, medical comorbidity, and the presence of renal dysfunction or anatomic anomaly, as well as patient preference, the patient population was not randomized. Patient demographics are summarized in Table 1.

2.2. *Surgical technique*

A detailed illustration of the surgical techniques for RAPN employed at our institutions can be found in the accompanying video material. While the same general principles guided each procedure, there were minor variations in technique between our institutions that relate largely to surgeon preference. It is of note that while all the attending surgeons are experienced minimally invasive surgeons who had surpassed the learning curve for RAPN by the end of the reported experience [3,4], the present study also includes the initial RAPN experience at each center; therefore, four independent learning curves have contributed to the present data.

Table 1 – Patient demographics and operative parameters

No. patients	183
No. tumors	191
Laterality	
Left	92
Right	88
Unknown	3
No. patients with multiple tumors	4
No. patients with solitary kidney	2
Age (yr)	59.3 (range: 28–83)
BMI (mg/kg per square meter)	30.3 (range: 16–48)
Tumor size (cm)	2.87 (range: 1.0–7.9)
Total operative time (min)	210 (range: 86–370)
Mean console time (min)	141.5 (range: 45–253)
Mean warm ischemic time (min)	23.9 (range: 10–51)
Calyceal repair	52.1%
Estimated blood loss (ml)	131.5 (range: 10–900)

BMI = body mass index.

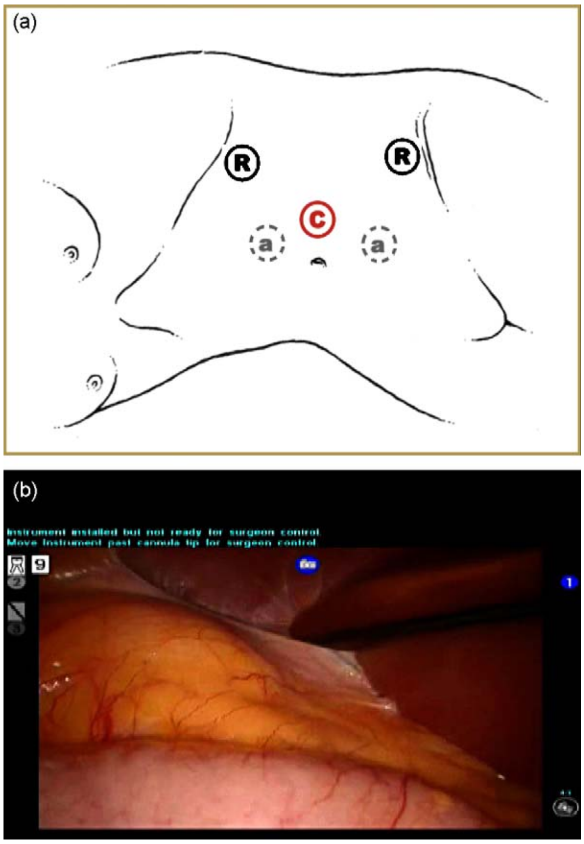

Fig. 1 – (a) Medial camera trocar arrangement. (b) The view offered by the medial trocar configuration. This approach allows for simple visualization of surrounding structures and tracking of instruments, although at the expense of a more distant viewing distance. Note that adjacent structures, including the bowel and the liver, are easily viewed with this approach. C = camera port (12 mm); R = robotic port (8 mm); a = assistant port (12 mm, placed at one of the indicated locations).

2.2.1. *Patient positioning and access*

For all procedures, the patient is placed in a flank position. The patient is secured to the table and all pressure points are padded.

A medial trocar configuration (Fig. 1a and b) is used at two centers (Washington University and Onze Lieve Vrouwziekenhuis Clinic). For this approach the camera is located medially near the umbilicus and the robotic ports are introduced along the midaxillary line, with one port a few finger breadths below the costal margin and the other a few finger breadths above the anterior superior iliac spine. One assistant port is placed medially, just cephalad or caudad of the camera port. In cases where a fourth arm is utilized, the additional robotic trocar is placed slightly more laterally, between the other two robotic arms. The strengths of this approach include a wide viewing distance and the ability to track instruments being passed into the abdomen by the assistant [1,3,5].

