Robot-Assisted Partial Nephrectomy

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99.1 Introduction

Over the past decades, surgical intervention has been the gold standard for the treatment of many kidney malignancies. Initially, open surgical approaches offered good oncological results but were associated with significant functional and aesthetic discomfort, particularly body surface alterations, muscle volume change, flank bulge, paresthesias, and postoperative numbness [1]. The subsequent advent of laparoscopy techniques addresses these issues, showing promising functional and oncological outcomes [2]. However, in particular, laparoscopic partial nephrectomy (LPN) has technical challenges, such as tumor dissection and intracorporeal suturing, relegating this procedure to experienced high-volume surgeons.

The introduction of robotic surgery with the da Vinci surgical system (Intuitive Surgical Inc., Sunnyvale, CA, USA) brought advances such as magnified three-dimensional visualization, fully intracorporeal articulating instruments under precise control, and the elimination of tremor, thus reducing the technical challenges of minimally invasive partial nephrectomy (PN), including tumor dissection and renal reconstruction. These additions have reduced the need for advance laparoscopic skills, allowing more surgeons to overcome these limitations.

In 2004, Gettman et al. [3] reported the feasibility of robot-assisted partial nephrectomy (RAPN). Since then, it has been increasingly adopted in the treatment of small and localized renal tumors.

This chapter reviews main data for the different surgical steps of RAPN and the main results available in the literature.

99.2 Preoperative Consideration

99.2.1 Indications

Nephron sparing surgery (NSS) is the gold standard surgical approach for patients with small renal masses. Benefits include preservation of renal function to limit the risk of chronic kidney disease and cardiovascular morbidity and lower non-cancer mortality rate [4]. Since 2009, worldwide urological guidelines recommend minimally invasive NSS such as RAPN as the preferred standard of treatment for renal cell carcinoma (RCC) T1a-b [5], with few studies expanding the indication to selected patients with cT2 tumors (Table 99.1) [6, 7]. Indications for NSS can be classified as absolute, relative, or elective (Table 99.2) [8].

99.2.2 Patient Selection and Preparation

In general, patients with indication for RAPN must undergo a thorough medical history and physical examination to identify potential issues that could arise during surgery, with emphasis in prior abdominal and retroperitoneal surgery, as well as comorbidities (diabetes mellitus, hypertension, and coronary artery disease, among others). In cases of severe cardiopulmonary disease RAPN may be contraindicated.

Any coagulopathies should be corrected prior to surgery. If not prohibitory, patients on anticoagulation medication are required to temporarily stop the medication in the perioperative period.

They are also instructed to fast for 8 h before surgery. Bowel preparation is not routinely used. A first-generation

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Table 99.1 2017 TNM (tumor node metastasis) classification system of RCC

T – Primary tumor	
TX	Primary tumor cannot be assessed
T0	No evidence of primary tumor
T1	Tumor ≤7 cm in greatest dimension, limited to the kidney
T1a	Tumor ≤4 cm or less
T1b	Tumor >4 but <7 cm
T2	Tumor >7 cm in greatest dimension, limited to the kidney
T2a	Tumor >7 cm but ≤10 cm
T2b	Tumors >10 cm limited to the kidney
T3	Tumor extends into major veins or perinephric tissues but not into the ipsilateral adrenal gland and not beyond Gerota's fascia
T3a	Tumor grossly extends into the renal vein or its segmental (muscle-containing) branches, or tumor invades perirenal and/or renal sinus fat (peripelvic fat), but not beyond Gerota's fascia
T3b	Tumor grossly extends into the vena cava below the diaphragm
T3c	Tumor grossly extends into the vena cava above the diaphragm or invades the wall of the vena cava
T4	Tumor invades beyond Gerota's fascia (including contiguous extension into the ipsilateral adrenal gland)

Table 99.2 Indications for nephron sparing surgery

Absolute	Relative	Elective
Tumors in solitary kidneys Poor renal function Bilateral synchronous renal tumors	Hereditary forms of RCC (Von Hippel–Lindau syndrome, hereditary papillary RCC, Birt–Hogg–Dubé syndrome, or tuberous sclerosis) Unilateral renal tumor with the risk of future renal insufficiency (diabetes mellitus, nephrolithiasis, or chronic pyelonephritis)	Small renal tumors (<4 cm) in a patient with normal contralateral kidney

cephalosporin is given 30–60 min before incision. Informed consent is obtained with a detailed discussion of potential complications such as hemorrhage, transfusion, incomplete tumor resection, urine leak, and conversion to radical nephrectomy or open surgery.

99.2.3 Tools to Make Surgical Decision-Making

The goal of NSS is to achieve the trifecta (negative margins, minimal decrease in renal function, and no complications) [9] and pentafecta (adding early and late renal functional outcomes, besides freedom from cancer recurrence) [10]. There are several tools that have been implemented to help urologist achieve these outcomes.

99.2.3.1 Preoperative Imaging

This is an important step toward surgical planning during PN. Conventionally, axial computed tomography is used for staging RCC. Anatomical and tumor characteristics can be analyzed through computed tomography (CT) and/or magnetic resonance imaging (MRI), and 3D reconstruction can evaluate the relationship between vascular, renal, and tumor structures to help in the planning of the surgical approach (Fig. 99.1).

Multiple anatomical scoring systems have been designated to determine the tumor complexity. Some examples are RENAL nephrometry score, which measures (R)adius, (E)xophytic/endophytic, (N)earness to collecting system/sinus, (A)nterior/posterior, and (L)ocation relative to polar lines; anatomical system integrating feature of location of renal tumors and their relationship with the most important anatomical structures (PADUA); and centrality index (C-index) [11]. More recently, adherent perinephric fat (APF) was addressed by Davidiuk AJ et al. [12] who introduced the Mayo Adhesive Probability (MAP). This score can calculate APF, a non-tumor-related factor that predicts the degree of difficulty during PN.

All these are good predictors of perioperative complexity and morbidity of NSS. These tools provide useful information for patient counselling and treatment planning.

Although CT and MRI provide valuable anatomical information, they are not sufficient to offer a detailed understanding of the surgical anatomy of the tumor and its relationship with renal structures (collecting system, parenchyma, and vascular structures). Emerging innovations in RAPN have introduce the term "precision surgery." The aim of this technology is to develop precise radiological information to guide the surgical approach to obtain better functional outcomes through the use of 3D virtual-rendered printed models [13]. Propiglia et al. (2017) [14] reported the feasibility and efficacy of preoperative 3D in avoiding global ischemia in comparison with non-preoperative 3D (80% vs 24%, $p < 0.01$).

With the aim of increasing the performance of the surgery, the 3D model can be integrated inside the robotic console by TilePro software (Fig. 99.2).

There is also a potential role of this technology for surgical training [15].

