Is robotic technology facilitating the minimally invasive approach to partial nephrectomy?

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OBJECTIVES

- Partial nephrectomy has become the standard therapy for the management of small renal masses. In an effort to overcome the perioperative morbidity associated with an open approach, and the extended warm ischaemia times associated with a laparoscopic approach, robotic platforms have been introduced. To establish its current status this study reviews the literature, and reports developments in robotic-assisted partial nephrectomy (RPN), highlighting results from various studies that investigate the oncological and functional efficacy of RPN.

PATIENTS AND METHODS

- A search of Medline, EMBASE and Cochrane library databases was completed in July 2010 and used to identify pertinent original articles, editorials, comments and reviews, using the search term ‘partial nephrectomy’. Links to related references were surveyed, and all articles finally included were based on relevance and importance of content, as determined by the authors.

RESULTS

- The robotic platform may offer the solution to bridge the gap between open and laparoscopic approaches, achieving warm ischaemia times that consistently average 20 minutes, and providing similar oncological and functional results via a shorter learning curve. It offers cosmesis and convalescence equivalent to that from laparoscopic partial nephrectomy, but with potentially fewer postoperative complications.

CONCLUSIONS

- In terms of oncological and functional outcomes, the early experiences of RPN in selected series of patients appear at least equivalent to open and laparoscopic partial nephrectomy series. Randomized comparisons between the approaches are lacking, as are longer-term follow-up data for the robotic technique and formal cost analysis; these will be necessary before RPN can replace open partial nephrectomy as the new standard for the management of small renal masses. Trends continue to emerge that highlight the advantage of using the robotic platform to achieve a minimally invasive approach for partial nephrectomy, and with time and increasing expertise, this may become further apparent.

KEYWORDS

robotic partial nephrectomy, partial nephrectomy, nephron sparing surgery, laparoscopic partial nephrectomy, small renal masses, robotic surgery

INTRODUCTION

Renal cancer is the third most common urological malignancy, with a rising incidence that is at least partially the result of its increased detection via imaging modalities [1]. Although many of these ‘incidentalomas’ have uncertain prognostic significance, some will progress to metastatic disease if left unmanaged so surgical excision remains the standard technique for management of localized renal tumours. This has traditionally been performed by radical nephrectomy; the lack of renal reconstruction provides surgical...
expediency, and complete kidney removal ensures maximal oncological efficacy, irrespective of the pathological stage. However, recent work has highlighted greater cardiovascular morbidity and mortality associated with lower renal function [GFR] [2], calling into question the need for radical surgical treatments that inevitably decrease renal reserve [3]. In the management of T1a disease (masses <4 cm), radical nephrectomy has been shown to be an independent risk factor for the development of chronic kidney disease [4]; hence, the logical conclusion has been to strive for oncological control while preserving renal function, i.e. nephron sparing surgery or partial nephrectomy.

OPEN PARTIAL NEPHRECTOMY

Initially used as the last resort for renal cancer patients with solitary kidneys, a wealth of literature now supports its use even in patients with normal renal function. Absolute indications include a solitary kidney, pre-existing chronic kidney disease, multiple or bilateral tumours, and those with a genetic predisposition for developing multiple tumours. The latest AUA and EAU guidelines for the management of stage 1 renal masses define partial nephrectomy as a standard of care that should also be strongly considered in elective patients (i.e. those with a healthy contralateral kidney) who have T1 disease (masses <7 cm) [5,6].

However, open partial nephrectomy (OPN) is not without its drawbacks. It often requires a muscle-cutting flank incision, sometimes with removal of a lower rib. This can lead to chronic morbidity, such as flank bulge, pain, paraesthesia and hernia formation [7–9]. In an effort to reduce the morbidity associated with OPN, laparoscopic partial nephrectomy (LPN) has evolved [10].

