Robot-Assisted Partial Nephrectomy

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Abstract
Since its introduction in 2004 by Gettman and colleagues [1], robot-assisted partial nephrectomy (RAPN) has been steadily gaining acceptance as part of a new standard of care for the treatment of localized renal malignancy. However, this rise to prominence has not been without its share of difficulties.

Keywords
Partial Nephrectomy · Radical Nephrectomy · Warm Ischemic Time · Laparoscopic Partial Nephrectomy · Robotic Technology

Introduction

Since its introduction in 2004 by Gettman and colleagues [1], robot-assisted partial nephrectomy (RAPN) has been steadily gaining acceptance as part of a new standard of care for the treatment of localized renal malignancy. However, this rise to prominence has not been without its share of difficulties.

Soon after the introduction of robot-assisted partial nephrectomy, initial studies evaluating operative parameters and immediate outcomes failed to find a significant advantage over other available techniques, namely open and laparoscopic partial nephrectomy [2, 3], leading some to suggest that RAPN had a limited role in the treatment of renal malignancy.

However, as the experience has matured, newer, more robust series have begun to demonstrate remarkable improvements in critical operative parameters, suggesting that robot-assisted partial nephrectomy does indeed have a place in the urologist's armamentarium.

In this chapter, we will discuss the evolution of renal surgery in general, and more specifically, the rising interest in robot-assisted partial nephrectomy, a technique which built upon the foundations forged by the pioneers of the late 20th century. We will then present a detailed atlas of technique for robot-assisted partial nephrectomy, detailing the methods employed by today's top robotic renal surgeons. Finally, we will

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explore the available literature pertaining to robot-assisted partial nephrectomy, detailing the outcomes associated with this burgeoning technique.

The Evolution of Renal Surgery

For many decades, open radical nephrectomy served as the gold standard for surgical treatment for renal cell carcinoma of any size. However, with the advent of high-resolution cross-sectional imaging, there has been a shift in the diagnosis of renal malignancy, away from large, generally symptomatic masses, to small, often serendipitously detected masses [4–8].

Along with this shift in the diagnosis of renal cancer came increased interest in nephron-sparing techniques, which would allow for complete resection of the tumor while preserving the unaffected portions of the kidney. Partial nephrectomy gained acceptance as a new standard of care for clinical stage T1 lesions, demonstrating equivalent cancer control to radical extirpation, as well as equivalent perioperative morbidity [9–14].

Moreover, long-term outcomes have demonstrated that preservation of the healthy, unaffected renal parenchyma is associated with a sharp decrease in the risk for long-term renal dysfunction and improved overall survival. Indeed, maximal preservation of renal functional reserve appears to be associated with a decreased risk of development of numerous diseases, including hypertension, diabetes mellitus, and cardiopulmonary diseases [11, 14, 15].

In the early 1990s, Clayman and colleagues introduced laparoscopic techniques for radical nephrectomy, ushering in the era of minimally-invasive renal surgery [16]. Soon after, Winfield et al. and McDougall et al. described the technique for laparoscopic partial nephrectomy, which rapidly gained acceptance at high-volume centers of excellence [17, 18]. Laparoscopic partial nephrectomy represented a significant leap forward in the treatment of localized kidney cancer. Reports soon demonstrated operative parameters on par with its open counterpart, and reproducible reports of oncologic equivalence were followed [9, 11, 19, 20].

However, despite the clear advantages of laparoscopic partial nephrectomy, the technique has failed to make inroads outside of high-volume academic centers, owing in large part to the formidable technical challenge associated with the approach, namely with regard to tumor excision and renal reconstruction, aspects of the procedure which are performed under the duress of warm ischemia. In fact, two troubling studies published in 2006 found that laparoscopic partial nephrectomy was sorely underutilized by the urologic community at large, with only 12% of all renal masses and less than 50% of renal masses less than 2 cm in size being addressed with nephron-sparing techniques [5, 21].

The introduction of robotic technology into urologic surgery has prompted a renaissance in the minimally-invasive treatment of urologic disease. Offering a magnified stereoscopic view, along with fully articulating wristed instruments, motion scaling, and elimination of tremor, robot assistance allows for precise handling of tissues and instruments, allowing even laparoscopically naïve surgeons to replicate the success of open surgery through a minimally-invasive approach [7, 22].

