Current Status of Robot-Assisted Laparoscopic Partial Nephrectomy

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Abstract With increased incidence of diagnosis of small renal masses, partial nephrectomy has been preferred over radical nephrectomy as the surgical treatment of choice. The transition from open to laparoscopic partial nephrectomy had been challenging for many urologists. Robotic-assisted laparoscopic partial nephrectomy (RLPN) is increasingly used to facilitate this transition. In this review, we examine the recent technical advances and clinical outcomes in RLPN. Many series had successfully reported the feasibility of using the da Vinci Surgical (Intuitive Surgical Inc, Sunnyvale, CA) System in laparoscopic partial nephrectomy. Recent advances had focused on reducing risk of renal damage by shortening the warm ischaemia time. These techniques included unclamped excision, selective arterial clamping and improved renorrhaphy methods. Operative times and warm ischaemia times have also improved once the learning curve are overcome, which is less steep than conventional laparoscopy. With longer follow-up and more widespread experience, the outcome of RLPN could be favourable compared to conventional laparoscopy. Improving techniques had made this surgery a safe and efficacious treatment option for small renal masses.

Keywords Laparoscopy · Robotic surgery · Partial nephrectomy · Renal neoplasms

Introduction

With widespread imaging with computer tomography scans, small renal tumours are increasingly diagnosed [1–3]. In the

attempt to preserve renal function in patients with suspicious small renal masses, urologists had moved towards partial nephrectomy in their surgical management. It had also been established that the oncologic outcome of partial nephrectomy was comparable to radical nephrectomy [4–7]. The next step in partial nephrectomy was to transition from open to laparoscopic approach, with the attendant benefits of laparoscopic surgery, such as shorter convalescent time and hospital stay. However, many surgeons found conventional laparoscopic partial nephrectomy to be highly challenging because of intracorporeal excision and suturing while attempting to shorten ischemia time. The traditional laparoscopic approach was therefore not widely adopted. Over the last few years, robotic-assisted laparoscopic partial nephrectomy (RLPN) with 3-D vision and instruments with 6° of freedom has allowed the surgery to be more feasible while decreasing warm ischemia time. In this review, we discuss the techniques used in RLPN and examine the reported clinical outcomes.

Evolution of Robotics in Renal Surgery

Laparoscopic nephrectomy had revolutionised renal surgery since the early 1990s [8]. The benefits of laparoscopic renal surgery such as shorter hospital stay, less pain, faster return to normal activities, better cosmesis were well-recognised [9]. In particular, obese patients were found to benefit from laparoscopic procedures with lower risk of postoperative wound and pulmonary complications [10, 11]. With the successful introduction of the Da Vinci Surgical system (Intuitive Surgical Inc, Sunnyvale, California) in radical prostatectomy, urologists had been keen to apply this advanced form of laparoscopy to renal surgery. Interestingly, in our experience, we had found that robotic-assisted laparoscopy was not found to be superior over conventional laparoscopy in radical nephrectomy [12]. As a result, most

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centers would still perform simple or radical nephrectomy through conventional laparoscopic means.

Partial nephrectomy, on the other hand, is well-suited for robotic assistance because of the requirement for instrument dexterity during the excision of the tumour and reconstruction of the collecting system and renal cortex. With conventional laparoscopic techniques, these tasks are difficult to achieve with the constraints of warm ischemia and limited degrees of motion with conventional instruments. The Da Vinci system had therefore been applied in this technically challenging operation.

Operative Set-up

The robotic set-up had been previously described by several centers [13–15]. With the patient in the 45° modified flank position, the robot is positioned at the back of the patient with its arms straddling across the table over the patient. With the Da Vinci-S system, the fourth arm can be placed for additional retraction where required, such as during lateral retraction. The assistant performs several critical steps in this operation through additional one or two ports. These steps include application of hilar bulldog clamps and tumour localisation with laparoscopic ultrasound probe. Therefore, an experienced patient side assistant is essential. When compared to robotic-assisted laparoscopic prostatectomy, the biggest difference with RLPN is the wider surgical field. For this reason, care must be taken during port placements to avoid clashing between the robotic arms and the assistant instruments.

Techniques to Lessen Ischaemic Damage or Ischemia Time

Most of the recent advances made in RLPN were aimed at reducing the risk of nephron loss during warm ischemia. Intra-arterial hypothermic perfusion was used in some early series of conventional laparoscopic partial nephrectomy [16, 17]. In this method, renal artery occlusion was performed using the intra-arterial catheter balloon with simultaneous iced saline infusion. Gettman et al. applied this technique to RLPN in 8 out of 13 patients of his initial reported series [15]. Later series mostly did away with renal arterial cooling and proceeded only with renal artery clamping [18].

