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Retroperitoneal versus Transperitoneal Robotic-Assisted Partial Nephrectomy: A Single-Institution Matched Pair Analysis

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List of Abbreviations

ABC	Arterial Based Complexity
ASA	The American Society of Anesthesiologists physical status classification system
BMI	Body Mass Index
CBC	complete cell blood count
CI	Centrality index
CSA	Contact Surface Area
CT	Computed tomography
ECOG/WHO PS	Eastern Cooperative Oncology Group/World Health Organization Performance Status
eGFR	estimated glomerular filtration rate
ESR	Erythrocyte sedimentation rate
ESRD	End-stage renal disease
FNA	Fine-needle aspiration
GFR	Glomerular filtration rate
Hb	Hemoglobin
IC	Intermediate care
ICU	Intensive care unit
ISUP	International Society of Urological pathology
IVC	Inferior vena cave
LDH	Lactate dehydrogenase
LOS	length of hospital stay
LPN	Laparoscopic partial nephrectomy
NSS	Nephron sparing surgery
OPN	Open surgical partial nephrectomy
OPN	Open surgical partial nephrectomy
PADUA	Preoperative Aspects and Dimensions Used for Anatomical classification system
RCC	Renal cell carcinoma
RN	Radical nephrectomy
RP	Retroperitoneal approach

RPN	Robotic-assisted partial nephrectomy
RRPN	Retroperitoneal robotic-assisted partial nephrectomy
TNM	Tumor Node Metastasis classification system
TP	Transperitoneal approach
TRPN	Transperitoneal robotic-assisted partial nephrectomy
VHL	Von Hippel-Lindau Syndrome
WHO	World Health Organization

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Introduction

1. The Kidney (Surgical Anatomy and function)

1.1. The function of the kidney

The kidney is a complex organ regulating fluid, electrolytes, and acid-base balances to sustain a suitable tissue and cell metabolism environment¹. The kidney's functional unit's glomerulus keeps these precise balances through glomerular filtration and tubular reabsorption and secretion¹. Other significant functions are renin, erythropoietin, prostaglandin production, vitamin D metabolization, and insulin degradation¹.

1.2. Surgical anatomy of the kidney

Detailed knowledge of the surgical anatomy is needed to optimize perioperative planning, including the surgical approach, thus improving the oncological and functional outcomes.

The left kidney is about 1-2 cm higher than the right kidney because of the liver. Posteriorly, kidneys lie on the psoas muscle, with the upper third of both kidneys is covered with the diaphragm in close relation to the pleura. Anteriorly, the right kidney is covered by the liver and the right colonic flexure, the descending part of the duodenum, and the head of the pancreas overlying the right renal hilum, while the left colonic flexure is covering the left kidney (Fig. 1). Posteriorly, the kidneys lie on rib 12 and the diaphragm, psoas major, quadratus lumborum, and transversus abdominis. The upper part of the kidneys is separated from the lung and pleura by the diaphragm except in the vertebrocostal trigone, where they are separated from the pleura by connective tissue (Fig. 2).

The left renal hilum is in close relation to the body of the pancreas and the splenic vessels. The adrenal glands lie on the upper pole of both kidneys². Adjacent to the posterolateral body wall lays the kidney and retroperitoneal structures. An approach through the retroperitoneum avoids abdominal organs, nerves, and vessels than the abdominal approach.