Robotic surgery's initial applications for minimally-invasive prostatectomy have propelled robotic technology to the fore and have led to a rapid increase in the number of robotic systems available throughout the United States and the rest of the world. Much as robotic technology has refined the minimally-invasive treatment of prostate cancer, robot assistance stands to provide substantial improvements in minimally-invasive nephron-sparing surgery, eliminating much of the technical challenge associated with the laparoscopic approach, and thereby reducing the barrier of entry for the urologic community. These important steps forward may indeed equalize access to the standard of care for all patients who are diagnosed with renal cancer.

Atlas of Technique

Despite the relative ease and short learning curve of robot-assisted partial nephrectomy [23], the technique remains quite challenging, especially to the novice renal surgeon. While the available robotic systems offer an enhanced three-dimensional view and an unprecedented range of instrument motion, there are significant limitations associated with the technique, chief among them the lack of haptic feedback. This loss of sensory perception requires the robotic surgeon to be intimately familiar with the strength of the robotic arms and to be able to rely largely upon visual cues to gauge the amount of tension being applied to delicate structures, as the robotic arms are capable of exerting an incredible amount of force, even when meeting resistance. Nowhere is this particular facet of robot-assisted renal surgery more critical than when dissecting near the hilar structures.

Therefore, it is recommended that any urologist considering robot-assisted renal surgery should first gain adequate experience with their robotic system. This would include sanctioned hands-on courses which provide the surgeon with thorough instruction in the handling of the robotic system, ideally in an environment which provides a live-animal model. Furthermore, it is recommended that the surgeon become facile with robot-assisted laparoscopic prostatectomy before attempting to employ robotic technology for the purposes of renal surgery.

It is also recommended that the initial transition to robot-assisted renal surgery be focused on radical nephrectomy. Beginning with radical nephrectomy will allow the surgeon to become familiar with the landmarks associated with robot-assisted renal surgery, while also affording the opportunity to become comfortable with hilar dissection using the robotic system.

Patient Selection and Other Considerations

Proper patient selection is critical to the success of robot-assisted renal surgery. While complex central and hilar tumors are capable of being addressed robotically, challenging cases such as these should not be attempted during the initial experience. As such, the ideal initial patients for the novice surgeon would be thin females with exophytic masses and uncomplicated renal vasculature. This particular patient will offer minimal interference from peri-renal fat, which will drastically reduce the difficulty of retraction and hilar dissection. Moreover, an exophytic renal mass is relatively simple to excise and reconstruct, which will minimize the risk of prolonged ischemic times during the initial experience.

It is critical to obtain a thorough patient history, paying special attention to prior abdominal and retroperitoneal surgery, as well as to medical renal disease and other comorbidities such as diabetes mellitus and hypertension. Patients who are on anticoagulation will generally require clearance to have their anticoagulants temporarily suspended in the perioperative period.

Proper informed consent is crucial. Patients must be counseled to the attendant risks of robot-assisted partial nephrectomy, including the risk for hemorrhage requiring transfusion, postoperative urine leak, and inability to completely resect the tumor. In addition, the patient must be counseled regarding the possibility of conversion to radical nephrectomy or to an open procedure.

As dissection of the hilar anatomy can be very difficult, it is recommended that a contrast-enhanced CT scan be performed whenever possible to identify the hilar anatomy. This will allow the surgeon to be prepared for multiple arteries and veins, as well as for anatomic aberrancy.

Patient Positioning and Trocar Placement

The patient should be placed in a flank position, in a manner nearly identical to that of a laparoscopic or open procedure. However, excessive flexion of the table is often not necessary when undertaking a robotic approach. In addition, the arms should be positioned as far cephalad as safely possible, to minimize collisions with the robotic arms. An axillary roll should be placed, and the patient should be secured to the table in a manner that will allow the table to be rolled if necessary.

Sequential compression devices should be placed to provide prophylaxis against deep venous thrombosis. In addition, a preoperative dose of fractionated heparin can be administered for further prophylaxis and should not lead to increased risk of bleeding complications.