Alternatively, the other two centers (Henry Ford and Swedish Urology) frequently use a modified trocar arrangement, with the camera

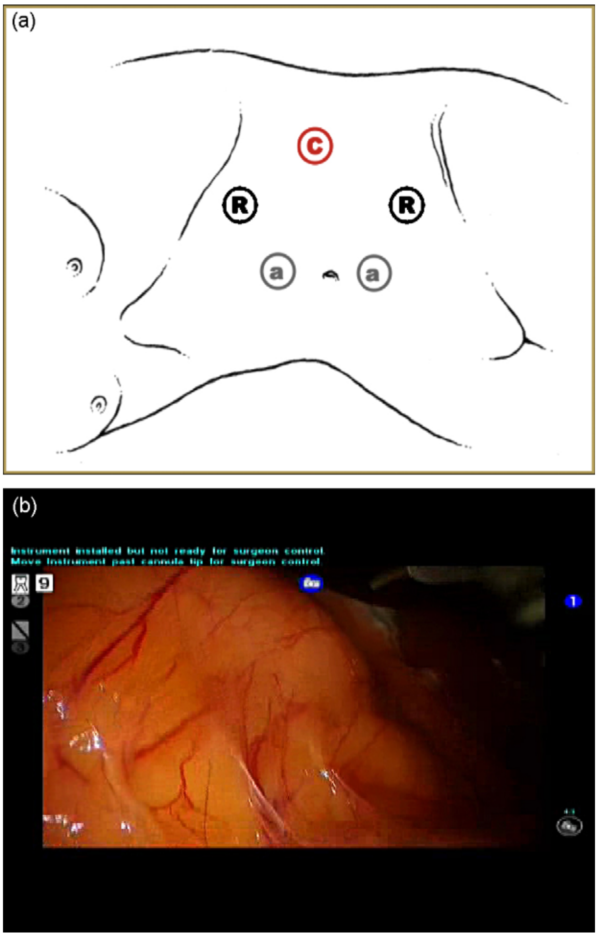

Fig. 2 – (a) Lateral camera trocar arrangement. (b) The view offered by the lateral trocar configuration. This approach provides a closer view of the kidney at the expense of a restricted field of view. Note by comparison with Fig. 1b that the closer view does not provide a clear view of the colon or liver.
C = camera port (8 mm); R = robotic port (8 mm); a = assistant port (5 or 12 mm, placed at both indicated locations).

port placed more laterally and with two assistant ports placed medially (Fig. 2a and b). This approach has been noted to provide a comparatively closer view of the target structures at the expense of a wider viewing angle [5–7]. Although the optics and orientation differ slightly between the two approaches, instrument mobility and technical considerations are comparable.

The decision to utilize a fourth robotic arm is left to surgeon preference, with use being more common in the lateral approach or for cases where an experienced bedside assistant was not available [8].

2.2.2. Bowel mobilization and hilar control

All dissection is carried out robotically. The bowel is mobilized and reflected medially to expose the retroperitoneum. The lower pole and ureter are identified and elevated, and the hilum is carefully exposed.

Once the hilum is identified and exposed, the fat surrounding the grossly visible mass is reflected to expose the capsule. In the majority of cases, the extent of the tumor is assessed with intraoperative ultrasound. Whenever possible, real-time imaging is displayed using the TilePro software (Intuitive Surgical, Sunnyvale, CA, USA) available on newer da Vinci systems. The capsule is then scored to demarcate the margins of dissection.