LAPAROSCOPIC PARTIAL NEPHRECTOMY

Central to any advancement in surgical technique for cancer must be the maintenance of oncological control. Lane and Gill [11] recently showed equivalent 5-year and 7-year cancer-specific survival rates in 2246 patients undergoing LPN and OPN for renal tumours ≤7 cm. A multicentre comparison study between 772 LPN and 1028 OPN procedures was able to conclude equivalent 3-month renal functional outcomes and 3-year cancer-specific survival in cT1 patients. Improvements in operative time (3.3 h vs 4.4 h), intraoperative blood loss (300 mL vs 376 mL) and the duration of hospitalization (3.3 days vs 5.8 days) were found for the laparoscopic approach [12]. This study did however highlight the disadvantages of LPN with regard to warm ischaemia time (WIT), which was significantly higher in patients treated with LPN compared with those treated with OPN (30.7 min vs 20.1 min) [12]. This can be explained by the intrinsic complexity of the laparoscopic procedure, especially with regards to completing tumour excision and renorrhaphy in a timely manner.

The WIT defines the period in which the renal vessels are clamped, either individually via laparoscopic bulldogs, or en bloc using a Satinsky clamp. Vessel clamping decreases blood loss and enables precise surgical incision and closure, ultimately providing better oncological control [13]. However, the high metabolic demands of renal tissue rapidly result in damaging effects following ischaemia, and subsequent reperfusion injury risks obviating any advantage of partial over radical nephrectomy.

Despite the significance of this critical time period, the safe maximum duration remains controversial. A large multi-institutional review of partial nephrectomy patients with a solitary kidney revealed associations between WIT >20 min and a higher incidence of acute and chronic renal failure [14]. Another study used renal scintigraphy to determine renal function and showed that WIT >30 min caused significant renal damage 1 year after LPN [15]. An international expert panel has reiterated that WIT remains the strongest modifiable surgical risk factor for postoperative chronic kidney disease stating that, regardless of the approach, tumours should be removed within the minimum possible duration of warm ischaemia, preferably less than 20 min [16]. Hence, WIT represents the Achilles heel of traditional LPN, and minimally invasive urologists have turned to robotic platforms in the hope of reducing it.

ROBOTIC PARTIAL NEPHRECTOMY

The extensive learning curve of LPN [17] in part, stems from the limitations of laparoscopic instruments, namely: counterintuitive movements; the fulcrum effect at their points of insertion; only four degrees of freedom; and the two-dimensional imaging systems. These difficulties are multiplied when operating on more complex tumours that are at less accessible angles, near vital hilar structures, or several in number. To address these challenges plus that of WIT, robotic partial nephrectomy (RPN) has been established (see Table 1).

In July 2010 a search of Medline, EMBASE and Cochrane library databases was completed and used to identify pertinent original articles, editorials, comments and reviews, using the search term ‘partial nephrectomy’. Links to related references were surveyed, and all articles finally included were based on relevance and importance of content, as determined by the authors. This review seeks to establish whether robotic technology facilitates the minimally invasive approach to partial nephrectomy.

The first report of RPN came in 2004, when Gettman et al. [18] described 11 transperitoneal partial nephrectomies using the da Vinci robot (Surgical System, Intuitive, CA). Patients with solitary enhancing predominantly exophytic lesions, averaging 3.5 cm, were selected for elective RPN. A 45° modified flank position was used for the transperitoneal RPN, with a 12-mm robotic endoscope placed in a mid-clavicular infra-umbilical position, and two 8-mm trocars for the medial and lateral robotic instruments. The medial camera position offered a global perspective of the surgical field, simulating the view of conventional laparoscopy (see Fig. 1, top panel). The assistant used conventional laparoscopic instruments passed through a 12-mm umbilical trocar. Hilar clamping was achieved by clamping the renal artery and vein using laparoscopic bulldogs (n = 5) or expansion of an intra-arterial catheter used for renal cooling (n = 8). During renorrhaphy, collecting system entry was confirmed and sutured in two cases, before closing the renal defect using a standard technique of 2-0 polyglactin and bolsters. The mean operating time was 215 min, estimated blood loss was 170 mL, and WIT was 22 min. There were no intraoperative complications, and one postoperative complication of ileus. There was one positive
### TABLE 1 Overview of robotic partial nephrectomy studies to date