With regard to trocar placement, there are two generally accepted approaches. The first and most widely utilized is a medial trocar arrangement, which places the camera port near the umbilicus. This approach replicates a standard transperitoneal laparoscopic approach and should therefore be familiar to most renal surgeons. The alternative approach locates the camera laterally, providing a closer view that is more akin to a retroperitoneal approach, even though the camera and instruments remain in the peritoneal space. Both approaches have been extensively described and are capable of providing adequate visualization and instrument mobility [1, 23–30].

However, in our center's experience, we find the medial approach to be more favorable for a number of reasons, chief among them the wide viewing angle provided by the relatively greater distance between the camera and the target structures. Not only does this approach allow for easier visualization of the surrounding structures, but it also allows the camera to be panned for tracking of instruments passed by the assistant, thus lowering the potential for iatrogenic injury. Furthermore, the digital zoom of later model robotic systems allows for closer inspection of the surgical field, though this zoom feature is often not necessary. In addition, the medial approach often requires only one assistant port, whereas the lateral approach is generally described as using two assistant ports. In the latter, the assistant is placed at somewhat of a disadvantage, as he or she must work on both sides of the camera arm [26]. A detailed illustration of the medial and lateral approaches can be found in Figs. 39.1 and 39.2.

In patients with excessive peri-renal fat or in instances when a surgeon must work with an inexperienced assistant, the fourth arm can be utilized to allow the surgeon greater control over the retraction [24, 31]. However, the novice surgeon must be cautioned that unlike robot-assisted laparoscopic prostatectomy, including the fourth arm in a robot-assisted partial nephrectomy is actually *more* technically demanding, due to crowding of the instruments and robotic arms into a comparatively smaller working space. As such, a four-arm approach should be considered an advanced procedure. An illustration of the four-arm approach can be found in Fig. 39.3.

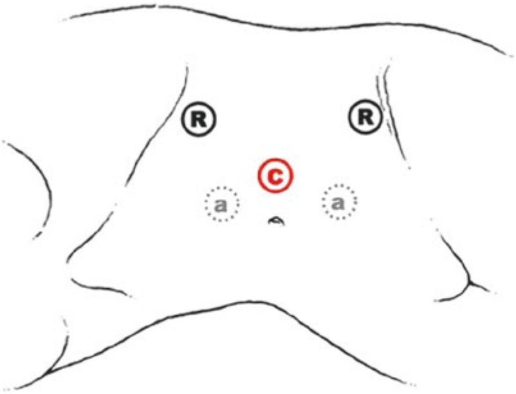

Fig. 39.1 Trocar configuration for the medial camera three-arm approach. A 30° downward-angled lens is used. R, robotic arm; C, camera; a, assistant port (12 mm). The *dotted line* indicates that the assistant port may be placed at either location; only one assistant port is generally necessary. For right-sided procedures, a 5 mm subxiphoid port may be used for placement of a liver retractor (not pictured)

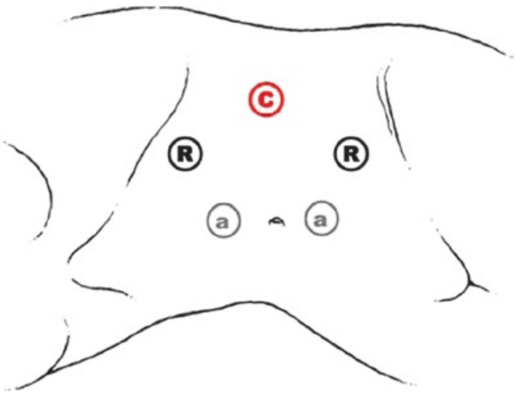

Fig. 39.2 Trocar configuration for the lateral camera approach. A 30° upward-angled lens is used. R, robotic arm; C, camera; a, assistant port (12 mm). Traditionally, two assistant ports are used. For right-sided procedures, a 5-mm subxiphoid port may be used for placement of a liver retractor (not pictured)

When placing the caudad port, the trocar should be introduced approximately 2 cm cephalad to the iliac crest in order to minimize external arm collisions with the hip. For right-sided tumors, an accessory subxiphoid port for a liver