99.2.3.2 Perioperative Imaging: Indocyanine Green (ICG)

ICG is a Food and Drug Administration (FDA)-approved water-soluble dye, which is highly bound to proteins (>95% of the injected fraction). Once injected in the intravascular

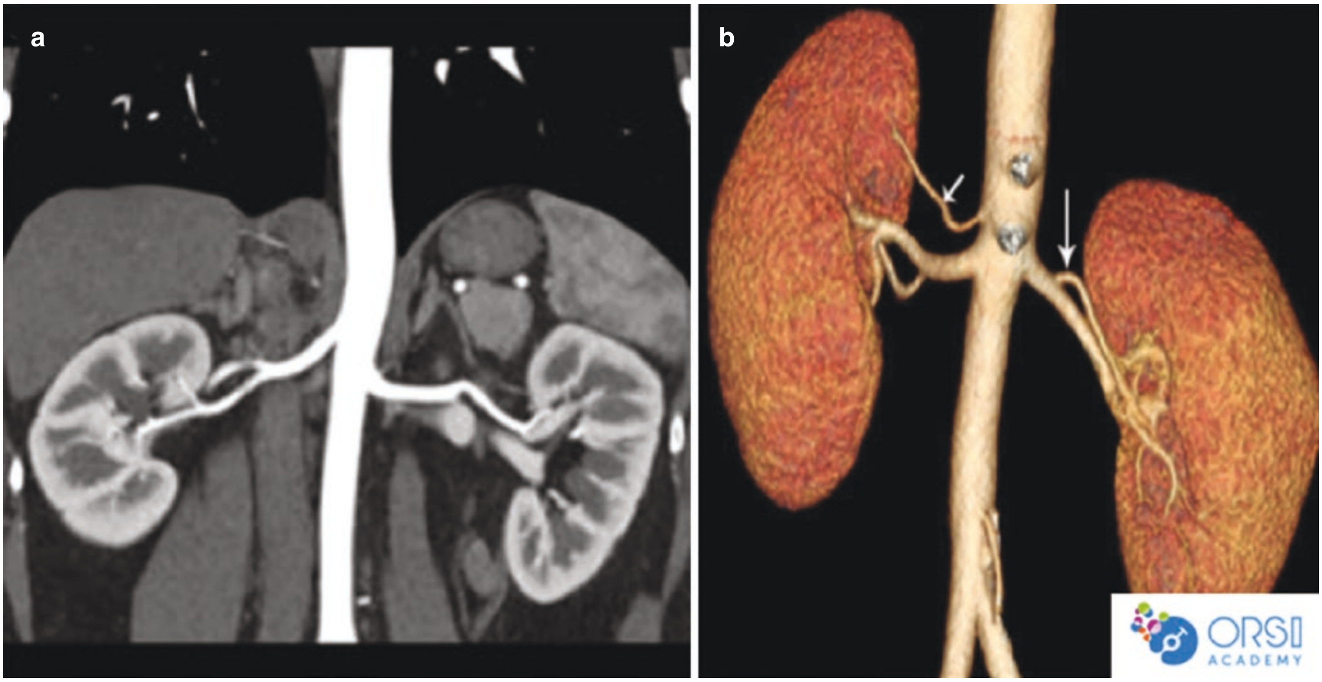


Fig. 99.1 (**a**) CT renal angiogram in a coronal view showing the bifurcation of the main renal arteries; (**b**) CT 3D reconstruction image exposing a right upper pole renal artery

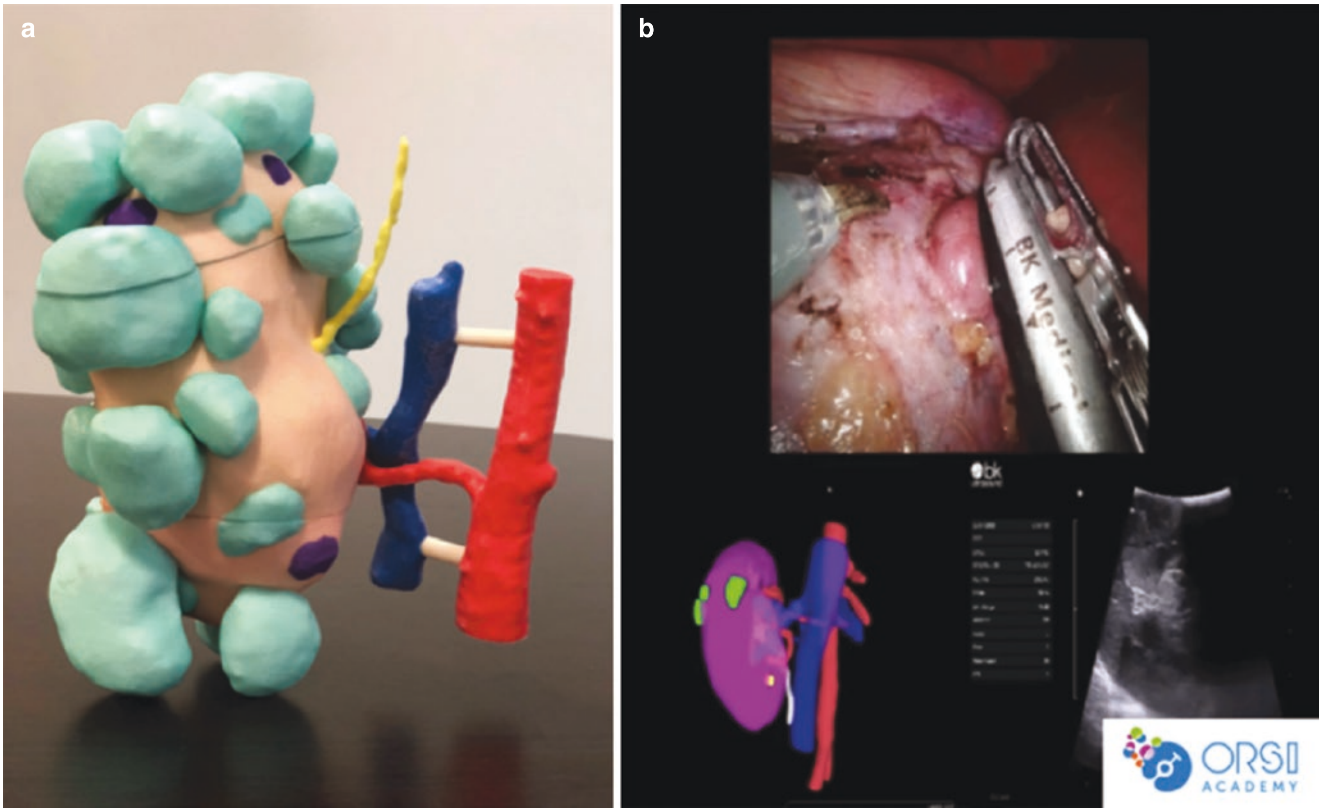


Fig. 99.2 (**a**) 3D printed reconstruction model. (**b**) TilePro technology; superimposed images of the 3D printed model and ultrasound on the in vivo image are shown