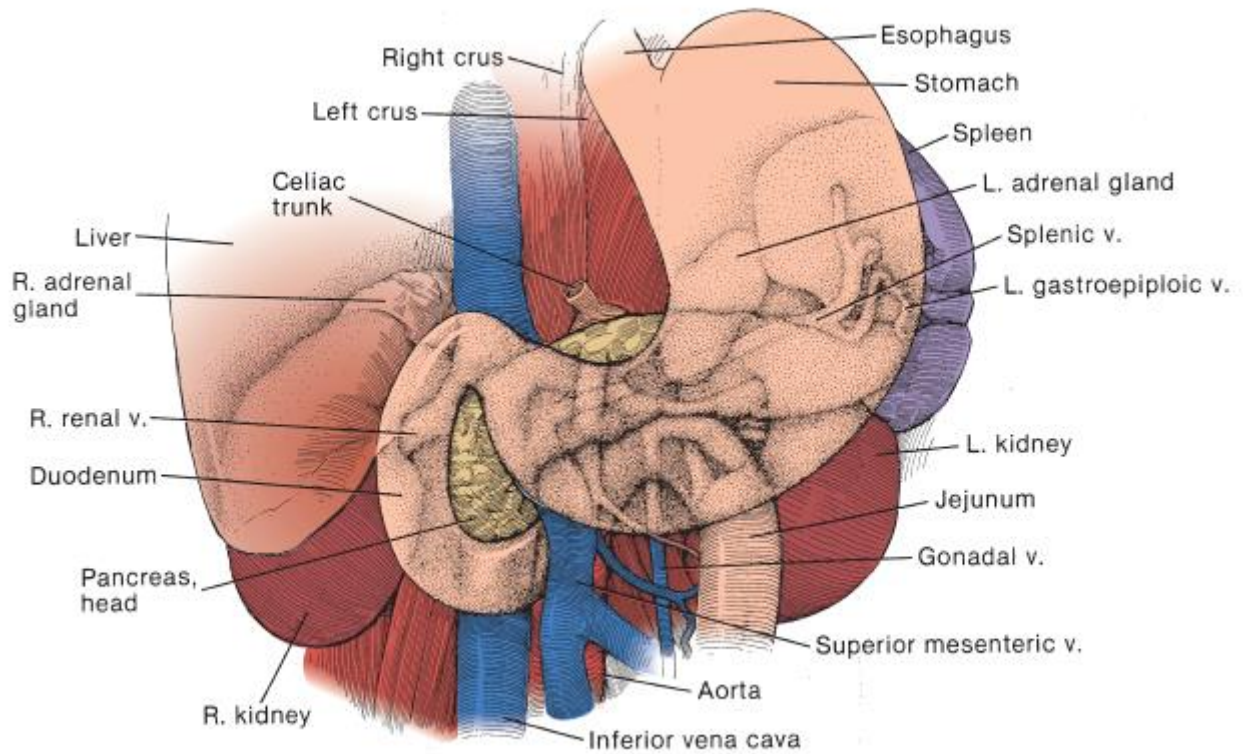


Figure 1: Topographic anatomy of the kidney. Adapted from MacLennan, Gregory T., and Frank Hinman. *Hinman's Atlas of Urosurgical Anatomy*. Elsevier/Saunders, 2012.

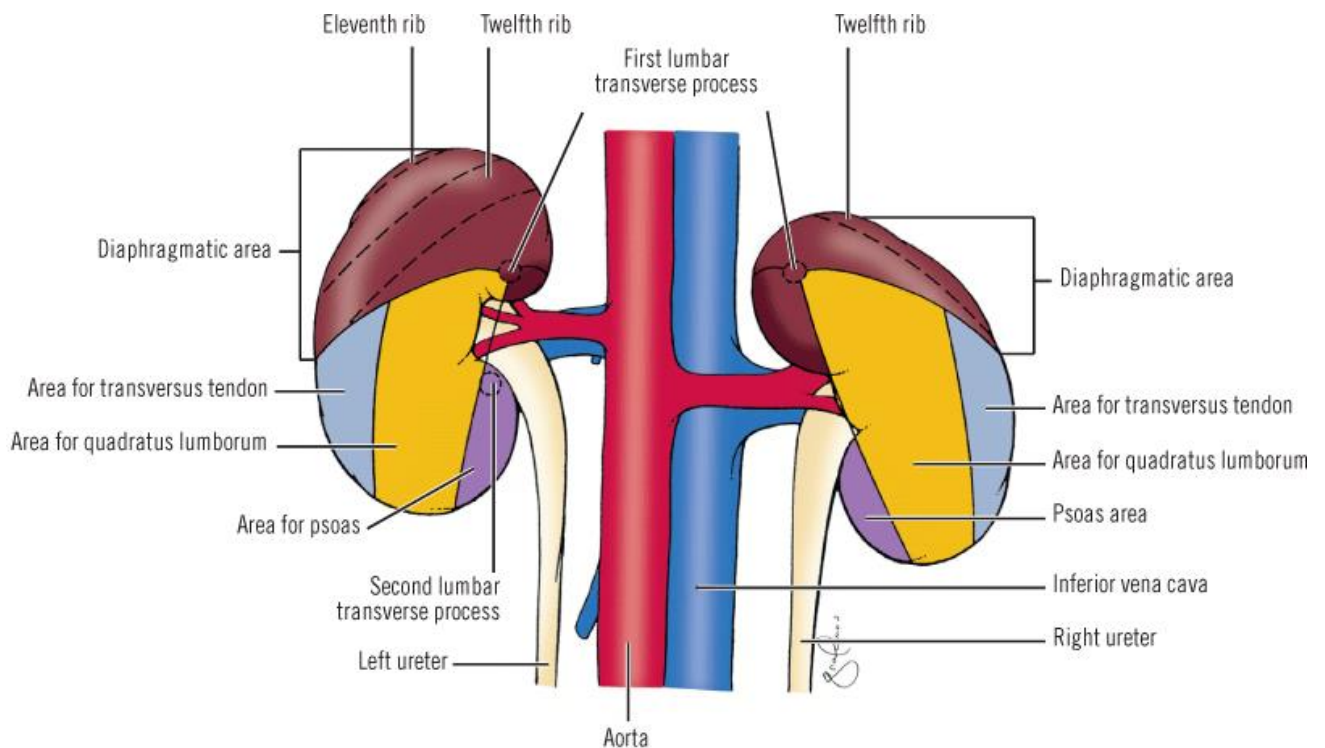


Figure 2: Schematic representation of the posterior relations of the kidney, adapted from Decker GAG, Du Plessis DJ. Lee McGregor's *Synopsis of Surgical Anatomy* (12th ed). Bristol UK: Wright, 1986.