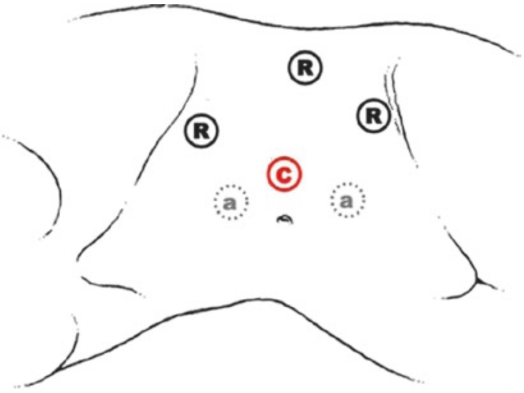

Fig. 39.3 Trocar configuration for the medial camera four-arm approach. A 30° downward-angled lens is used. R, Robotic arm; C, Camera; a = assistant port (12 mm). The *dotted line* indicates that the assistant port may be placed at either location; only one assistant port is generally necessary. For right-sided procedures, a 5 mm subxiphoid port may be used for placement of a liver retractor (not pictured)

retractor is often necessary. This port should be placed as close to the midline as possible, so as not to interfere with the right robotic arm.

Robot Docking and Instrument Selection

The robot should be docked at an angle, on a line connecting the expected location of the renal hilum and the umbilicus. The elbows of the working arms should be pushed out as far laterally as the device will allow, in order to maximize the excursion of the arms and to minimize external collisions.

The right hand should be outfitted with the robotic scissors, which should be connected to monopolar electrocautery. The left hand should be outfitted with the ProGrasp forceps. The assistant should retract with a laparoscopic suction device. Other instruments to have available on the field for the assistant include a Weck (Teleflex, Research Triangle Park, NC, USA) Hem-o-lok clip applier, a LapraTy (Ethicon, Cincinnati, OH, USA) clip applier, a laparoscopic ultrasound probe, and a laparoscopic bulldog applier or Satinsky clamp. In addition, a vascular stapler device with multiple reloads should be readily available, in the event of misadventure requiring emergent nephrectomy.

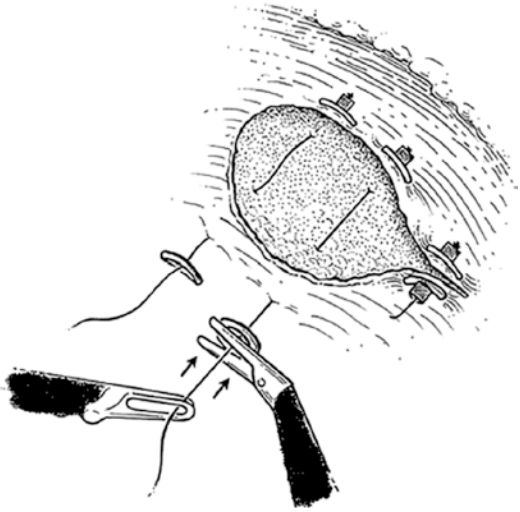

Fig. 39.4 Illustration of the sliding-clip renorrhaphy. Sutures are prepared on the back table by cutting an 0 polyglactin suture to a length of 12–15 cm. A knot is tied at the end, followed by a LapraTy clip and a Hem-o-lok clip. Once the suture has been placed through-and-through, the assistant places a second Hem-o-lok clip on the loose end of the suture, which is then slid into place by the surgeon. The repair is locked in place with a LapraTy clip

On the back table, the surgical assistant should prepare the renorrhaphy sutures, as well as sutures for collecting system repair. As we will discuss later, we strongly recommend the use of a sliding-clip technique for renal reconstruction. As the required sutures can be time consuming to prepare, it is crucial that these sutures are fashioned beforehand.

The collecting system sutures should consist of one or two 2-0 polyglactin sutures, cut to a length of 12 cm. At the end, a knot should be tied, followed by a LapraTy clip. Hem-o-lok clips should not be used on these sutures, as they are non-degradable and could erode into the collecting system. The renorrhaphy sutures are 0 polyglactin sutures cut to a length of 12–15 cm. At the end, a knot is tied, followed by a LapraTy clip, then a Hem-o-lok clip (Fig. 39.4).

In addition, bolster material and tissue sealants should be immediately available, should either be necessary to achieve satisfactory closure and hemostasis.

Initial Dissection

The bowel is reflected along the white line of Toldt, thus exposing the retroperitoneum. For right-sided tumors, the duodenum must also be carefully reflected in order to gain access to the hilum. Great care must be taken during this maneuver, as the vena cava lies directly inferior to the duodenum, and is therefore prone to iatrogenic injury.