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of patients</th>
<th>Tumour size (cm)</th>
<th>OR time (min)</th>
<th>WIT (min)</th>
<th>EBL (mL)</th>
<th>LOS (days)</th>
<th>PSM/recurrence</th>
<th>Mean follow-up (months)</th>
<th>Complications/conversions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mottrie 2010</td>
<td>62</td>
<td>2.8 (1–7)</td>
<td>91</td>
<td>20 (9–40)</td>
<td>140</td>
<td>5</td>
<td>1/-</td>
<td>NR</td>
<td>3 vein repairs, 5 haematomas, 2 haematomas/embolizations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 MI, 1 PE, 3 leaks, 2 haematomas, 1 anemia, 2 AVM, 1 C. diff, 2 OPN</td>
</tr>
<tr>
<td>Benway 2009</td>
<td>129</td>
<td>2.9</td>
<td>189</td>
<td>19.7</td>
<td>155</td>
<td>2.4</td>
<td>5/0</td>
<td>≤12</td>
<td>1 MI, 1 DVT, 1 hypertensive crisis, 1 haematoma, 1 anemia, 1 OPN, 1 Cryo</td>
</tr>
<tr>
<td>Benway 2009</td>
<td>50</td>
<td>2.5</td>
<td>145.3</td>
<td>17.8</td>
<td>140.3</td>
<td>2.5</td>
<td>1/0</td>
<td>12</td>
<td>1 PE, 1 abscess, 1 OPN</td>
</tr>
<tr>
<td>Michli 2009</td>
<td>20</td>
<td>2.7 (0.5–2.7)</td>
<td>142 (65–315)</td>
<td>28.1 (19–40)</td>
<td>263 (20–1600)</td>
<td>2.8</td>
<td>0/NR</td>
<td>NR</td>
<td>1 PE, 1 abscess, 1 OPN</td>
</tr>
<tr>
<td>Kaouk 2009</td>
<td>2</td>
<td>2.0</td>
<td>170 (113–227)</td>
<td>NR</td>
<td>100</td>
<td>3.5 (2.8–4.2)</td>
<td>17/NR</td>
<td>NR</td>
<td>None</td>
</tr>
<tr>
<td>Lee 2009</td>
<td>9</td>
<td>NR</td>
<td>275 (170–417)</td>
<td>NR</td>
<td>49 (5–150)</td>
<td>2.9 (1.9–4.8)</td>
<td>NR/NR</td>
<td>6 (0.2–25)</td>
<td>1 urinoma, 1 port-site infection</td>
</tr>
<tr>
<td>Wang 2009</td>
<td>40</td>
<td>2.5 (1.0–5.0)</td>
<td>141 (87–219)</td>
<td>20 (13–40)</td>
<td>137 (25–500)</td>
<td>2.5 (1–4)</td>
<td>1/NR</td>
<td>NR</td>
<td>1 leak/stent, 3 cardiopulmonary, 1 PE, 1 haematoma, 1 transfusion</td>
</tr>
<tr>
<td>Kural 2009</td>
<td>11</td>
<td>3.2</td>
<td>185</td>
<td>27.3</td>
<td>286</td>
<td>3.9</td>
<td>0/0</td>
<td>7.5 (3–14)</td>
<td>1 pseudoaneurysm</td>
</tr>
<tr>
<td>Jeong 2009</td>
<td>31</td>
<td>3.4</td>
<td>169.9</td>
<td>20.9</td>
<td>198.3</td>
<td>5.2</td>
<td>0/1</td>
<td>12</td>