Bulldog clamps were used for the majority of cases at our institutions; however, while two institutions routinely clamped artery and vein, the other two only clamped the vein for larger tumors $\geq$4 cm or for centrally located tumors. In addition, one center used a Satinsky clamp for en bloc hilar control for select anterior or hilar tumors. The advantages and disadvantages of each clamping method have been discussed elsewhere [2]. Regardless, in the present experience, all clamping methods were capable of providing and maintaining a relatively bloodless field during tumor resection and reconstruction.

2.2.3. Tumor excision and renal reconstruction

Tumor excision is carried out sharply using the robotic scissors. Biopsy of the resection bed is left to surgeon discretion.

In some centers, once excision is complete, the cortex of the resection bed is cauterized for hemostasis using monopolar or bipolar energy. Large vessels are oversewn using 2-0 polyglactin sutures with LapraTy (Ethicon, Cincinnati, OH, USA) clips in lieu of tied knots. Likewise, the collecting system is oversewn if necessary using a polyglactin suture. The use of bolsters and tissue sealants is left to surgeon preference.

Sliding-clip renorrhaphy is then performed using 0 polyglactin sutures and Weck (Teleflex, Research Triangle Park, NC, USA) Hem-O-Lock clips. This technique for renal reconstruction has been extensively described in prior reports [3].

2.3. Data analysis

Comparative analysis of data was performed in Excel (Microsoft, Seattle, WA, USA) using a Mann-Whitney *U* test. A standard *p* value of 0.05 was used to determine significance. Correlative analysis was performed using Spearman rank correlation using GraphPad Prism (GraphPad Software, Inc., La Jolla, CA, USA).

3. Results

3.1. Operative data

Mean warm ischemic times (WIT) across the entire series averaged 20.7 min (range: 0–51 min; median: 22 min). Accounting only for those cases where the vessels were clamped, mean WIT was 23.9 min (range: 10–51 min; median: 23 min). For those patients requiring calyceal repair, the mean WIT was 25 min (median: 25 min), and for those who did not require calyceal repair, the mean WIT was 14.1 min (median: 15.5 min). The WIT for patients with multiple tumors was 29.3 min (range: 18–35 min; median: 32 min). Operative data are summarized in Table 1.

Tumor size was positively correlated with both overall operative time ($p = 0.003$) and WIT ($p = 0.005$). The need for calyceal repair was correlated with WIT ($p < 0.0001$), but did not have an impact on overall operative time ($p = 0.4$).

3.2. Laboratory data

Laboratory data are outlined in Table 2. While serum creatinine and eGFR were noted to decline within the first 24 h, both returned to baseline by the time of last follow-up, indicating excellent preservation of renal functional reserve.

Spearman rank correlation found that tumor size, overall operative time, and WIT did not have a significant effect upon changes in serum creatinine ($p = 0.25$, $p = 0.18$, $p = 0.29$, respectively) nor upon observed decreases in hemoglobin ($p = 0.68$, $p = 0.37$, $p = 0.51$, respectively). Unfortunately,

Table 2 – Laboratory values associated with robot-assisted partial nephrectomy

Parameter	Mean (range)	Change from baseline (p value)
Preoperative creatinine (mg/dl)	1.03 (0.6–2.0)	NA
Creatinine 24 h postoperation (mg/dl)	1.18 (0.6–2.4)	+0.16 (<0.0001)
Creatinine at last follow-up (mg/dl)	1.04 (0.6–2.0)	+0.01 (0.84)
Preoperative eGFR (mg/ml per square meter)	82.2 (41–124)	NA
eGFR at 24 h (mg/m per square meter)	69.4 (20–140)	−12.8 (0.04)
eGFR at last follow-up (mg/ml per square meter)	79.4 (34–127)	−2.8 (0.74)

eGFR = estimated glomerular filtration rate; NA = not applicable.

eGFR data were limited in our database, which did not allow for correlative analysis.

3.3. Pathologic data

Pathologic data were available for 173 patients and are summarized in Table 3. Overall, 68% of tumors excised exhibited malignant features. Positive surgical margins on final pathology were encountered in seven patients (3.8%), and were distributed throughout the experience. Two of these patients were found to have benign pathology (angiomyolipoma), while the remaining five patients had malignant tumors, for an overall positive surgical margin rate of 2.7% for malignancy.