space, it has the ability to appear green when excited by light in the near-infrared spectrum [16]. The incorporation of a near-infrared fluorescent (NIF) camera on the da Vinci robotic platforms (Firefly) has allowed this technology to be introduced into minimally invasive surgery. NIF following intravenous administration of ICG highlights the vasculature and is a valuable aid in the surgical dissection of vascular structure and selective clamping, improving the time of ischemia [17]. After injection of ICG, the intravascular distribution of the dye makes the kidney hyperfluorescent, and clamping a selective renal artery limits the diffusion of the dye to that particular zone making it non-fluorescent, allowing to identify accurately the vascular supply of the tumor area. This technology ensures only regional rather than global ischemia. Several studies have shown the benefits of selective clamping over global clamping, an improved short-term renal functional outcome with a decrease of 1.8% (ICG) vs 14.9% (non-ICG) of glomerular filtration rate (GFR) [18]. In addition to providing valuable information on renal irrigation, some types of renal tumors absorb less ICG than normal renal parenchyma, thus appearing hypofluorescent when compared to their surroundings in particular with clear cell RCC (up to 96% agreement) [19]. However, the sensibility and specificity to routinely identify RCC malignancies are 84% and 57%, respectively [20].

The usual dose in RAPN is 0.5 mg/kg, and the renal vascular anatomy can be visualized after intravascular administration in 60 s. The washout period of the dye from the kidneys is 20 min.

Contraindications: ICG contains sodium iodide and should be used with caution in patients who have a history of allergy to iodides because of the risk of anaphylaxis. However, an intravenous dosage of ICG up to 5 mg/kg is considered nontoxic.

Adverse Reactions: Anaphylactic or urticarial reactions have been reported in patients with or without a history of allergy to iodides in <0.5%, with severe side effects in <0.05% [21].

ICG is an emerging technology that has proven to be a useful surgical adjunct to RAPN; this is a field where the use of this technique will increase in the future (Fig. 99.3).

99.2.4 Intraoperative Ultrasound and TilePro

The da Vinci system has a software (TilePro) which allows the surgeon direct visualization of intraoperative ultrasonographic image onto the console screen in real time [10, 22].

Intraoperative ultrasound (IUS) is of particular importance to provide information about renal tumor anatomy, in particular for tumors with large endophytic growth or hilar location. The features than can be assessed by IUS are the tumor margin, depth of penetration, vascular anatomy, and the relationship of the pelvicalyceal system [8, 14].

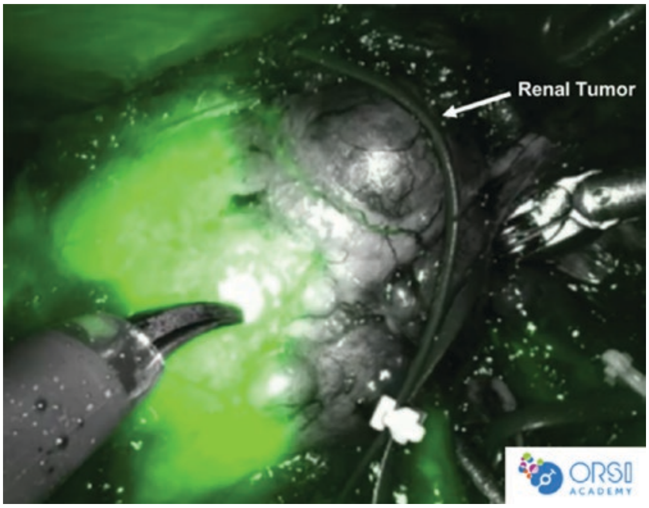


Fig. 99.3 ICG administration during selective clamping, demonstrating the use of Firefly feature in the da Vinci robot system

Fig. 99.4 Demonstration of the use of the TilePro feature and use of live intraoperative ultrasound during RAPN

This technology is advantageous, especially in intraparenchymal and complex tumors, according to the nephrometry score. By delimiting tumor margin, it has shown to reduce operative and warm ischemia time (WIT) and percentage of negative surgical margins [23].

There are available several IUS probes that can be used and integrated to this feature [10, 22]. In RAPN, the surgeon can control the probe through the robotic probe ProART allowing more autonomy and precision [24] (Fig. 99.4).

99.3 Surgical Technique

99.3.1 Room Setup and Robot Installation

Every aspect of robotic surgery is very important. The first step of surgery is adequate surgical room setup. The robot and surgical equipment should be ideally positioned to facilitate the operating workflow. For RAPN transperitoneal surgery, patient cart is placed on the backside of the patient usually with the camera arm at the level of the target anatomy. The assistant and scrub technician are positioned on the opposite side of the robot as illustrated in Fig. 99.5.

99.3.2 Patient Positioning and Port Placement

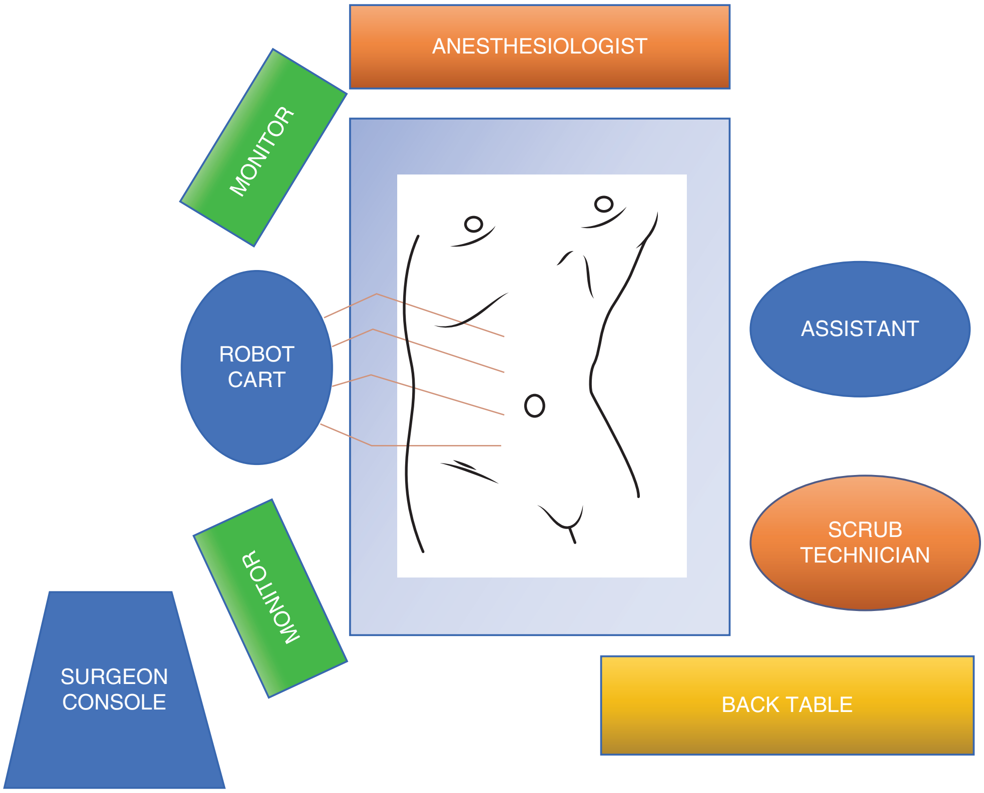
Patient positioning and port placement are essential conditions for an effective achievement of the surgical procedure. In RAPN, the adequate distance between robotic arms and ideal location of the robot cart in the backside of the patient is fundamental for an optimal docking.