The lower pole of the kidney should then be identified, and just off the lower pole, the ureter and gonadal vasculature should be identified. It is preferable to leave the gonadal vein intact if at all possible, and therefore, the vein should be dropped medially whenever possible. Great care must be taken to avoid excessive skeletonizing of the ureter, so as not to compromise the blood supply.

The pocket created by elevating the ureter should allow the kidney to be placed on gentle lateral stretch. Dissection should be carried carefully cephalad to reveal the hilar vessels. Astute surgeons may be able to detect the venous impulse which is the hallmark of the renal vein [24]. The artery should lie directly posterior to the vein.

The extent of hilar dissection should be largely dictated by the needs of the preferred method of vascular control. If a laparoscopic Satinsky clamp is to be used to clamp the hilum en bloc, then further dissection between the artery and the vein is not generally necessary. However, if laparoscopic bulldog clamps are to be used, separation of the artery and vein will be necessary. The ProGrasp forceps are best suited for this task, as they are able to bluntly dissect the plane between the vein and the artery. Great care should be taken to eliminate the posterior hilar fat from the field, to ensure that the bulldog clamps are able to fully close.

In some instances, it may be possible to isolate a segmental arterial branch which provides the entire blood supply to the tumor. Selective clamping of this artery may lead to less ischemic insult, as the unaffected portions of the kidney remain perfused. However, while effective for polar tumors, such dissection increases the risk of vascular injury and should be considered an advanced technique [32, 33].

Preparing for Excision

The fat surrounding the tumor should be reflected to expose a 1 cm margin of normal capsular tissue around the mass. This maneuver will greatly aid in reconstruction. The fat overlying the kidney should be left intact, but may be inadvertently released from the surface of the tumor. If this occurs, the fat should be immediately collected and placed with the specimen.

Intraoperative ultrasound should then be performed to assess the extent of the tumor and to delineate the margins of dissection, which should be marked by scoring the capsule. If selective clamping of a segmental renal artery is to be employed, color Doppler flow should be used to assess for complete cessation of flow after temporary occlusion of the segmental artery.

Once the stage is set for excision, the renal vasculature should be carefully occluded with either a Satinsky clamp or bulldog clamps. If a Satinsky clamp is to be used, it is imperative that the assistant closely monitors the clamp and takes steps to avoid external collisions which could lead to avulsion of the vasculature. Due to the inherent risks of the Satinsky clamp method, we prefer the use of bulldog clamps, which are used to occlude the vessels individually. As the bulldog clamps may weaken during reprocessing, it is recommended to clamp the artery doubly whenever possible to ensure complete occlusion. Clamping of the vein is left to surgeon preference, though it is highly recommended, especially for central, anterior, or hilar tumors.

Tumor Excision

The tumor is then sharply excised using the robotic scissors. The ProGrasp may be used to gently spread the tissues and present the underlying parenchyma for dissection. Great care should be taken to follow the expected curvature of the tumor. If the tumor is entered, the last steps should be retraced, and the tumor should be recaptured. Should this occur, it is recommended to repair this defect on the back table after extraction, to avoid an iatrogenic false-positive margin.

Dissection should be carried out from near to far, using the attachment of the far side as a hinge that will allow for relatively simple retraction as excision is carried out. Any entry into large venous channels or into the collecting system should be noted. Once excision is complete, the tumor should be placed out of the field nearby for later extraction. At this juncture, the assistant may collect a biopsy of the resection bed, if deemed necessary.

Renal Reconstruction

Reconstruction should be undertaken with all deliberate speed. The cortex should be cauterized for hemostasis; however, cautery should not be applied to the medulla. At this juncture, the robotic scissors should be replaced with a needle driver; the ProGrasp should remain on the left hand, as this instrument has the capacity to serve as a needle driver, if necessary. If there has been entry into the collecting system or into a large venous sinus, these areas should be oversewn using the 2-0 polyglactin suture in a running fashion. The repair should be secured with a LapraTy clip to obviate the need for knot tying. Should a bolster or tissue sealants be deemed necessary, they may be applied now or shortly after commencing the renorrhaphy.