<td>1 transfusion</td>
</tr>
<tr>
<td>Ho 2008</td>
<td>20</td>
<td>3.5 (2–5.5)</td>
<td>82.8 (75–95)</td>
<td>21.7 (15–27)</td>
<td>189 (50–260)</td>
<td>4.8 (4–7)</td>
<td>0/0</td>
<td>&gt;12</td>
<td>None</td>
</tr>
<tr>
<td>Ho 2008</td>
<td>25</td>
<td>3.1 (1.5–4.5)</td>
<td>82.6 (75–90)</td>
<td>22 (17–27)</td>
<td>122.6 (60–230)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>None</td>
</tr>
<tr>
<td>Deane 2008</td>
<td>10 (11)</td>
<td>3.1</td>
<td>229 (98–375)</td>
<td>32.1 (30–45)</td>
<td>115 (25–300)</td>
<td>2.0</td>
<td>0/0</td>
<td>16 (4–37)</td>
<td>1 HALPN re-exploration for bleeding</td>
</tr>
<tr>
<td>Aron 2008</td>
<td>12</td>
<td>2.4</td>
<td>242</td>
<td>23.0</td>
<td>329</td>
<td>4.7</td>
<td>0/0</td>
<td>7.4</td>
<td>2 LPN</td>
</tr>
<tr>
<td>Rogers 2008</td>
<td>8 (14)</td>
<td>3.6 (0.8–6.4)</td>
<td>192 (165–214)</td>
<td>31 (24–45)</td>
<td>230 (100–450)</td>
<td>2.6 (2–3)</td>
<td>0/0</td>
<td>3</td>
<td>None</td>
</tr>
<tr>
<td>Rogers 2008</td>
<td>11</td>
<td>3.8 (2.3–6.4)</td>
<td>202 (152–253)</td>
<td>28.9 (20–39)</td>
<td>220 (50–750)</td>
<td>2.6 (1–4)</td>
<td>0/NR</td>
<td>NR</td>
<td>2 urinary leaks</td>
</tr>
<tr>
<td>Rogers 2008</td>
<td>148</td>
<td>2.8</td>
<td>197</td>
<td>27.8</td>
<td>183</td>
<td>1.9</td>
<td>6/0</td>
<td>7.2 (2–54)</td>
<td>2 OPN conversions, 3 ileus, 2 PE, 2 leaks, 1 bleeding, 1 rhabdomyolysis</td>
</tr>
<tr>
<td>Kaul 2007</td>
<td>10</td>
<td>2.3 (1.0–3.5)</td>
<td>155 (120–185)</td>
<td>21 (18–27)</td>
<td>92 (50–150)</td>
<td>1.5</td>
<td>17/0/0</td>
<td>15 (6–28)</td>
<td>1 bleeding, 1 leak</td>
</tr>
<tr>
<td>Caruso 2006</td>
<td>10</td>
<td>1.95</td>
<td>279</td>
<td>26.4</td>
<td>240</td>
<td>2.6</td>
<td>0/NR</td>
<td>NR</td>
<td>1 HALPN, 1 OPN</td>
</tr>
<tr>
<td>Philips 2005</td>
<td>12</td>
<td>1.8</td>
<td>265</td>
<td>26</td>
<td>240</td>
<td>2.7</td>
<td>NR/NR</td>
<td>NR</td>
<td>1 LPN, 1 HALPN, 1 OPN</td>
</tr>
<tr>
<td>Gettman 2004</td>
<td>13</td>
<td>3.5 (2.0–6.0)</td>
<td>215 (130–262)</td>
<td>22 (15–29)</td>
<td>170 (50–300)</td>
<td>4.3 (2–7)</td>
<td>1/0</td>
<td>[2–11]</td>
<td>1 ileus</td>
</tr>
</tbody>
</table>