The patient is placed in a modified lateral decubitus position with a 20–30° ipsilateral rotation of the shoulder and hip and with the operative side up. The arms should be positioned as far cephalad as possible to minimize conflict with the robotic arms. A back supporter is placed at the level of the scapula, beside an axillary and back roll. The anterior abdomen is placed on the lateral edge of the bed to minimize interference with the operative table. The lower leg is flexed, with paddings between the legs, lower knee, and ankle joints. The table is flexed at the anterior superior iliac spine joint to achieve an adequate working space and avoid collisions between robotic arms. The patient is secured to the table with a strong tape (Fig. 99.6).

In our institution, a four-arm approach is preferred with the addition of one assistant trocar (AirSeal). Pneumoperitoneum is routinely established using a Hasson technique and the trocar inserted with a blunt obturator. During trocar placement, a pressure of 12 mmHg is used, while during the whole surgery, we routinely used a SurgiQuest AirSeal insufflation system to adjust the pressure to 5 mmHg in order to perform a low-impact surgery. In our experience, this is feasible in the majority of cases; however, in obese patients, the pressure should be higher (8 mmHg or above) in order to obtain an adequate working space. We use a linear trocar placement configuration in the pararectus space (da Vinci Xi), with the lower fourth arm located more lateral, appearing as a “J” configuration with all instruments more than 6 cm apart. The AirSeal trocar is placed more medially in the paraumbilical area (left side) and more medially between the first and second arms (right side) (Fig. 99.7).

With regard to trocar placement in the Si system, we used a medial approach in which the 12-mm camera port is placed 2 cm cranial and lateral to the umbilicus. We found this approach more favorable as it provides a wider angle of view by the greater distance between the camera and the kidney

Fig. 99.5 Room and robot equipment setup



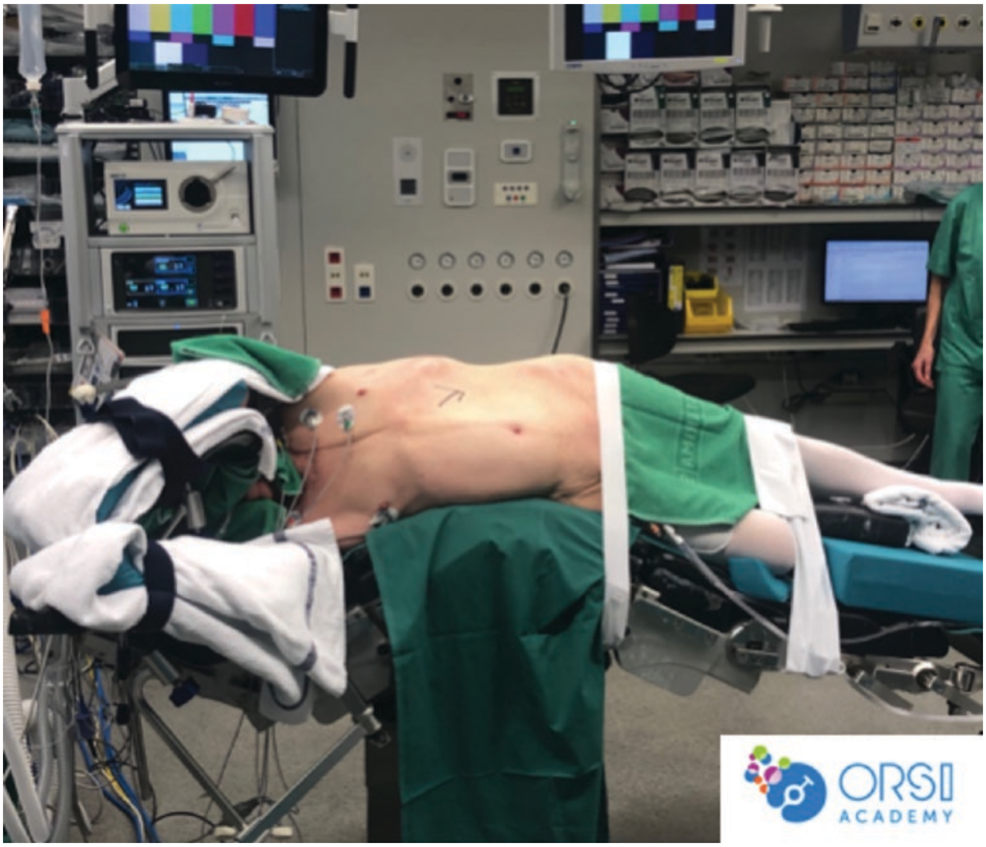


Fig. 99.6 Patient positioning

and also allows the camera to easily track instruments entering through the assistant port. The cranial robotic trocar is placed subcostally on the pararectal line. A 12-mm AirSeal assistant trocar is then placed between camera trocar and the caudal robotic arm. The two caudal robotic trocars should be placed carefully to avoid collision and maintain a sufficient mobility of the robotic arms. The most posterior one is placed approximately 2 cm caudal to the lower pole of the kidney and as lateral as possible. The medial one is placed in the lower quadrant of the abdomen 1 cm lateral from the pararectal line respecting a minimum distance of 8 cm from the previous one (Fig. 99.8).

99.3.3 Robot Docking

The da Vinci Si should be docked from the back of the patient at a right angle to the surgical table, on a line connecting the expected location of the renal hilum and the umbilicus. The articulations of the working arms should be driven out laterally in order to maximize their movement arcs and to minimize external conflict.

The da Vinci Xi system is also docked from the side of the patient but with less strict specifications than the Si, in part for the numerous technological improvements that allow for a more consistent and efficient docking. The patient cart features the four arms mounted onto a rotating overhead boom that can rotate and pivot into virtually any position. The arms are smaller and thinner with a greater range of motion diminishing the probability of collision. It has a laser crosshair on the boom that can facilitate aligning the camera port, and the camera has an autotarget feature that allows for an optimal automated robotic arm placement.

99.3.4 Robotic Instruments

The instruments commonly used include a 30° lens, Monopolar Curved Scissors, bipolar ProGrasp forceps, and a large needle driver. The large needle driver is often used as a grasper when positioned on the fourth robotic arm or Tip-Up Fenestrated Grasper or Double Fenestrated Grasper (da Vinci Xi). In complex cases, an additional large needle driver for the renorrhaphy can be used.