An additional two patients were noted to have positive margins intraoperatively and underwent re-resection to obtain a negative margin; final pathology on both patients revealed angiomyolipoma. All patients with positive margins have been observed, and at ≤26 mo of follow-up (median: 16 mo) no patient has demonstrated evidence of disease recurrence on repeat cross-sectional imaging.

3.4. Complications and conversions

Two cases (1%) were converted to open procedures for failure to progress: one patient was noted to have extensive perinephric scarring and another's body habitus severely limited the mobility of the robotic arms. One case was aborted when intraoperative ultrasound failed to identify the tumor; re-evaluation revealed that the suspicious lesion was likely a resolving focal infection.

There were a total of 18 complications (9.8%). Of these, 15 (8.2%) were major and 3 (1.6%) were minor complications. Major complications included three pseudoaneurisms requiring embolization; two postoperative bleeds requiring transfusion; two chylous leaks, which were managed conservatively; and two postoperative urine leaks, both requiring stent placement and drainage of the urinoma. In addition, one patient suffered a hepatic laceration, which required re-exploration; one patient suffered a splenic laceration, which was repaired; and one patient developed a subcapsular renal hematoma, which was monitored. Finally, two patients suffered postoperative stroke, and one patient suffered a myocardial infarction, none of which were fatal.

The three minor complications included one patient with cellulitis surrounding an incision, and two instances of gross hematuria, both of which resolved spontaneously. At the time of this report, there has been no disease-specific mortality in our series.

Table 3 – Overview of pathology

Total no. malignant tumors (%)	118 (68)
Clear cell carcinoma	66
Papillary	37
Chromophobe	10
Mixed renal cell carcinoma	3
Spindle cell/mucinous carcinoma	1
Mature teratoma/carcinoid	1
Total no. benign tumors (%)	55 (32)
Oncocytoma	15
Angiomyolipoma	22
Fibroconnective dysplasia	4
Leiomyoma	3
Benign cyst	2
Fat necrosis	1
Adenoma	1
Other (unspecified)	7
No. positive margins (%)	7 (3.8)
Benign final pathology	2 (1.2)
Malignant final pathology	5 (2.7)

4. Discussion

Over the past 5 yr, partial nephrectomy has increasingly been advocated for all patients with small localized renal masses, even for those with a normal contralateral kidney [9–12].

In 1993, Winfield et al and McDougall et al published the first reports of successful laparoscopic partial nephrectomy (LPN) [13,14]. The technique was soon adopted at high-volume centers, with reports clearly demonstrating that LPN was capable of providing oncologic and functional outcomes equivalent to open partial nephrectomy, while at the same time offering patients a more rapid convalescence [10,15–20].

However, despite clear advantages over an open approach, the increased challenge of partial nephrectomy has arguably led to its profound underutilization within the urologic community at large. Indeed, at last report, only 7.5% of all extirpative renal surgeries were being performed with nephron-sparing techniques, and only 20% of renal tumors between 2 and 4 cm were treated via LPN [21–23]. These numbers are most certainly cause for concern.

The introduction of robot-assistance may help to reduce the barriers of entry for minimally invasive NSS. Indeed, RAPN appears to be associated with a relatively slight learning curve, with the potential for technical proficiency in <30 procedures for experienced renal surgeons, even in those without prior laparoscopic experience [3,4].

While early reports on RAPN did not demonstrate a clear advantage to the robotic approach [24,25], remarkable improvements in operative parameters have been noted with longer experience and as techniques have been refined. Recent reports comparing RAPN and LPN have found equivalent oncologic control between the two treatment modalities, with RAPN providing significant reductions in intraoperative blood loss, length of hospital stay, and most critically, in WIT [26,27].

The present report represents the largest RAPN experience described to date and further illustrates the safety and efficacy of RAPN for the management of localized renal malignancy.