*Figures in parentheses denote the range of each variable, where reported. AVM, arteriovenous malformation; C. diff, Clostridium difficile; Cryo, cryotherapy; EBL, estimated blood loss; DVT, deep vein thrombosis; HALPN, hand-assisted laparoscopic partial nephrectomy; LOS, length of stay; LPN, laparoscopic partial nephrectomy; MI, myocardial infarction; NR, not reported; OPN, open partial nephrectomy; OR, operating room; PE, pulmonary embolism; PSM, positive surgical margins; WIT, warm ischaemia time.*
margin reported and the patient underwent radical nephrectomy. All 13 patients were tumour-free after 2–11 months follow-up. Even in these initial cases, the authors found that RPN offered reduced difficulty of tumour excision and intracorporeal suturing for renal reconstruction, benefiting from three-dimensional stereoscopic magnification and intuitive movements of the robotic EndoWrist instruments (Intuitive Surgical, Sunnyvale, CA).

Kaul et al. [19] began their experiences with the standard da Vinci surgical system, exploiting the lateral placement of a 12-mm 30° ‘upward’ scope camera port, with similar results in operating time, WIT and blood loss, 155 min, 92 mL and 21 min, respectively, and no tumour recurrences after a mean follow-up of 15 months. The authors benefitted from ‘excellent visualisation of the hilar anatomy’, as well as obviating the need for any colon retraction by the assistant. They described a less restricted range of motion of the robotic arms as a result of the lateral camera port placement which greatly facilitated dissection of the upper and lower poles of the kidney, as well as adjacent organs such as the liver/duodenum and spleen (see Fig. 1, bottom panel).

Stifelman and colleagues reported 12 transperitoneal partial nephrectomies using a hybrid robotic-assisted laparoscopic technique [20]. In this series, a standard laparoscopic approach was used to expose the kidney, before docking the robot to complete hilar dissection, tumour excision and renorrhaphy. There were three conversions: brisk bleeding required conversion to hand-assisted laparoscopy, dislodged vascular clamps necessitated conversion to an open approach, and a robot malfunction required completion using standard laparoscopy. The ergonomic benefits of the robotic platform were once again highlighted, but the importance of experienced assistance and a readily available scrubbed surgeon to handle urgent open conversion were emphasized.

Rogers et al. [21] performed the first multi-institutional review which described reproducible outcomes with 148 RPNs performed by nine different primary surgeons at six different centres (mean tumour size 2.8 cm, mean operative time 197 min, mean WIT 27.8 min). There were six positive margins and no evidence of tumour recurrence after a mean follow-up of 7.2 months. The authors highlighted their immediate oncological and perioperative success despite the cases representing each surgeon’s first experience of RPN.

Although a favourable opinion regarding the use of the robot continued to be reported from these series, a consensus emerged of the absolute necessity for patient-side assistants with high levels of experience, who must be able to provide: suction; exposure; countertraction; cautery; suture delivery and change robotic instrumentation. Perhaps more than any other surgical technique, such an investment in the robotic team proves essential to make this approach successful.

MODIFYING TECHNIQUE TO REDUCE WARM ISCHAEMIA TIME

While satisfactory reports of WIT had been described for early RPN case series (see Table 1), the surgical indications for this technology had at first largely been restricted to individual, small and superficial renal masses. Hence, efforts were made to modify the robotic technique and reduce WIT to safely extend the surgical indications for RPN to include multiple, larger and more complex renal masses.

In an effort to complete haemostatic sutures in a time-sensitive manner, sliding-clip techniques have been developed [22,23]. The use of Hem-O-Lok clips (Teleflex, Durham, NC) has now become a common alternative to traditional intracorporeal tied-suture renorrhaphy, which can be slid in place under complete control of the console surgeon. The clips can be secured using an absorbable Lapra-Ty clip (Ethicon EndoSurgery, Piscataway, NJ) [23]. The technique has been reported to allow more precise control and readjustment of the tension placed during renorrhaphy, thereby minimizing the risk of inadvertent tearing while reducing mean WIT from 28 min to 21 min [23,24]. The popularity of this
technique has led to its adoption by multiple groups, with similar success [25]. Some groups have further modified the sliding clip technique by employing a second Hem-O-Lok clip after the first, instead of the Lapra-Ty, claiming that faster securement of the suture can be completed after hilar unclamping so further reducing ischaemia time [26].

Other attempts to reduce WIT have seen surgeons omitting surgical bolsters during renorrhaphy [27,28]. While the bolsters may provide additional security, some have postulated that they are not instrumental for haemostatic closure [29]. In a series of 20 cases which used this modified technique to perform RPN on a mean tumour size of 3.0 cm, WIT and blood loss were found to be 21.7 min and 189 mL, respectively. No intraoperative complications, conversions, postoperative bleeding or urinary leakages were reported, and local recurrence was negative at 1-year follow-up for all 20 patients [28].