In an attempt to shorten warm ischaemia time, early unclamping technique has been developed after placement of the first layer of medullary sutures. This technique, initially developed during the era of laparoscopic partial nephrectomy, resulting in halving of warm ischaemia time [19], has been used in RLPN, with median warm ischaemia time of 16 min in one report [20].

White et al. had reported no vascular clamping in eight patients with non-endophytic tumours less than 4 cm [21]. When compared to a contemporary group of RLPN patients with arterial clamping, operative time was significantly shorter while mean estimated blood loss was higher in the unclamped group. Operative outcomes and adverse events, including the need for a blood transfusion, were comparable in both groups.

Selective renal parenchymal clamping is another technique described to avoid arterial clamping. A special laparoscopic Simon clamp (Aesculap AG, Tuttlingen, Germany) is placed across the renal parenchyma immediately proximal to an exophytically-located tumour [22]. This was analogous to manual renal compression in open renal surgery to arrest bleeding during parenchymal breach. Developed for conventional laparoscopic partial nephrectomy, this technique has since been translated to the da Vinci platform, albeit in a small series [23].

Selective arterial clamping is a recent technique that had undergone evaluation in porcine models [24]. In this technique, only the segmental artery supplying the tumour was clamped. Results showed no significant rise in serum creatinine over a 7-day period. This promising technique would allow tumour excision and renorrhaphy to proceed without the constraint of main arterial clamping. Gill et al. had used and reported this technique in 15 patients [25]. Using combination of microdissection with selective ligation of branch renal artery/vein and hypotensive anaesthesia during deep tumour excision, bleeding was minimised with zero ischaemia. This series had recently been updated to 49 patients, with median resection time of 19 min (range 5 to 40 min) and estimated blood loss 150 mls (range 20–1500 mls). There were three high grade non-urologic complications and transfusions were required in 12 patients post-operatively [26].

To shorten the time taken for renorrhaphy and overall ischemia time, the sliding-clip technique for renorrhaphy had been described [27, 28]. Using Weck (Teleflex, Research Triangle Park, NC) Hem-o-lok clips placed at both ends of the suture, the console surgeon slid the clips to tighten the tension of the renorrhaphy to achieve a secure, haemostatic apposition of the cortical defect. This avoided knot-tying and could shorten hilar clamping time by up to 7 min [29].

Another technique to shorten renorrhaphy time is the use of barbed sutures. Barbed sutures, which were widely in plastic and gynaecologic surgery, have unidirectional etching to resist slippage through tissues and reduces the need for constant traction. After successful feasibility studies in porcine models [30]. The first clinical study was performed on 15 patients using the V-Loc 180 absorbable wound closure device (Covidien, Mansfield, MA) [31]. By comparing with preceding 15 patients using

conventional braided polyglactin suture (Vicryl, Ethicon, Johnson & Johnson, Somerville, NJ), the authors had shown significant shorter warm ischaemia time in the V-Loc group (18.5 vs 24.7 min). With the Vicryl group, additional clips had to be applied regularly during renorrhaphy to prevent slipping. This was not required in the V-Loc group.

Technique of Tumour Excision and Renorrhaphy at the Indiana University

At Indiana University, we apply laparoscopic bulldog clamps to the artery and the vein separately prior to excision of the tumour. Exposure of the hilar vessels is aided by using two short 5-inch vessel loops to encircle the artery and vein. These vessel loops are clipped with a polymer clip. Traction on these loops can then facilitate the placement of the bulldog clamps. In cases of difficult hilar dissection, we would use a laparoscopic Satinsky clamp applied by the assistant to mass-clamp the hilum. One must be careful to avoid external collisions in this case. After identifying the location of the tumour with laparoscopic ultrasound, the renal capsule around the tumour is scored to provide a line by which excision of the tumour can follow. Excision of the tumour is performed with curved scissors initially directed away from the tumour. Retraction is provided by the fenestrated bipolar forceps or PK dissector on the left arm and the assistant's suction-irrigator. A biopsy of the resection bed is taken and sent for frozen section analysis. Initial haemostasis is obtained using argon-beam coagulator directed towards the cortex, avoiding the more central area to avoid thermal damage to the collecting system.