99.3.5 Retroperitoneal Versus Transperitoneal RAPN

The traditional approach to RAPN has been the transperitoneal (TP) due to its familiar anatomical orientation and larger working space. However, a retroperitoneal (RP) RAPN can offer potential advantages. It gives a direct approach to the renal hilum and to posterior tumors, overcoming the surgical

Fig. 99.7 Port placement configuration in da Vinci Xi. (**a**) right RAPN and (**b**) left RAPN

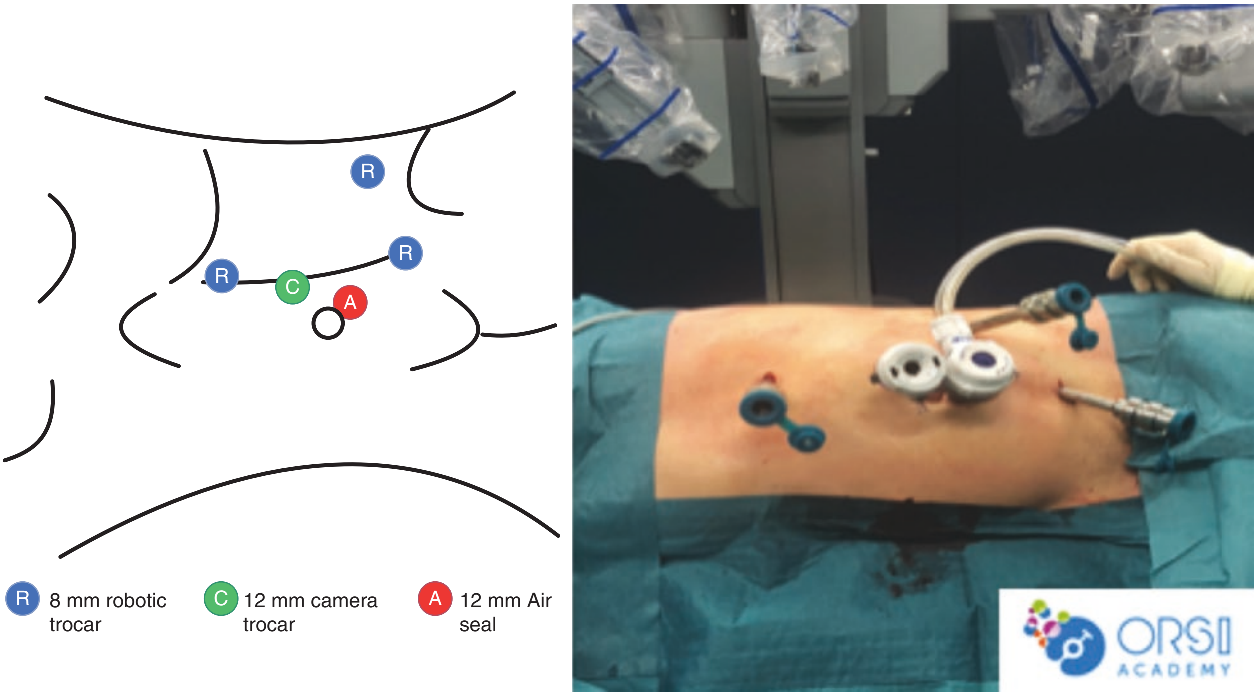


Fig. 99.8 Port placement configuration left RAPN in da Vinci Si

complexity of pure laparoscopic RP surgery. In patients with previous abdominal surgeries, in whom multiple peritoneal adhesions can be found, RP technique can be advantageous in reducing surgical complexity and potential injury to abdominal organs [25]. A previous meta-analysis compared the perioperative outcomes of TP ($n = 229$) vs RP ($n = 220$) approaches and found no significant differences regarding complication, conversion, WIT, estimated blood loss (EBL), and positive surgical margin (PSM). RP RAPN had a shorter operative time than TP RAPN ($p = 0.05$, 153.4 min vs. 183.3 min).

Thus, it appears to be equally safe and efficacious to choose either of these surgical approaches [26].

99.3.6 Ischemia and Hilar Control

The major goal of NSS is to maximize renal function preservation in the safest oncological way. Preservation of renal function has been one of the main advantages of NSS, but also a matter of concern, since it has an important role in long-term survival, particularly in patients with preexisting chronic kidney disease [27]. The expansion of PN over radical nephrectomy (RN) came for the growing evidence that renal function was significantly better preserved with NSS compared to RN [28]. Traditionally, PN was performed with interruption of blood flow to the kidneys; by doing this, some nephrons may not survive the ischemic insult, thus affecting in some degree postoperative renal function [29]. Several previous studies had failed to prove a standard limit of renal ischemia during NSS, with no significant changes occurring between 20 min after clamping and extending up to 60 min, doubting whether WIT itself is the cause of renal function loss or rather serves as an indicator of a more complicated surgery [30]. However, available data supports that the length of WIT remains associated with postoperative renal function, and WIT should be limited to 20–25 min; when it exceeds this limit, it becomes an independent risk factor of acute kidney injury and new-onset chronic kidney disease [31–34]. Moreover, recent reports found that renal ischemia per se is not a significant factor affecting renal function and that other factors play an important role in functional outcomes [35]. These outcomes can be divided into modifiable (WIT, tumor size, and preserved functional renal tissue) and non-modifiable groups (preoperative renal function, and nephrometry score), with preserved functional tissue and tumor size playing a predominant role.

Several techniques of renal clamping have been described: total clamping, early unclamping, off-clamping, and selective clamping.

The early unclamping involves clamping the renal hilum for the duration of tumor excision and placement of the initial inner renorrhaphy running suture. All subsequent suturing in the resected bed is done in the reperfused kidney. In this way, the WIT can be reduced by more than 50% with similar estimated blood loss and bleeding complications. Also, there is improved visualization and direct suture control of any residual arterial and/or venous bleeding in the resection bed after the first layer of renorrhaphy. Gill et al. (2007) reported that this technical modification allowed a significantly shorter WIT (14.4 vs 31.9 and 31.6 min in previous periods of experience; $p < 0.0001$), which resulted in significantly superior RF outcomes (decrease in eGFR within 90 postoperative days: 11% vs 18% and 20%, respectively; $p < 0.0001$) [36].

The selective clamping technique implies a selective clamping of arterial branches suppling blood flow to the tumor area without compromising blood flow in the remaining parenchyma (Fig. 99.9). In particular, this has been useful in complex tumors not suitable for off-clamp techniques. The term “zero ischemia” denotes a supra-selective clamping of tertiary or higher-order arterial branches to induce a very selective tumor ischemia [37]. To achieve this type of ischemia, precise preoperative imaging such as CT angiography was shown to be helpful to assist the surgeon in the delineation of renal and tumoral vasculature. ICG can also be helpful to demonstrate the efficacy of super-selective clamping before tumor resection [18] (Fig. 99.10).