The posterolateral body wall is composed of four muscle layers from an outer layer composed of the latissimus dorsi, the posterior extension of the external oblique and the serratus posterior inferior muscles, a middle layer composed of the sacrospinalis, and the posterior portion of the internal oblique, an inner layer composed of the quadratus lumborum and iliacus, the transversus abdominis muscle, and an innermost layer, of the psoas muscle and the diaphragm (Fig. 3).

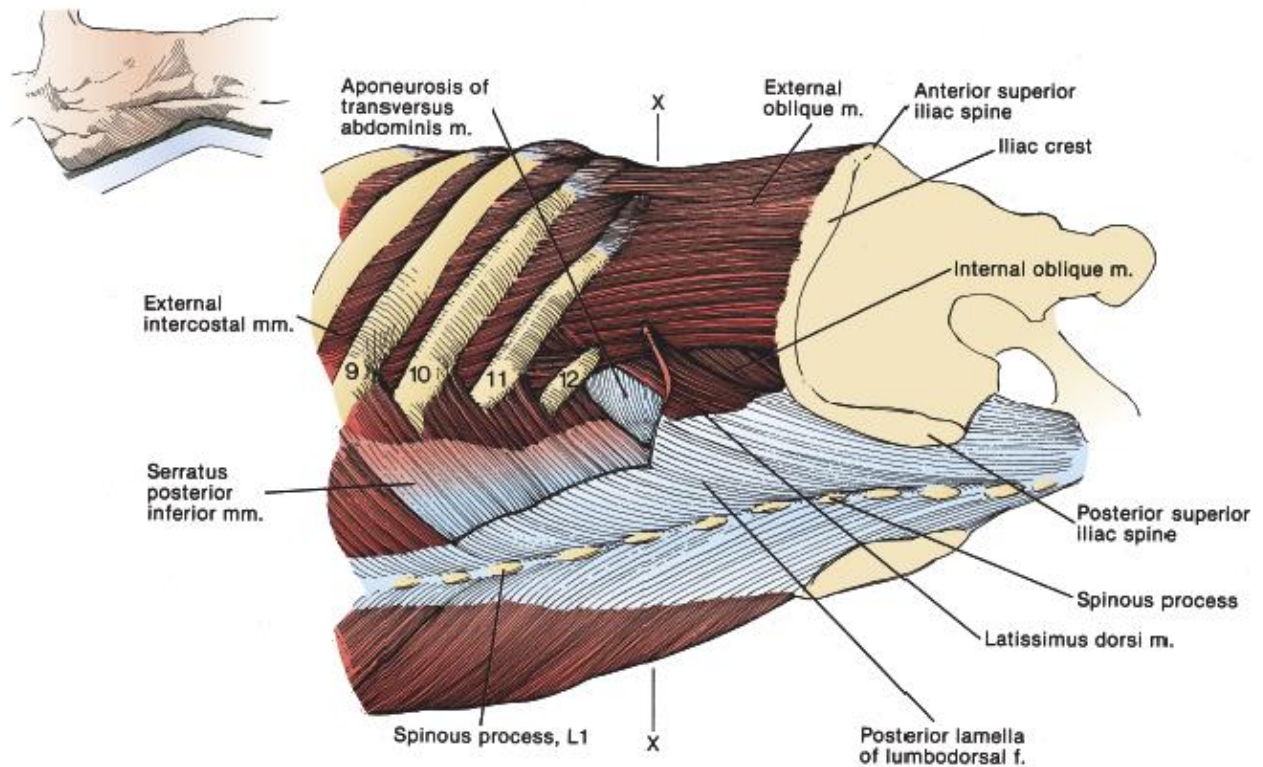


Figure 3: Posterolateral and posterior body wall, Adapted from MacLennan, Gregory T., and Frank Hinman. *Hinman's Atlas of Urosurgical Anatomy*. Elsevier/Saunders, 2012.

The anterior renal fascia (also known as Gerota's fascia) encloses the kidney, adrenal gland, and perinephric fat. Gerota's fascia layers are fused anteriorly with the fascia of the opposite kidney, posteriorly with the psoas fascia and side of the vertebral body; superiorly, it splits to enclose the adrenal gland then fuses again to make the suspensory ligament of the adrenal gland, which fuses with the diaphragmatic fascia, inferiorly, the posterior layer fuses with the iliac fascia, the anterior layer fuses with the connective tissue of the iliac fossa (Figure 4) ³.