Alternative techniques of providing a bloodless field while minimizing WIT have been evaluated. Herrell and colleagues have recently described the placement of a laparoscopic Simon clamp across the renal parenchyma, 2–3 cm proximal to the resection line, to facilitate tumour excision [30]. This is based on animal studies that suggest the superiority of selective parenchymal or partial renal artery clamping when compared with complete renal artery clamping [31]. This has been shown with minimal blood loss and no per operative complications in three patients with predominantly exophytic tumours (averaging 4.9 cm) [30]. Nguyen and Gill have also reported an ‘early unclamping’ technique, which has been used for both LPN and RPN [32,33]. This involves unclamping the hilum after tumour excision and placing the first layer of sutures in the excised bed; any residual bleeding points are sutured under direct vision to secure complete haemostasis, before continuing with pelvi-calceal repair and bolstered renorrhaphy in the perfused kidney. While this has served to halve WIT in the laparoscopic approach, it is also associated with a higher risk of blood transfusion (15% vs 8.7%, P = 0.043) [34,35]. ‘Early unclamping’ with RPN has also been shown to have a longer WIT when compared with its use in laparoscopic partial nephrectomy (21 min vs 14 min, P = 0.05). White et al. [36] have started investigating clampless techniques. Eight RPNs for small exophytic renal masses (mean 2.4 cm) were performed without occluding the renal hilum; through the judicious use of suction/irrigator, monopolar cautery and suture ligation, the authors were able to identify active bleeding and maintain a clear operative field. When compared with a contemporary matched group of patients with tumours who had RPN with hilar occlusion, the number of parenchymal/capsular sutures, adverse events and length of stay were similar and operative time was significantly shorter in the clampless cohort. Mean blood loss was higher in the clampless group, although probably because of a single outlier patient who lost 2000 mL intraoperatively.

A variation on the clampless technique is the use of radiofrequency ablation (RFA) to obtain a bloodless margin via coagulative necrosis; a Habib 4X RFA device (AngioDynamics, Queensbury, NY) is used with ultrasound-guidance to create a coagulation plane for clampless tumour resection [37]. In a comparison study between 36 LPN and 42 RFA-assisted clampless RPNs, blood loss, transfusion and complication rates were found to be similar, although collecting system reconstruction was more frequent and operating times were longer in the RFA group [38]. No positive margins were reported in this series. Although potential concerns include the feasibility of performing renorrhaphy (if necessary) on friable, cauterized, tissue; dependence on the assistant performing the rim ablation with the non-articulating instrument; and visibility of the tumour edge limited by the tissue changes after ablation.

Surgeons are also evaluating the benefits of topical haemostatic agents to aid in the rapid completion of the surgical steps performed during warm ischaemia; FloSeal™ (Baxter Inc, Deerfield, IL), a bovine gelatin matrix with human thrombin, and TachoSil™ (Nycomed Pharma, Asker, Norway), an absorbable equine collagen patch combining human fibrinogen and thrombin, have been used to control residual haemorrhage in the treatment of small superficial renal tumours [39,40]. Recently, Tachosil™ has also been shown to provide a simple and effective seal of the renal collecting system in a porcine chronic survival model [41]; this may facilitate the removal of larger renal tumours that penetrate the renal calyces, and offer a haemostatic agent that is more convenient to use than those which require either mixing alone (e.g. FloSea™ or both warming and mixing (e.g. Tisseseal™; Baxter Inc, Deerfield, IL) [42].

EXPANDING INDICATIONS

With increasing experience, groups performing RPN began to expand their patient selection criteria. Indeed, some groups have hypothesized that the advantages of RPN may become more evident with the treatment of more complex cases [43]. The efficacy of RPN for hilar, endophytic and/or multiple renal tumours has been shown by Rogers et al. in 14 tumour resections (averaging 3.6 cm) from eight patients [44]. The mean operating time, blood loss and WIT were 192 min, 230 mL and 31 min respectively, and surgical margins were negative in every case. In another study this group went on to describe the successful clearance of 11 renal hilar tumours in a collaborative study with surgeons from the National Institute of Health (Bethesda, MD) [45]. Furthermore, Gill et al. [46] have compared five robotically assisted hilar resections with a series of 25 hilar tumours resected by LPN, finding a shorter WIT (31 min vs 36 min) despite having operated on larger tumours in the RPN cohort (4.1 cm vs 3.7 cm) [46].