Sliding-clip renorrhaphy should then be performed [23–25, 34–36]. The prepared sutures should be placed at 1 cm intervals along the length of the defect. After completing the second throw, the assistant places a Hem-o-lok clip on the loose end. This clip need not be placed in direct apposition to the capsule, as it will be slid into position under tension by the surgeon. However, the assistant should take care to ensure that the suture is placed as close to the middle of the clip as possible, as this will allow the clip to be slid along the suture with greater ease.

The Hem-o-lok clip is then slid into position by straddling the suture with the jaws of the needle driver. Appropriate tension has been placed when the capsule dimples slightly. As this maneuver is being performed, the ProGrasp should hold tension on the loose end of the suture in a direction perpendicular to the capsule, so as to minimize the risk of tearing through the capsule. Once the Hem-o-lok clip has been slid into place, the repair is locked in place by a LapraTy clip. This clip, too, may be slid over the suture, though it does not slide as readily as the Hem-o-lok clip. Once all renorrhaphy sutures have been placed, they may be re-tightened by the surgeon to precisely calibrate the tension upon the repair.

The clamps should then be carefully removed from the hilum, and the repair should be inspected for hemostasis. Should slight bleeding be encountered, a period of observation is warranted, as reperfusion of the kidney will lead to an increase in mass which may further apply tension to the repair and can thus tamponade the bleeding. Should bleeding persist, the clips can be further re-tightened or additional sutures may be placed.

Extraction and Closure

Once hemostasis has been verified, the specimen should be placed in a retrieval bag and the robot should be undocked. The specimen should then be extracted through a widened incision in order to prevent undue compression of the often delicate tumor. A drain may be left in place if deemed necessary.

The fascia of the extraction site should be repaired, though repair of the remaining sites is generally not necessary, as the risk of herniation is low [37]. The skin incisions should be closed after irrigation.

Postoperative Care and Management of Perioperative Complications

Appropriate analgesia should be provided. Serum chemistries and hematocrit should be monitored in the immediate postoperative period and on a daily basis. Mild ileus should be expected, though most patients will tolerate a diet by postoperative day 1. Ambulation may safely be commenced on postoperative day 0.

Immediate postoperative complications may include cardiac events, deep venous thrombosis, acute renal insufficiency or failure, unrecognized bowel injury, and renal hemorrhage. The latter may be self-limited and may respond to observation and possible transfusion of blood products. On rare occasions, significant bleeding may prompt further intervention, such as selective embolization or return to the operating theatre for completion nephrectomy. Patients who develop renal insufficiency may require nephrology evaluation and may very rarely require dialysis. Provided that ischemic time did not exceed 30 min, it is very likely that renal insufficiency will be self-limited [38].

Unrecognized bowel injuries often have an atypical presentation in the minimally-invasive setting. Unlike open procedures, patients may not develop the classic signs of leukocytosis, peritonitis, and ileus. Rather, they will often develop leukopenia, tenderness limited to the port site closest to the injury, and diarrhea [39]. If bowel injury is suspected, immediate evaluation with abdominal imaging and general surgery consultation is warranted.

Intermediate complications may include urine leak and development of an arteriovenous malformation. Urine leaks may have a delayed presentation and may be heralded by flank pain, excessive drainage from a port site, and fever. Abdominal imaging will confirm the diagnosis. Treatment requires the placement of a ureteral stent and percutaneous drainage of the urinoma; repair is rarely required [40]. Arteriovenous malformation or pseudoaneurysm is a rare complication which can occur at any time and often presents as painless gross hematuria. Arteriography confirms the diagnosis, and treatment often consists of selective embolization or, in rare instances, completion nephrectomy [41–43].

Long-Term Follow-Up

Long-term follow-up consists of periodic imaging and laboratory evaluation, including abdominal CT, chest X-ray, complete blood count, basic metabolic panel, and hepatic function panel. It is of note that if a bolster was used in reconstruction, the material may persist with a defect that appears to contain air. This may often be confused with an abscess unless the radiologist is provided a proper history.