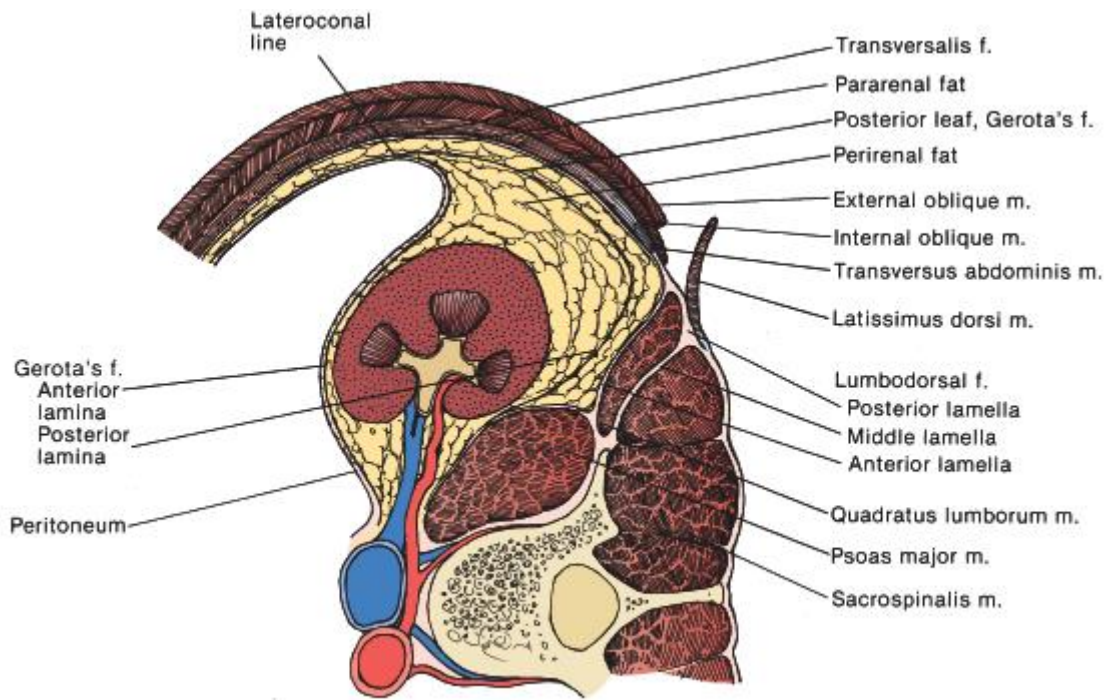


Figure 4: Transverse section of the kidney and its surrounding fascial layers Adapted from MacLennan, Gregory T., and Frank Hinman. *Hinman's Atlas of Urological Anatomy*. Elsevier/Saunders, 2012.

The renal hilum structures are from anterior to posterior, a single renal vein, a single renal artery, and the renal pelvis; the renal hilum is rotated anteriorly because of the psoas muscle⁴. From the retroperitoneal orientation on the right side, the right renal artery is easily identifiable as it lies anterior to the renal vein; on the left side, both the renal vein and artery are parallel to each other.

2. Renal tumors

2.1. Epidemiology

Renal cell carcinoma accounts for about 3% of all tumors, with the most significant prevalence in Western countries⁵. In 2016, 14,640 patients were diagnosed with a renal tumor in Germany. Kidney cancer incidence rates rose steadily until the mid-1990s when they hit a plateau or fell in several countries⁶. Increased diagnosis of incidental renal tumors during upper abdominal radiological examinations⁷, i.e., at a smaller tumor size and lower stage⁶, has made the renal tumor surgically treatable⁷.

Accumulating data indicates that, also within the same histological subtype, renal cell tumors constitute histologically and molecularly heterogeneous diseases⁸. Renal cell carcinoma (RCC) accounts for nearly 96% of adult renal tumors; males have been affected twice as frequently as females⁹. 65-70% of adult renal cell carcinoma (RCC) is Clear cell renal cell carcinoma (CCRCC). Papillary renal cell carcinoma (PRCC) is 15-20% of adult RCCs, differentiated into type 1 and 2; type 2 shows a worse prognosis than type 1. Chromophobe renal cell carcinoma (ChRCC) is 5-7% of adult RCCs¹⁰.

2.2. Etiology

The direct etiology of RCC variable types is still under investigation; smoking, obesity, hypertension, and diabetes are risk factors of RCC¹¹. Also, diabetes is considered a risk factor for RCC¹². A recent Systematic Analysis shows that the risk of RCC is lowered by regular exercise, low to moderate intake of alcohol, and fruit and vegetables¹².

2.3. Classification and staging systems

2.3.1. The Tumor Node Metastasis (TNM) classification system

The TNM system is recommended for clinical and scientific use (Table 1)¹³.

T - Primary Tumor			
TX	Primary tumor cannot be assessed		
T0	No evidence of primary tumor		
T1	Tumor \leq 7 cm or less in greatest dimension, limited to the kidney		
	T1a	Tumor \leq 4 cm or less	
	T1b	Tumor > 4 cm but \leq 7 cm	
T2	Tumor > 7 cm in greatest dimension, limited to the kidney		
	T2a	Tumor > 7 cm but \leq 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 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 fascia	
	T3b	Tumor grossly extends into the vena cava below the diaphragm	
	T3c	Tumor grossly extends into vena cava above the diaphragm or invades the wall of the vena cava	
T4	Tumor invades beyond Gerota fascia (including contiguous extension into the ipsilateral adrenal gland)		
N - Regional Lymph Nodes			
NX	Regional lymph nodes cannot be assessed		
N0	No regional lymph node metastasis		
N1	Metastasis in regional lymph node(s)		
M - Distant Metastasis			
M0	No distant metastasis		
M1	Distant metastasis		
pTNM stage grouping			
Stage I	T1	N0	M0
Stage II	T2	N0	M0
Stage III	T3	N0	M0
	T1, T2, T3	N1	M0
Stage IV	T4	Any N	M0
	Any T	Any N	M1