More recently Patel et al. [47] have described a single-surgeon experience of RPN for tumours greater than 4 cm (mean 5.0 cm) [47]; when compared retrospectively with a RPN cohort of smaller tumours (mean 2.1 cm), despite a longer median WIT (25 min vs 20 min), blood loss, total operative time, hospital stay, complication rates and changes in postoperative eGFR were similar.

COMPARISON WITH STANDARD LAPAROSCOPIC TECHNIQUES

The first case-controlled study with LPN was described by Stifelman and colleagues [48]; 10 hybrid robotic-assisted partial nephrectomies were performed on tumours averaging 2.0 cm, and compared with 10 LPNs with a mean tumour size of 2.2 cm. Intraoperative and postoperative outcomes were statistically similar, and while safe and
feasible for small exophytic masses, the authors concluded that their clinical approach did not offer any clinical advantage over conventional laparoscopic nephrectomy. Nevertheless, a comparison study of 11 hybrid RPNs (mean tumour size 3.1 cm) and 12 LPNs (mean size 2.3 cm) produced a shorter learning curve for RPN; despite comparing the first cohort of RPNs performed by an experienced open surgeon (with limited laparoscopic reconstructive experience), to the most recent LPNs performed by two experienced laparoscopic surgeons (with a greater than 60 LPN case experience). The intraoperative and perioperative results were also equivalent [17].

Bhayani and colleagues [23] reported the RPN learning curve for an experienced minimally invasive surgeon; proficiency in terms of overall operative time was achieved by 19 cases, and by 26 cases for those portions performed under warm ischaemia. Mottie has also confirmed reaching mean WITs of <30 min and <20 min after 10 and 30 cases respectively [49].

In contrast, early experience with LPN has been associated with increased complications [50], and a steeper learning curve (continuing after >200 cases in portions of the case performed during warm ischaemia), even among experienced laparoscopic surgeons [51]. A retrospective comparison study of 62 LPNs and 40 RPNs (of mean tumour size 2.5 cm and 2.4 cm, respectively) was performed by a single experienced laparoscopic surgeon; WIT was found to be 19 min in the robotic cohort vs 25 min in the LPN cohort. Operative time and length of stay were also superior with the robotic technique, and one positive margin was found in each cohort [52]. A matched cohort single-surgeon series of 150 patients also showed excellent renal functional and oncological outcomes in RPN, with the only significant difference found in the lower intraoperative blood loss of the LPN cohort (222 mL vs 323 mL), despite fewer RPN patients requiring blood transfusion [53].

A separate multi-institutional analysis of perioperative outcomes (comparing 118 LPNs with 129 consecutive RPNs) also showed less blood loss, shorter hospital stay and WIT (19.7 min vs 28.4 min) in the RPN cohort. Subgroup analysis revealed that tumour complexity (as defined by the need for collecting system repair) had no effect on operative time or blood loss for RPN, but did affect LPN [43]. The advantage of robotic assistance, in terms of WIT, was identified for both simple (15.3 min vs 25.2 min) and complex (25.9 min vs 26.7 min) cases, leading the authors to conclude that the robot may benefit even experienced laparoscopic surgeons. They suggested that the ease of tumour dissection and repair may allow for a more uniform experience with RPN as opposed to LPN, where difficult angles or large defects may demand more time and skill.

CURRENT STATUS

In 2010, Benway et al. [25] retrospectively reported the outcomes of 183 RPNs completed at four high-volume centres. Seven positive margins were found postoperatively, and two (which were subsequently corrected) intraoperatively; at a median follow-up of 16 months no patient had shown evidence of disease recurrence based on repeated cross-sectional imaging. There was also no significant change in eGFR from baseline at the last follow-up, although the study failed to report the number of patients with available serum creatinine data and the mean duration of follow-up. The authors contrasted their 9.8% complication rate (15 major and three minor) with 18.6% from a large LPN series of 771 patients treated via a laparoscopic approach; and although conceding the possibility of selection bias, this perioperative complication rate at least showed that RPN can be safely performed in high volume centres.