In the off-clamping technique, tumor excision and renal reconstruction are performed completely unclamped. This technique has been preferred in tumors with favorable anatomic features as small size, exophytic lesion, and low nephrometry scores [38].

A recent meta-analysis from Cacciamani et al. (2017) has addressed the different clamping techniques. When compared with on-clamp techniques, off-clamp approach had lower operative times (a weighted mean difference (WMD) of −17.88, 95% CI 31.33 to −4.43, $p = 0.009$) but greater

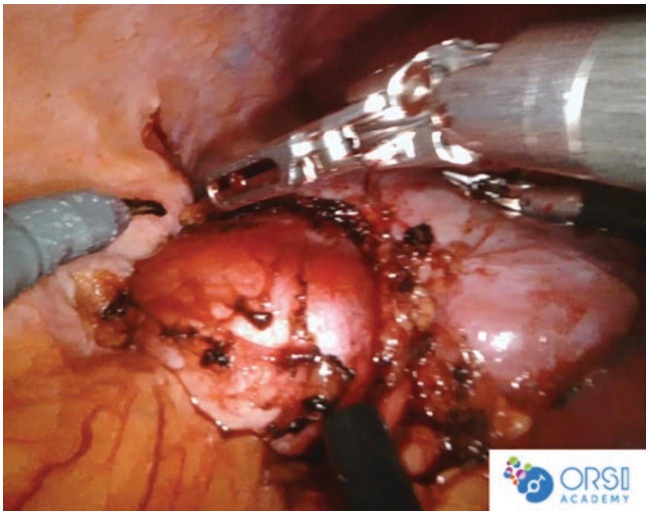


Fig. 99.9 Tumor demarcation

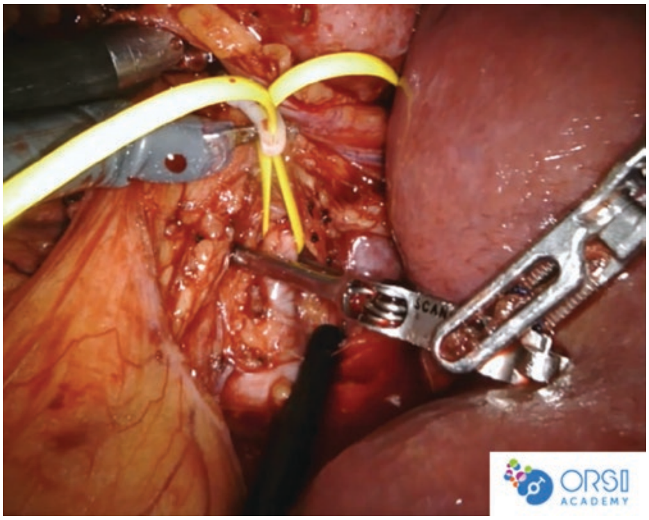


Fig. 99.10 Selective clamping during RAPN

EBL (WMD, 47.83; 95% CI 21.40 to 74.26; $p = 0.0004$). However, both groups were similar regarding transfusion rates, open conversion rates, LOS, positive margins, and complications. Comparison between super-selective and main artery clamping revealed superior renal functional preservation in the super-selective clamping group (WMD, 9.74; 95% CI 5.03–14.44; $p < 0.0001$) [39].

Based on the results, various techniques of hilar clamping are safe and feasible approaches, with similar perioperative and oncological outcomes compared to main artery clamping and potentially superior functional outcomes.

To resume, nowadays, there is a lack of consensus of which is the best approach in terms of renal functional recovery after surgery; all data reported to date support that long-term RF is dependent not only in minimizing WIT to <25 min, but also preoperative RF and the amount of healthy parenchyma preserved play an important role in the functional outcomes, and these variables appeared to be interlinked with each other.

99.3.7 Surgical Technique (Step by Step)

The first step before starting with the procedure is to prepare the surgical field and release all adhesions, if found, to avoid possible complications that could happen out of view. After that, the colon needs to be mobilized. The bowel is reflected along the white line of Toldt. The role of the assistant is to provide a medial countertraction on the colon which allows to develop a relatively avascular plane between the posterior mesocolon and Gerota's fascia. During bowel mobilization, it is important to stay outside Gerota's fascia. An important landmark is the gonadal vein. To identify the hilum, the gonadal vein should be followed into the cranial direction. On the left side the gonadal vein should be followed until the insertion into the renal vein, on the right side it should be followed until the vena cava is seen and then it should be further followed to the renal vein. Once the renal vein and renal artery are localized, a vessel loop secured with a Hem-o-lok is placed around them.

The next step is to open Gerota's fascia and to mobilize the whole kidney. Gerota's fascia should be open in a safe distance from the tumor. The reason for that is to find the capsule and dissect along the capsule until the mass is exposed. The overlying Gerota's fascia on the top of the mass should be kept for histopathological staging and also can be used as a handle for retraction.

An intraoperative ultrasound is introduced manually by the assistant. It is used to identify the location, depth, and border of the tumor. It allows also to demarcate the tumor margin using the monopolar scissors (Fig. 99.9).

99.3.8 Tumor Excision

Once the tumor is demarcated, the excision can be started using a sharp maneuver (Fig. 99.11). The ProGrasp can be used to spread the tissue. The goal is to follow the expected curvature of the tumor. The direction of dissection should be from near to far. During the excision of the tumor, the assistant has a crucial role: to push the parenchyma in order to expose the dissection plane to the surgeon. Once excision is complete, the specimen should be place out of the field for later retrieval.

99.3.9 Resection Technique

The strategies to perform a partial nephrectomy can be grouped into four main categories: simple enucleation (SE), enucleoresection (ER), wedge resection (WR), and polar