Our results demonstrate excellent oncologic outcomes, with a positive margin rate of only 2.7%, which is consistent with prior published laparoscopic series [19,20], and lower than the largest RAPN series currently available [28]. It is likely that our comparatively lower rate of positive margins represent increased surgeon expertise, as the present series includes large and robust institutional experiences, rather than a collection of initial experiences [28].

Moreover, our relatively low rate of overall perioperative complications (9.8%) compares very favorably with large LPN series, including a recent report by Gill and colleagues, who reported a complication rate of 18.6% in 771 patients treated via a laparoscopic approach [19]. While this comparison is not conclusive and may be skewed by biases in patient selection for each approach, at the very least our findings suggest that RAPN is a safe technique for NSS.

Finally, though extended follow-up was not available for all of the patients in our series, over the short term, renal function appears to be well preserved in patients undergoing RAPN. Further evaluation of functional outcomes is underway at our institutions.

There are a few limitations to the present analysis that warrant mention, chief among them the retrospective nature of our review. As such, our collective experience may be subject to selection bias. However, as many factors, such as tumor size and the presence of medical comorbidity, undoubtedly influence the decision to pursue NSS, we feel that this is a bias not unique to this particular report.

Another potential criticism is that a surgeon with developed laparoscopic skills does not need to rely upon robotic technology to safely and efficiently perform partial nephrectomy. However, we are inclined to disagree. We do not dispute that there are highly skilled surgeons who are capable of performing LPN with remarkable efficiency. However, a recent report has found that even for experienced laparoscopic renal surgeons, RAPN is associated with tangible improvements in operative parameters, such as WIT [27]. Furthermore, many patients, especially those in rural areas, may not have ready access to high-volume centers; these patients are at increased risk of undergoing unnecessary radical extirpation, which can have significant long-term consequences. Any technology that may reduce the challenge of minimally invasive renal surgery stands to hasten its dissemination into the urologic community at large, which should, in turn, equalize patient access to the modern standard of care.

Yet another criticism is the increased reliance upon the assistant during RAPN, as the surgeon is not scrubbed at the bedside [8,25]. While concerns of this nature may indeed be valid, there were no untoward events in our series that could be directly attributed to the experience of the assistant, which varied widely from junior-level residents to attending surgeons. Therefore we were unable to explore the veracity of these claims.

Finally, it must be acknowledged that there is a high capital expense associated with the purchase and maintenance of a robotic system. However, these costs are perhaps somewhat offset by the reusable nature of most of the robotic instrumentation, as well as by the shorter length of hospital stay noted in prior reports [26,27]. Formal cost analysis, however, is presently lacking, and therefore the above comments remain merely speculative at this juncture.

5. Conclusions

In experienced hands, RAPN is a viable alternative to both the open and laparoscopic approaches to NSS, offering excellent short-term outcomes and cancer control. Future refinements of the procedure should be directed towards further reduction in WIT, ideally below 20 min. Prospective analysis of RAPN, including direct comparison with LPN and the open approach, is critically needed to further evaluate this evolving technique.

Author contributions: Brian M. Benway 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: Benway, Bhayani, Rogers, Porter, Mottrie.
Acquisition of data: Bhayani, Rogers, Porter, Mottrie.
Analysis and interpretation of data: Benway, Mottrie.
Drafting of the manuscript: Benway.
Critical revision of the manuscript for important intellectual content: Bhayani, Rogers, Porter, Figenshau, Mottrie.
Statistical analysis: Benway.
Obtaining funding: Bhayani.
Administrative, technical, or material support: None.
Supervision: Bhayani, Rogers, Porter, Figenshau, Mottrie.
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Appendix A. Supplementary data

The Surgery in Motion video accompanying this article can be found in the online version at doi:10.1016/j.eururo.2010.01.011 and via www.europeanurology.com. Subscribers to the printed journal will find the Surgery in Motion DVD enclosed.

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