The group at Fox Chase Cancer Centre has recently described their first 100 RPN, as performed by four different surgeons [54]. Over half of the patients had a nephrometry score ≥7 and 47% had endophytic tumours. Median tumour size was 2.8 cm and median operating time and WIT were 203 min and 25.5 min respectively. Two open conversions resulted from ventilatory issues with the pneumoperitoneum and severe hepatomegaly impeding liver retraction. The group found mean postoperative change in GFR to be 6.32 mL/min/1.73 m² although this was not related to WIT. On final pathology, 5.7% of specimens showed positive margins, which appeared unrelated to individual surgeon experience, though the numbers were too small to exclude a low power effect. No patient showed tumour recurrence over a mean follow-up of 12.7 months, leading the authors to reiterate the short-term oncological efficacy of RPN.

FUTURE PERSPECTIVES

The robotic platform continues to inspire further modifications in an effort to maximize patient benefit. Robotic-assisted laparoendoscopic single site (R-LESS) partial nephrectomy has recently been successfully completed, without conversion or complication, in two patients with solitary renal masses using a multichannel Triport™ device (Advanced Surgical Concepts, Co Wicklow, Ireland) [55]. Mean tumour size was 2.0 cm and the lesions were sufficiently exophytic to warrant a clampless technique. Additional comparison studies will be necessary, using standardized aesthetic and pain scoring scales, to determine whether there is a true benefit of this approach over a traditional robotic technique. Also, the current da Vinci system is not designed for a single-site approach, and despite this group’s innovative use of paediatric 5-mm robotic instruments and parallel placement of the second 5-mm robotic trocar through the same skin incision alongside the Triport™, there are still difficulties with external clashing of robotic instruments.

Magnetic Anchoring and Guidance Systems help free up space, via the use of extracorporeal magnets to retract and manoeuvre trocarless intracorporeal instruments [56]. Voice/foot-controlled instruments have been used in LPN in the porcine model to improve the working space for the primary surgeon, and the same logic could be extended to RPN by replacing patient-side assistants with robot-controlled instruments [57]. These devices may go someway toward empowering the primary surgeon with greater freedom of movement and more control.

New technology may also expedite the transition of surgeons who are new to RPN. Kall et al. [58] have described using Applied Medical’s Gelport™ device (Rancho Santa Margarita, CA) to allow rapid hand-assisted laparoscopic dissection of the kidney. This allows trainee surgeons to begin RPN using a hybrid approach, to complete the more complex initial stages of partial
docking the robot onto the Gelport to which they are more comfortable, before nephrectomy using traditional methods with which they are more comfortable, before docking the robot onto the Gelport to complete tumour resection and renorrhaphy [58].

CONCLUSION

There are a variety of ways to accomplish nephron sparing surgery; early experiences of RPN appear oncologically and functionally at least equivalent to mature laparoscopic partial nephrectomy series. Furthermore, in appropriately selected patient groups, robotic and laparoscopic approaches seem equivalent to the current standard of care (open partial nephrectomy).

RPN continues to achieve WITs which approach 20 min. RPN offers similar cosmesis and convalescence to LPN, but with a shorter learning curve and potentially fewer intraoperative and postoperative complications. Although formal cost analysis and longer-term follow-up studies will be needed before the robotic technique becomes the new standard for the surgical management of small renal masses, its benefits are already being realized. Trends continue to emerge that highlight the advantage of using the robotic platform to achieve a minimally invasive approach for partial nephrectomy, and with time and increasing expertise, this may become more apparent in terms of intraoperative and postoperative outcomes.

CONFLICTS OF INTEREST

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Abbreviations: OPN, open partial nephrectomy; LPN, laparoscopic partial nephrectomy; RPN, robotic-assisted partial nephrectomy; WIT, warm ischaemia time; RFA, radiofrequency ablation; R-LESS, robotic-assisted laparoendoscopic single site