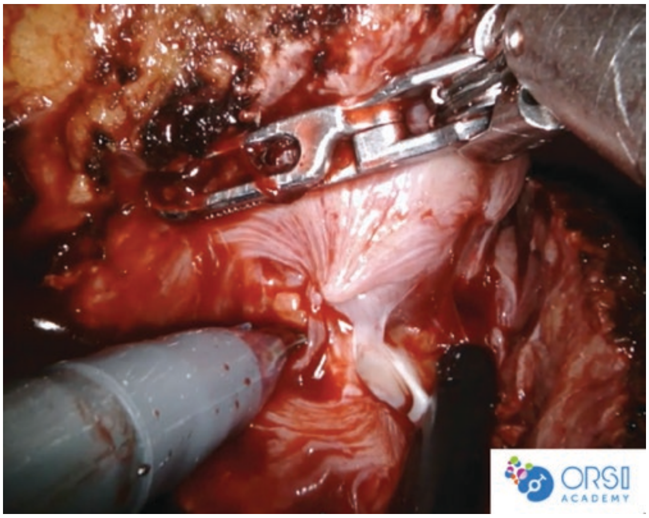


Fig. 99.11 Tumor enucleoresection

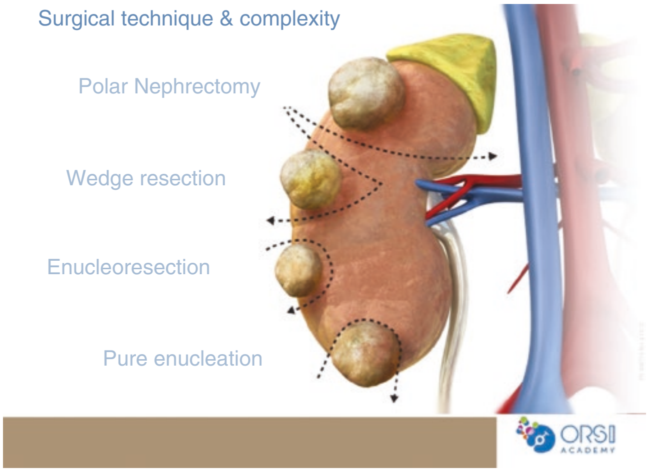


Fig. 99.12 Surgical technique of RAPN

nephrectomy. In SE only, the tumor pseudocapsule is seen without the overlying tissue. In ER, there should be a minimal save margin (≥1 mm) with visible tumor contours. During the WR, the tumor contour cannot be detected because of the resected parenchyma. A polar nephrectomy is defined as an excision of the upper or lower pole of the kidney. By this resection, at least 30% of the kidney should be removed by simultaneously cutting into hilar fat and transecting the collecting system (Fig. 99.12).

99.3.10 Renorrhaphy

The reconstruction after the tumor excision should take all deliberate speed. In our center, we are performing the renorrhaphy in two layers. For the first layer, a running 18-cm Monocryl 3–0 suture preloaded with a Hem-o-lok is used. The technique is to start in the parenchyma from outside to inside (Fig. 99.13). The goal is to have the clip outside the kidney. The open vein or calices should be close separately to minimize the risk of postoperative bleeding or urine leakage. The use of the same needle size is important. The fact of getting used to the same movements allows us to avoid take-off to deep bites and prevent injury of big vessels lying under the defect. The last stitch is brought outside the parenchyma and secured with a Hem-o-lok clip. To perform the renorrhaphy, a sliding-clip technique is used which allows us to introduce the right tension to the suture. This technique was first described by Benway et al. [40].

After the completion of the first layer renorrhaphy, the bulldog clamp can be removed. Before starting with the second layer, the kidney needs to be checked for any bleeding.

The second layer is performed using a V-Loc running suture. Every stitch is secured with a Hem-o-lok clip. After the renorrhaphy is completed, additional clip is placed like a “hook” on the suture to avoid the arbitrary sliding (Fig. 99.14).

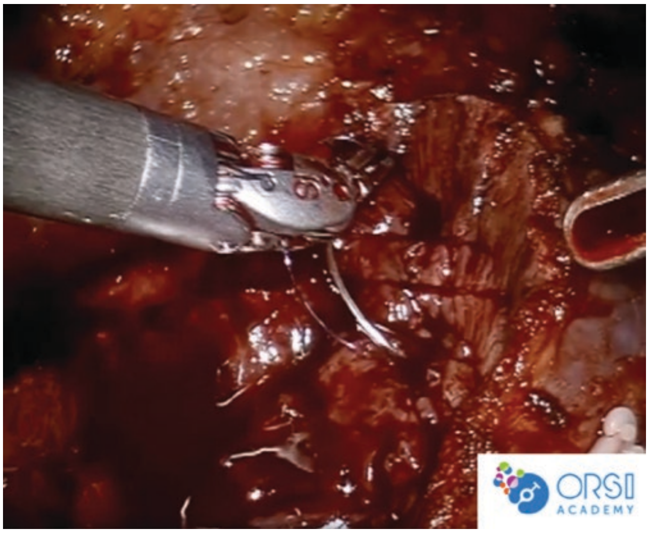


Fig. 99.13 Inner renorrhaphy using Monocryl 3–0 with SH-plus needle preloaded with an Hem-o-lok

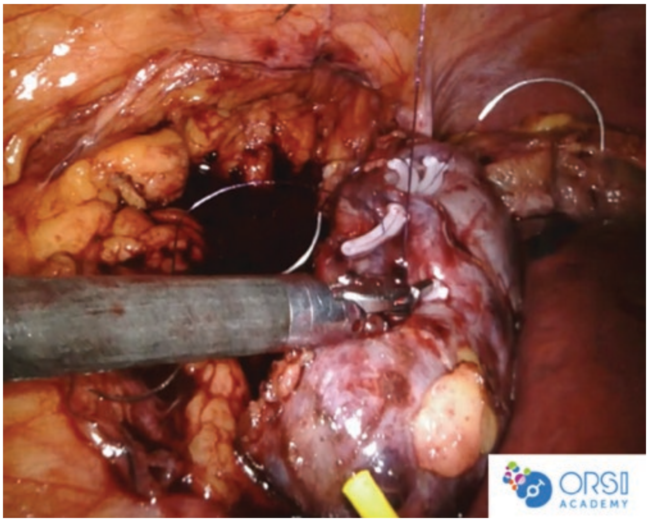


Fig. 99.14 Outer renorrhaphy using Vicryl 1 with CT-plus needle preloaded with an Hem-o-lok

99.4 Results and Outcomes

Minimally invasive PN has replaced open PN as the standard of care in small renal masses. The advent of robotic surgery for minimally invasive PN has significantly reduced the use of the laparoscopic approach, in part for the shorter learning curve. However, outcomes continue to be dependent over surgical experience in order to obtain significant difference when compared to laparoscopic PN. Back in 2012, Aboumarzouk et al. [28] reported a systematic review (SM) and meta-analysis (MA) of the comparison of RAPN and LPN; seven studies were included in the analysis, with a total of 717 patients. There was no difference between groups regarding operative times, estimated blood loss (EBL), conversion rates, length of stay, or complications. The RAPN group had only achieved significantly less WIT than the LPN group ($p = 0.0008$). A limitation of the studies included was the early phase surgical experience of the surgeons involved. Subsequently, Choi JE et al. (2015) carried out an SR and MA of 23 studies and 2240 patients. In this analysis, RAPN was found to be associated with significantly lower rate of conversion to open surgery and conversion to radical surgery, shorter WIT, smaller change of estimated glomerular filtration rate, and shorter length of stay.