Outcomes of Robot-Assisted Partial Nephrectomy

Initial published reports on robot-assisted partial nephrectomy demonstrated respectable operative parameters and excellent short-term outcomes. Operative times in these series ranged from 142 to 279 min, while warm ischemic times ranged from 20 to 32 min. In addition, rates of positive margins were quite low, with only seven positive margins reported in a total of 256 patients across all series, representing only 2.7% of all patients evaluated. At a period of up to 16 months, no patient in any of the initial series developed disease recurrence [1–3, 22, 29, 30, 44–46]. It is of note that these series represented the initial experience of the early adopters of the technique and were therefore likely confounded by the learning curve of the procedure. Furthermore, each study except for one was hindered by the relatively small number of patients in each experience, with typical study sizes ranging from 8 to 13 patients. Nevertheless, these results provided evidence of feasibility for the procedure.

However, initial comparative analyses pitting robot-assisted partial nephrectomy against laparoscopic partial nephrectomy raised some understandable concern that the additional expense of robot assistance did not justify its inclusion in the renal surgeon’s armamentarium. For instance, in the first published comparative analysis between robot-assisted partial nephrectomy and laparoscopic partial nephrectomy, Caruso et al. found that the robot assistance did not confer any specific advantage over a laparoscopic approach, including critical parameters such as overall operative time and warm ischemic time [3]. However, it is of note that the authors focused solely on patients with exophytic tumors, which are arguably relatively simple to address, regardless of approach. A larger and more recent comparative analysis, however, has found that the benefits of a robot-assisted approach become more apparent as tumor complexity increases [34]. Indeed, robot-assisted partial nephrectomy has been finding increased application in addressing complex central and hilar tumors that might otherwise recommend an open approach [45, 46].

More recent reports, however, have begun to demonstrate substantial improvements in operative parameters, with overall operative times ranging from 83 to 174 min. Perhaps more critical is the profound reduction in warm ischemic times, which range from 18 to 22 min in the most recent analyses [23, 28, 34, 47].

Likewise, contemporary comparative studies have begun to demonstrate a clear advantage of robot-assisted partial nephrectomy over a standard laparoscopic approach. In the largest single-surgeon series to date, Wang and Bhayani found that robot-assisted partial nephrectomy provides significantly shorter overall operative times as well as warm ischemic times, when compared with laparoscopic partial nephrectomy [47]. These results are further corroborated in a large multi-institutional series from Benway and colleagues [34], who found that warm ischemic times were nearly 9 min shorter in the robot-assisted arm (19.7 vs 28.4 min for the laparoscopic approach, $p<0.0001$). A summary of the outcomes of contemporary comparative series is outlined in Table 39.1.

Learning Curve and Technical Refinements

The above-mentioned improvements in operative parameters for robot-assisted partial nephrectomy appear to be multifactorial, likely owing to refinements in technique, coupled with larger study sizes with a greater number of cases performed after the learning curve for the procedure has been surpassed.

As with any procedure, robot-assisted partial nephrectomy presents unique technical challenges during a surgeon's initial experience. As such, the procedure does carry with it a learning curve. A recent analysis evaluating 50 patients who underwent robot-assisted partial nephrectomy by a single surgeon, however, found that the learning curve for the procedure is quite modest. Evaluating by overall operative time, the learning curve could be surpassed in only 19 procedures. However, examining those portions which are performed under warm ischemia, including tumor excision and renal reconstruction, the learning curve is somewhat more substantial, requiring 26 cases to develop proficiency [23].

These figures compare favorably, however, to laparoscopic partial nephrectomy, using the same parameters for evaluation. In a 2005 report from Link and colleagues, the authors found that while overall operative time did appear to decrease with surgeon experience, the learning curve for those portions of the procedure performed under the conditions of warm ischemia could not be identified, even after 200 procedures [48]. As will be discussed later, this striking contrast suggests that most surgeons will be able to develop proficiency with a robot-assisted approach within a relatively short period.

Another important factor in evaluating contemporary literature is an important refinement in technique, which greatly improves the efficiency of renal reconstruction. Sliding-clip renorrhaphy obviates the need for intracorporeal knot tying, which, though comparatively simple to perform using robot assistance, is nevertheless challenging and time consuming. The use of sliding clips allows the surgeon to quickly and efficiently close the renal defect, while exercising unprecedented control over the tension of the repair. A recent analysis evaluating the impact of this refinement found that adoption of a sliding-clip technique can provide reductions in warm ischemic times of up to 8 min [23].