To repair the defect, we prefer a two-layer closure. The deeper layer consisting of the collecting system, blood vessels and deep cortex is closed with a 2/0 polyglactin or barbed absorbable suture attached at the end with a 10 mm polymer clip and a Lapra-Ty clip (Ethicon Endosurgery, Cincinnati, Ohio). Deep bites within this layer are avoided as this could injure deeper blood vessels, contributing to formation of pseudoaneurysms and arteriovenous fistulas. After running the entire resection bed, the suture is passed out through the cortex and anchored with a 10 mm polymer clip. It is important to ensure that the non-absorbable clips are on the renal cortical surface and not adjacent to the collecting system, to prevent migration into the collecting system. For the outer cortical layer repair, we prefer using a single-arm polydioxanone 0 barbed suture in a horizontal mattress configuration. After each pass through the cortex, the closure is reinforced with a polymer clip and slid down to the desired tension. The clamps are removed after completion of the outer layer closure. The ends of both

inner and outer layer sutures are reinforced with Lapra-Ty clips. A gelatin-thrombin mixture is added to the closure.

Clinical Outcomes

The first reported series of RLPN consisted of small number of patients and the results merely showed feasibility of the operation [13, 15]. Despite the perceived advantages of wristed instruments, there was no demonstrable benefit over conventional laparoscopic partial nephrectomy [18].

In more recent multi-center series, the clinical outcomes are more promising. The largest published comparative series between 118 conventional laparoscopic partial nephrectomy and 129 RLPN cases had shown no difference in operative times [32]. Intra-operative blood loss was less in the RPLN group (155 mls vs 196 mls), as was length of hospital stay (2.4 vs 2.7 days), though this was not clinically significant. Warm ischemic times were also shorter in the RPLN group (19.7 vs 28.4 min). Postoperative complications were similar in both groups, as was the positive margin rate. In another published large comparative series from a single center, RLPN again showed shorter operative time (140 vs 156 min) and shorter warm ischemia time (19 vs 25 min) with no difference in estimated blood loss and positive margin rate [33].

In the largest single-arm series of RLPN published to date with 189 patients, the mean operative time was 210 min while mean ischemic time was 23.9 min. The positive margin rate was found in 3.8% of pathological specimens, of which none exhibited disease recurrence on follow-up [34].

At the AUA 2011 Annual Meeting, a collection of 1035 cases of RLPN was presented from 23 institutions. Warm ischaemia time was 24.7 min (range 6 to 77 min), estimated blood loss was 216 ml (range 5 to 2,800 mls) and 96% exhibited negative pathological surgical margins [35]. This series had shown that RLPN could consistently be performed safely across various institutions.

The data from these series are summarized in Table 1.

Conclusion

Randomised studies between conventional laparoscopic partial nephrectomy and RLPN will be difficult to conduct and may never materialise. In its absence, existing comparative studies had shown great promise with RLPN in terms of clinical and early oncologic outcomes. With more centers performing RLPN and longer term follow-up, RLPN would continue to mature in its role in the management of renal tumors.

Table 1 Recent series of robotic partial nephrectomy

Authors	No. of RLPN	No. of LPN	Single/multi-center	Size (cm)	OR time (min)	WIT (min)	EBL (cc)	No. of intraoperative complications	Postoperative Complication (major)	No. of positive margin
Gettman et al. [15]	13	–	Single	3.5	215	22 (clamp) 33 (cold saline)	170	0	1: ileus	1
Phillips et al. [13]	12	–	Single	1.8	265	26	240	1: bleed, to hand-assist 1: clamp dislodged, to open 1: robot malfunction, to LPN	1: urine leak	NA
Caruso et al. [18]	10	10	Single	1.95	279	26.4	240	1: bleed, to HA 1: bleed, to open	0	0
Wang et al. [33]	40	62	Single	2.5	140	19	136	1: indistinct US margin, to open 1: adhesion, to cryoablation	1: urine leak	1
Benway et al. [32]	129	118	Multi	2.9	189	19.7	155	1: adhesion, to open 1: indistinct US margin, to open	2: transfusions 3 urine leak 2 AVM	5
Benway et al. [34]	183	–	Multi	2.87	210	23.9	131.5	2: no progress, to open	1 pulmonary embolus 1 MI 1 rectus hematoma 1 transfusion 1 subcapsular hematoma requiring completion nephrectomy 3 pseudoaneurysms 2 bleed requiring transfusions 2 chylous leaks 2 urine leaks 1 hepatic laceration 1 splenic laceration 1 renal hematoma 2 stroke 1 myocardial infarct	7
Munver et al. [35]	1035	–	Multi	2.9	198	24.7	216	56	118	4%
Sundaram et al. [unpublished data]	60	–	Single	2.9	200	25.0	100	1: to open 2: to radical nephrectomy	0	1

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