Table 1: 2017 TNM classification system¹⁴

2.3.2. Anatomic classification systems:

These are objective systems used mainly to provide information for nephron-sparing surgery or tumor ablation techniques; they evaluate tumor size, location, relation to the pelvicalyceal system, and exophytic or endophytic features¹⁴. Anatomic classification systems include the Preoperative Aspects and Dimensions Used for Anatomical (PADUA) classification system¹⁵, the RENAL nephrometry score system¹⁶, Centrality index (CI)¹⁷, Contact Surface Area (CSA)¹⁷, Arterial Based Complexity (ABC)¹⁸, and Zonal NePhRO scoring system¹⁹.

2.3.2.1. The Preoperative Aspects and Dimensions Used for Anatomical (PADUA) classification system (Table 2,3 & Fig. 5)

Anatomical feature	Score
Longitudinal (polar) location	
Superior/inferior	1
Middle	2
Exophytic rate	
50%	1
< 50%	2
Endophytic	3
Renal rim	
Lateral	1
Medial	2
Renal sinus	
Not involved	1
Involved	2
Urinary collecting system	
Not involved	1
Dislocated/infiltrated	2
Tumor size (cm)	
4 cm	1
4.1–7 cm	2
> 7 cm	3

Table 2: PADUA scoring system classification¹⁵

PADUA complexity	Score
Low complexity	6-7
Intermediate complexity	8-9
High complexity	≥ 10