More recently, Cacciamani GE et al. (2018) [39] performed a comprehensive SR and cumulative MA of the worldwide English literature on RAPN to critically evaluate the impact of the different surgical approaches and techniques on the operative, perioperative, functional, oncologic, and survival outcomes. They included 98 RAPN comparative studies, with a total of 20,282 patients. RAPN was superior to open PN in EBL (weighted mean difference, 85.01; $p < 0.00001$), transfusions (OR, 1.81; $p < 0.001$), complications (OR, 1.87; $p < 0.00001$), hospital stay (weighted mean difference, 2.26; $p = 0.001$), readmissions (OR, 2.58; $p = 0.005$), percentage reduction of latest estimated glomerular filtration rate (weighted mean difference, 0.37; $p = 0.04$), overall mortality (OR, 4.45; $p < 0.0001$), and recurrence rate (OR, 5.14; $p < 0.00001$). When compared to LPN, RAPN was superior in terms of ischemia time (weighted mean difference, 4.21; $p < 0.0001$), conversion rate (OR, 2.61; $p = 0.002$), intraoperative (OR, 2.05; $p > 0.0001$) and postoperative complications (OR, 1.27; $p = 0.0003$), positive margins (OR, 2.01; $p < 0.0001$), percentage decrease of latest estimated glomerular filtration rate (weighted mean difference, −1.97; $p = 0.02$), and overall mortality (OR, 2.98; $p = 0.04$). This MA brings compelling results about the equivalent and in some superior outcomes of RAPN compared to open PN and LPN.

The studies included in this SR and MA have several limitations. There is no Level I evidence reported thusfar, and no study has reported more than a 5 year followup. Thus, the oncological outcomes should be viewed with caution.

A study from Maurice et al. (2016) has proven that RAPN vs. open PN is associated with 7–8 cm^3 less excisional volume loss. The technical advantages of the robotic system allow the tumor excision to be more precise, and with this, more healthy parenchyma can be preserved [41].

Regarding volume loss during PN, Dagenais et al. (2017) have shown that precise tumor excision has significant effect on renal function, even more important than ischemia time and tumor complexity. This suggests that it is more important to make a careful tumor excision and minimize volume loss, even if this implies scarifying more time of ischemia, for a net benefit on long-term renal function [42].

These two previous studies conclude that RAPN relative to open PN is associated with lower excisional volume loss and in consequence with lower postoperative renal function detriment.

The main limitation of the literature concerning this topic is the retrospective and/or nonrandomized nature of these studies; thus, definitive conclusion could not be drawn. To establish robust safety and effectiveness outcomes of robotic surgery, well-designed randomized clinical studies with long-term follow-up periods are needed. However, RAPN has now emerged as a safe, effective, even preferred, PN surgical approach for treatment of small renal masses.

99.5 Limitations and Complications

99.5.1 Lack of Haptic Feedback

This is a field of concern to surgeons embarking in robotic surgery. A surgeon must learn to adapt from tactile to visual feedback. Recent studies demonstrate that surgeon experience is sufficient to compensate this limitation, with no more haptic feedback-related complication than those undergoing open or laparoscopic surgery [43].

99.5.2 System Failure

Robotic system malfunction is rare, occurring at a rate of 14.7% of all robotic surgeries. The most prevalent reported malfunctions are falling of burnt/broken pieces of instruments into the patient (14.7%), electrical arcing of instruments (10.5%), unintended operation of instruments (8.6%), system errors (5%), and video/imaging problems (2.6%). However, if this is the case, conversion rates are low (0.17–16%). The reschedule rate for system malfunction has been reported to be 2.5% [44].

99.5.3 Postoperative Complications

A postoperative complication rate of 15.6% has been reported previously. Among them, hemorrhage complications are one of the most common. Intraoperative hemorrhage occurs in 1.0% and postoperative hemorrhage in 5.8%. Only 1.1% required blood transfusion, and the reported bleeding re-exploration rate is 0.2% [45].

Another common complication is urinary leakage seen in 1.1%, which is comparable to open PN and laparoscopic PN rates (2.3% and 3.1%, respectively) reported in multicenter studies [36]. Decompression of the urinary tract is in most cases a resolutive treatment. Re-operative renal surgery for urine leakage is extremely rare.

Postoperative acute renal failure has been reported around 0.8%, with only 0.2% requiring hemodialysis. A thorough evaluation and a nephrologist consultation are recommended if renal failure further persists or deteriorates.

The main limitation of the literature concerning this topic is the retrospective and/or nonrandomized nature of these studies; thus, definitive conclusion could not be drawn. To establish robust safety and effectiveness outcomes of robotic surgery, well-designed randomized clinical studies with long-term follow-up periods are needed.

99.6 The Learning Curve for RAPN

It is difficult to assess the level of surgeon expertise among the publications available in the literature, which is a relevant factor impacting RAPN outcomes. Previous studies have addressed the issue of surgical experience and patient's outcomes, demonstrating a correlation between the learning curve and suboptimal outcomes, but none of them have aimed to define the surgical learning curve for RAPN [46, 47]. A recent prospective study at two tertiary care referrals European Centers with extensive experience (>200 total procedures) and high annual volume (>30 procedures/ year), which evaluated the RAPN outcomes accordingly to increasing surgical experience in 457 patients demonstrated a median WIT of 14 min, a rate of Clavien-Dindo (CD) >2 of 15%, and PSMs of 4%. They demonstrated a median WIT of 14 min, a rate of Clavien-Dindo (CD) >2 of 15%, and PSMs of 4%. Increased surgical experience resulted in shorter WIT (estimated WIT was 20, 13, and 11 min after 10, 150, and 300 procedures, respectively; $p < 0.0001$) and higher probability of CD >2–free postoperative course (estimated probability of CD >2–free postoperative course was 77, 87, and 96% after 10, 150, and 300 procedures, respectively; $p = 0.001$), but not with PSMs ($p = 0.7$). This study demonstrates that perioperative outcomes after RAPN are importantly affected by surgeons' experience and found that after 150 RAPNs, no further improvement was observed with respect to ischemia time, but the learning curve appears endless with respect to complications.

These results support the statement that RAPN is a complex procedure with a reasonably long learning curve, and special attention should be given to training surgeons to avoid suboptimal outcomes during the learning process [48].

99.7 The Future

RAPN has now emerged as a safe, effective, even preferred, surgical approach for the treatment of small renal masses. Technical advances in robotic surgery, along with demonstration of equivalent results to open surgery for T1a tumors, provided the groundwork for approaching larger lesions. In a recent study, Bertolo R et al. (2018) [49] reported outcomes of RAPN for clinical T2 renal tumors in 298 patients with a median tumor size of 7.6 (7–8.5) cm, a median ischemia time of 25 min, an EBL of 150 mL, and an intraoperative and postoperative complication rate of 5.4% and 21%, respectively. They found RAPN to be safely feasible, with acceptable perioperative and functional outcomes.

With the worldwide expanding utilization and implementation of robotic surgery in NSS, experience has grown consistently, and this allows experienced surgeons to expand the utilization of RAPN in more complex tumors. Moreover, image-guidance technology and novel intraoperative implements could aid in expanding the role of RAPN for these larger tumors. We expect to see in the near future a major role of RAPN for these expanded indications.

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