The Case for Robot-Assisted Partial Nephrectomy

As discussed earlier, there has been a striking shift in the diagnosis of renal malignancy toward smaller masses amenable to nephron-sparing

Table 39.1 Overview of contemporary series comparing RAPN to LPN

	Caruso et al. (2006) [3]		Aron et al. (2008) [2]		Deane et al. (2008) [22]		Wang and Bhayanl (2009) [47]		Benway et al. (2009) [23]		Jeong et al. (2009) [49]		Kural et al. (2009) [50]	
	LPN	RAPN	LPN	RAPN	LPN	RAPN	LPN	RAPN	LPN	RAPN	LPN	RAPN	LPN	RAPN
N	10	10	12	12	11	11	62	40	118	129	26	31	20	11
Tumor size	2.2	2	2.9	2.4	2.3	3.1	2.4	2.5	2.6	2.9	2.4	3.4	3.1	3.2
OR time	253	279	256	242	290	229	156	140 ($p=0.04$)	174	189	139	169 ($p=0.03$)	226	185
WIT	29	26	22	23	35	32	25	19 ($p=0.03$)	28	19 ($p<0.0001$)	17.2	20.9	35.8	27.3 ($p=0.02$)
EBL	200	240	300	329	198	115	173	136	196	155 ($p=0.03$)	208	198	388	286
Complications	1	1	1	1	1	1	9	8	8.60%	10.20%	1	1	1	1
Conversions	1	2	0	2	1	0	3	1	4.50%	1.60%	0	1	3	0
PSM	1	0	0	0	0	0	1	1	3.90%	1%	NR	NR	5%	0%
Recurrence	NR	NR	NR	NR	NR	NR	0	0	0	0	2	2	0	0

WIT, warm ischemic time; EBL, estimated blood loss; PSM, positive surgical margin; NR, not reported surgery. Yet, despite its emergence as a standard of care, partial nephrectomy has struggled to make inroads in the urologic community at large in the laparoscopic era. Certainly, a major barrier to entry for most surgeons has been the formidable and likely forbidding learning curve of laparoscopic partial nephrectomy.

Robot-assisted partial nephrectomy stands to reduce and perhaps eliminate this barrier of entry, providing enhanced visualization and improved dexterity of the surgical instrumentation, compared to a traditional laparoscopic approach. Indeed, Deane and colleagues conclusively demonstrated that after just ten robot-assisted procedures, a laparoscopically naïve surgeon was able to perform robot-assisted partial nephrectomy with a level of competency equivalent to laparoscopic partial nephrectomy performed by experienced laparoscopic renal surgeons [22]. Certainly, these data, coupled with that of Benway et al., suggest that robot-assisted partial nephrectomy is a procedure which is rapidly learned, allowing for a relatively short learning curve to achieve technical competence [23]. This, in turn, indicates that the introduction of robotic technology may stand to level the playing field, allowing most urologists to offer their patients the current standard of surgical care.

Furthermore, the drastic reductions in overall operative times, and perhaps more critically, reductions in warm ischemic times with a robot-assisted approach could theoretically lead to improved long-term functional outcomes, though this particular facet of outcomes has yet to be explored in the robotic literature.

However, there are a few criticisms of the robot-assisted approach which warrant discussion. First, the adoption of robotic technology requires a substantial capital expense, which may render its adoption less attractive to lower volume centers. While comparative cost analysis is presently lacking in the literature, one must consider the potential for cost reductions, in terms of shorter overall operative times and shorter hospital stay [23, 47], as well as the potential for improved functional outcomes, which may reduce the overall cost burden upon the healthcare system.

Also, many authors have raised concerns over the reliance upon the bedside assistant for critical maneuvers, including those employed to establish and protect the means of hilar control [3, 31]. Some authors have described techniques which may reduce the dependence upon the bedside assistant, including the use of the fourth arm for retraction, and even for hilar clamping [31, 32]. However, it should be noted that in our institutional experience, we have not noted any untoward outcomes which could be attributed to the inexperience of the bedside assistant, and therefore, the veracity of these concerns has yet to be rigorously validated [34].

Conclusions

Robot-assisted partial nephrectomy is a safe and efficacious procedure for patients diagnosed with localized renal masses. The relatively slight learning curve, coupled with the potential for drastic improvements in critical operative parameters, indicates that robot-assisted partial nephrectomy may represent the future standard of care for the surgical management of small renal masses.

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