Table 3: PADUA score complexity¹⁵

Introduction

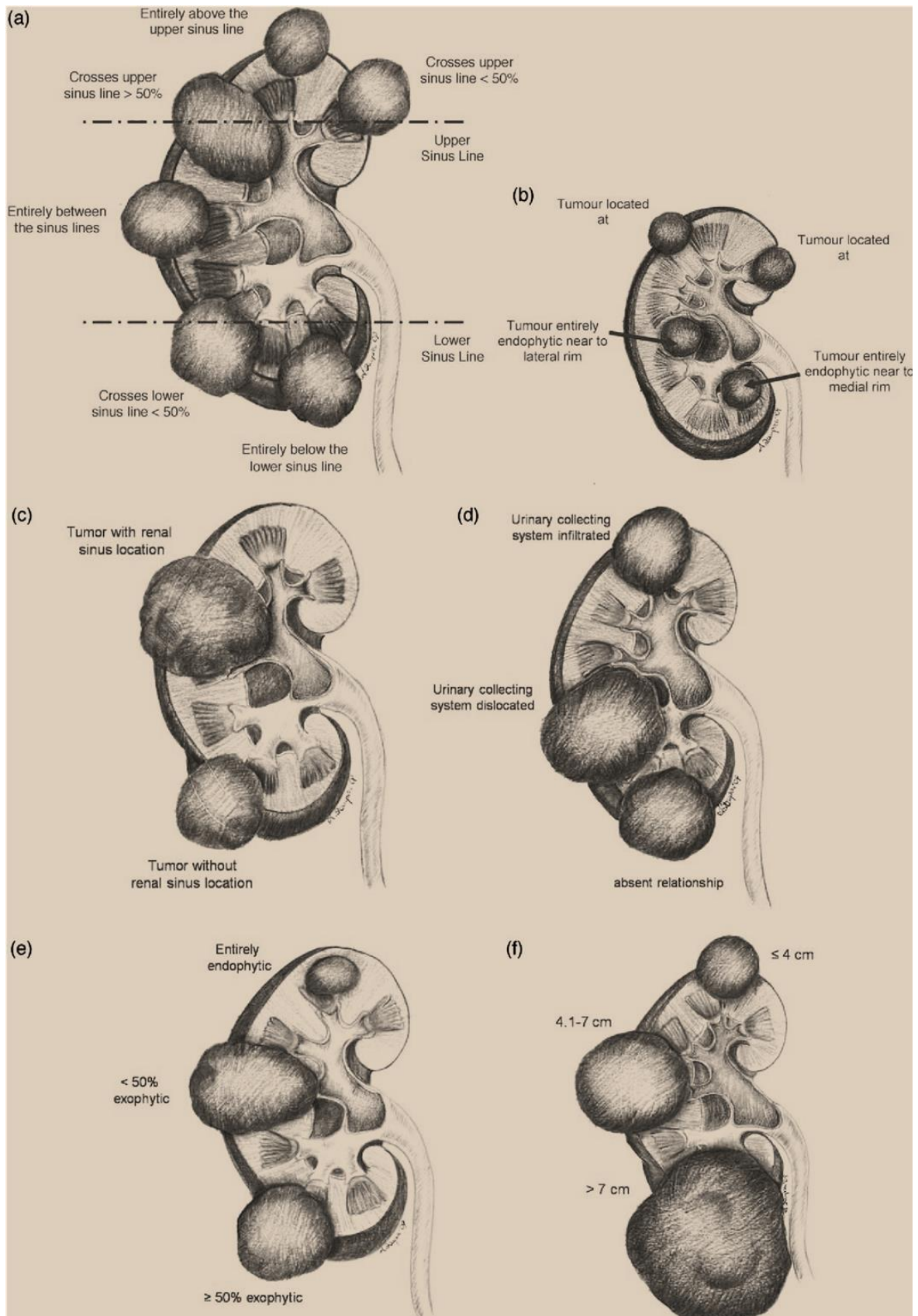


Figure 5: a) Longitudinal classification of the tumors; (b) margin location of the tumors; (c) tumor relationship with renal sinus; (d) tumor relationship with urinary collecting system; (e) tumor deepening into the parenchyma; (f) tumor size classification¹⁵

2.4. Treatment of localized renal tumors

2.4.1. Surgical treatment

2.4.1.1. Radical nephrectomy versus nephron-sparing surgery

The increased diagnosis of incidental renal tumors during upper abdominal radiological investigations²⁰, i.e., at a smaller tumor size and lower stage⁶, has made the renal tumor surgically treatable⁷. Partial nephrectomy is the treatment of choice for localized RCC (pT1)²¹. Studies demonstrate improved kidney function maintenance and a reduced risk of coronary disease development compared to radical nephrectomy²².

2.4.1.2. Adrenalectomy

Upper pole involvement does not predict involvement of the adrenal gland²³. Unless there is clinical evidence of adrenal gland invasion, Adrenalectomy should not be performed¹⁴.

2.4.1.3. Lymph node dissection

There is no oncological survival advantage of lymph node dissection in clinically negative lymph node involvement (N0), including high-risk nonmetastatic RCC²⁴.

2.4.1.4. Embolization

Embolization can be used to control flank pain or visible hematuria in surgically unfit patients or unresectable tumors²⁵.

2.4.1.5. Radical nephrectomy techniques

All radical nephrectomy techniques: open, laparoscopic with its variations (conventional, hand-assisted, retroperitoneal or transperitoneal approach), robot-assisted radical nephrectomy is of similar oncological outcomes with significant benefits for minimally invasive techniques as less postoperative pain and shorter Length of hospital stay²⁶⁻²⁹.

2.4.1.6. Partial nephrectomy

2.4.1.6.1. Open partial nephrectomy

In 1884, Wells proposed open partial nephrectomy (OPN) as a treatment option for localized renal masses; Czerny was the first to use the new technique back then. Because of high postoperative morbidity, It was not until Vermtoon in 1950 suggested removing of the peripheral tumors with a margin of normal parenchyma, leading to more adoption of the technique³⁰.

2.4.1.6.2. Laparoscopic partial nephrectomy

laparoscopic PN (LPN) was introduced in 1993; LPN was considered an alternative for OPN after about a decade when large series with long follow up showed comparable oncological outcome^{31,32}. Although the technical difficulties and long learning curve, LPN is widely adopted because of its proven benefits, mainly decreased operative time, intraoperative blood loss, and d length of hospital stay (LOS)³³.

Gill et al. reported the retroperitoneal approach's initial case (Fig.6,7) for LPN³⁴. A meta-analysis suggests that the retroperitoneal approach provides shorter operative time and comparable surgical and oncological outcomes than the transperitoneal approach, especially with posterior renal masses³⁵.

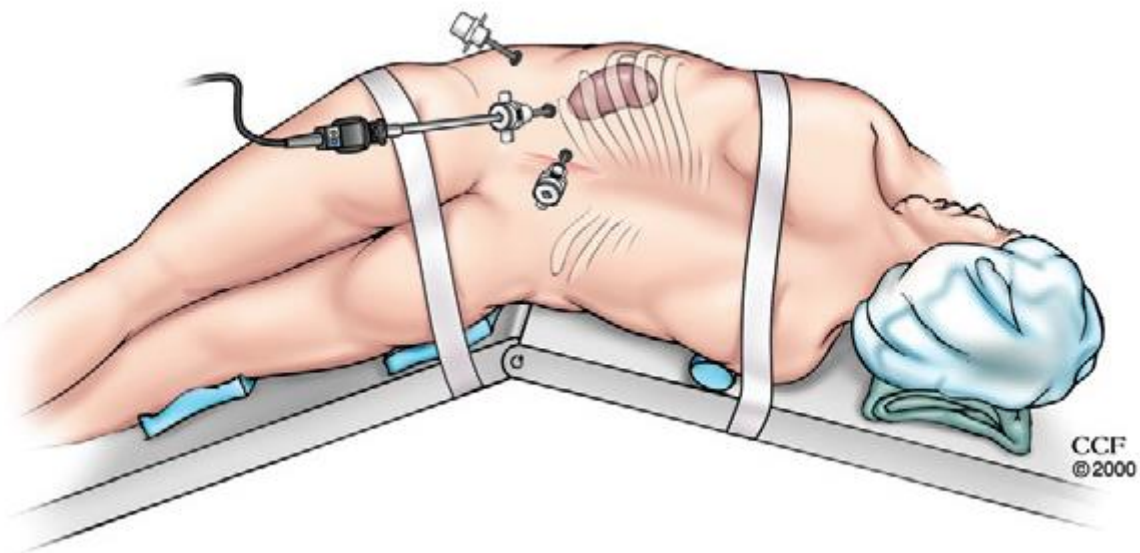


Figure 6: Patient positioning for left retroperitoneal access with port placement. (Cleveland Clinic Center for Medical Art & Photography, 1999-2012.)

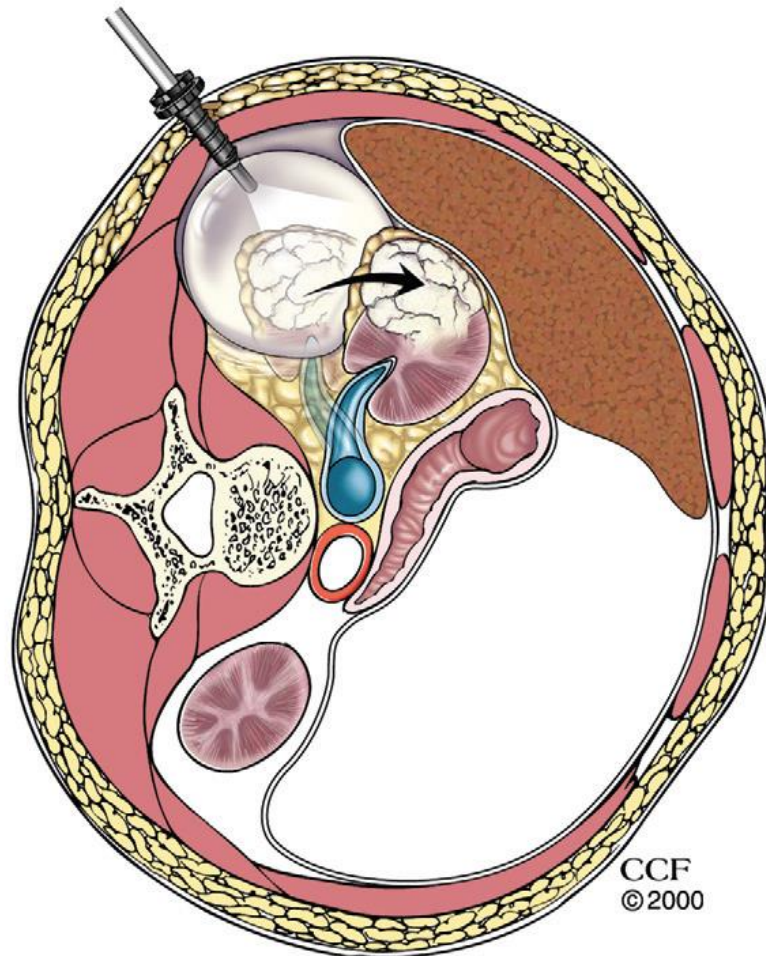


Figure 7: Retroperitoneal access: balloon dilation. (Cleveland Clinic Center for Medical Art & Photography © 1999-2012)

2.4.1.6.3. Robotic-assisted partial nephrectomy

Robotic surgery provides the benefits of three-dimensional (3D) vision in high resolution, a wide range of endowrist instrument motion with fine surgical movement scaling. The first series of robotic-assisted partial nephrectomy (RPN) was published in 2004³⁶; the popularity of RPN has grown considerably³⁷. Although similar oncological outcomes, the RPN shows lower complication rates and shorter hospital stay than open partial nephrectomy (OPN)³⁸. RPN has widely replaced laparoscopic surgery as the favored minimally invasive approach for localized renal tumors³⁹.

2.4.1.6.3.1. Transperitoneal approach

The transperitoneal approach allows robotic arms enough space to eliminate external arm collision and familiar abdominal organ landmarks, making the transperitoneal approach convenient for most robotic surgeons³⁶. Nevertheless, accessing lateral and posterior renal masses often increases operation time and difficulty³⁶. The transperitoneal approach has its limitations in the presence of adhesions due to prior abdominal surgery²¹.

2.4.1.6.3.1.1. Technique description:

The patient is placed in a flank position. The optic Hasson trocar is placed via minilaprotomy pararectal and supraumbilical. Another four trocars are inserted under sight, a 12mm trocar in the median lower abdomen and three 8 mm da Vinci trocars laterally below the costal arch, the lateral lower abdomen above the iliac spine, and the lower abdomen (Fig. 8). After medial mobilization of the bowel and ureteral identification, hilar dissection was carried out utilizing the renal vein as the primary landmark with renal artery isolation.

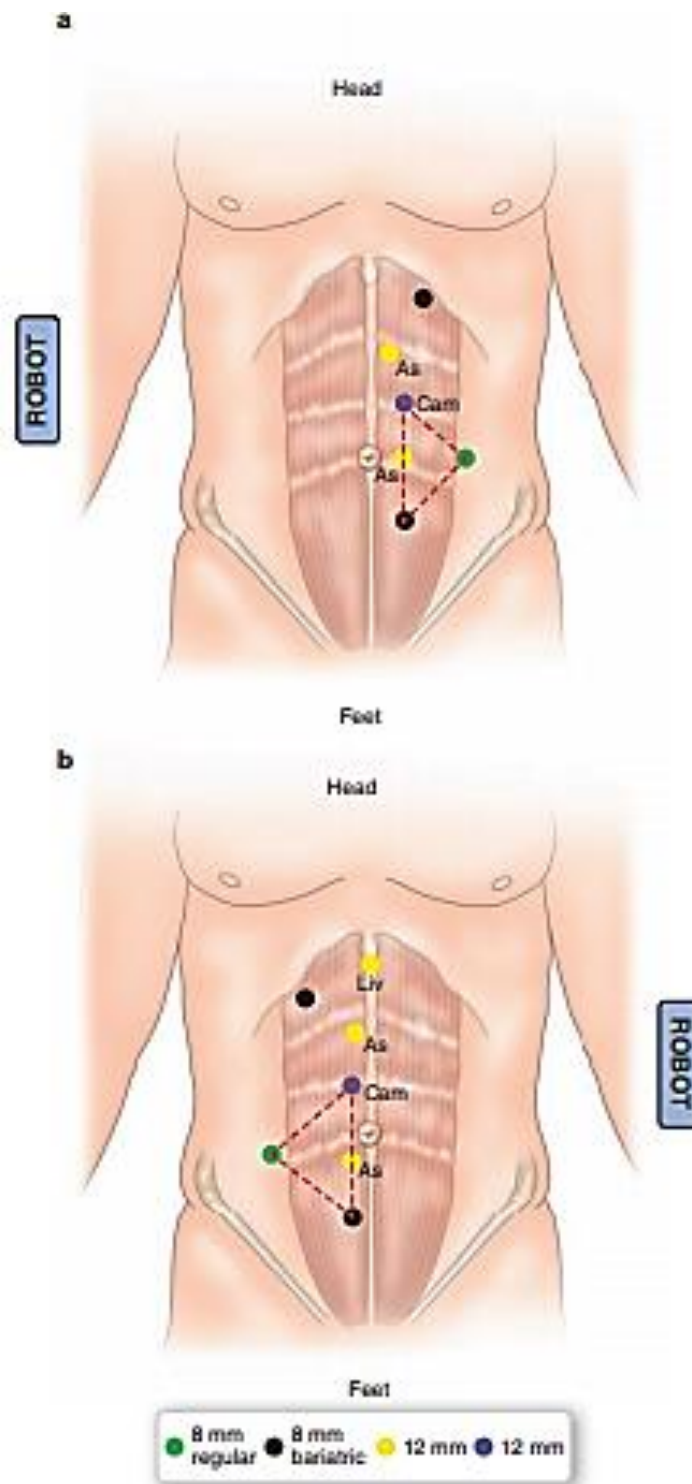


Figure 8: Trocar placement for transperitoneal robotic-assisted partial nephrectomy (a) Trocar placement for left partial nephrectomy. (b) Trocar placement for right partial nephrectomy (Su, L.-M. (Ed.). (2017). *Atlas of Robotic Urologic Surgery*)

2.4.1.6.3.2. Retroperitoneal approach

As approaches to access the retroperitoneal space have been established, space limitation and unfamiliar anatomy are no longer obstacles in adopting the retroperitoneal approach⁴⁰. The retroperitoneal approach tends to be more appropriate than the transperitoneal approach to access tumors on the dorsal renal surface, allowing more convenient access to the renal hilum and reducing the need to mobilize bowel or kidney ²¹.

2.4.1.6.3.2.1. Technique description

The patient is placed in the lateral decubitus position (Fig. 9). The optic Hasson trocar is placed 2 cm above the lumbar triangle. The lumbodorsal fascia is traversed with Metzenbaum scissors, blunt dissection of the perforation canal to achieve the stab incision. Palpation of the Psoas muscle and the 12th rib. Entering under vision with laparoscopic 0° camera with a dilatation trocar (a 130-millimeter KiiR balloon trocar (Applied Medical, Rancho Santa Margarita, CA), Inflation of the trocar with 500 ml air. Removal of the dilatation balloon and placement of 12 mm optic Hasson trocar⁴¹.



Figure 9.1: Patient positioning for retroperitoneal robotic-assisted partial nephrectomy. (Image courtesy of Daniar Osmonov, MD)



Figure 9.2: Patient positioning for retroperitoneal robotic-assisted partial nephrectomy. (Image courtesy of Daniar Osmonov, MD)

Retropneumoperitonium is created. The first Da Vinci trocar is inserted 3 cm above and at least 7 cm away from the camera trocar along the posterior axillary line. The second Da Vinci trocar is placed along the anterior axillary line and at least 7 cm away from the camera trocar. Insertion of the working trocar 3 cm above the anterior superior iliac spine (Fig.10). Robot on the patient's head (Fig.11).

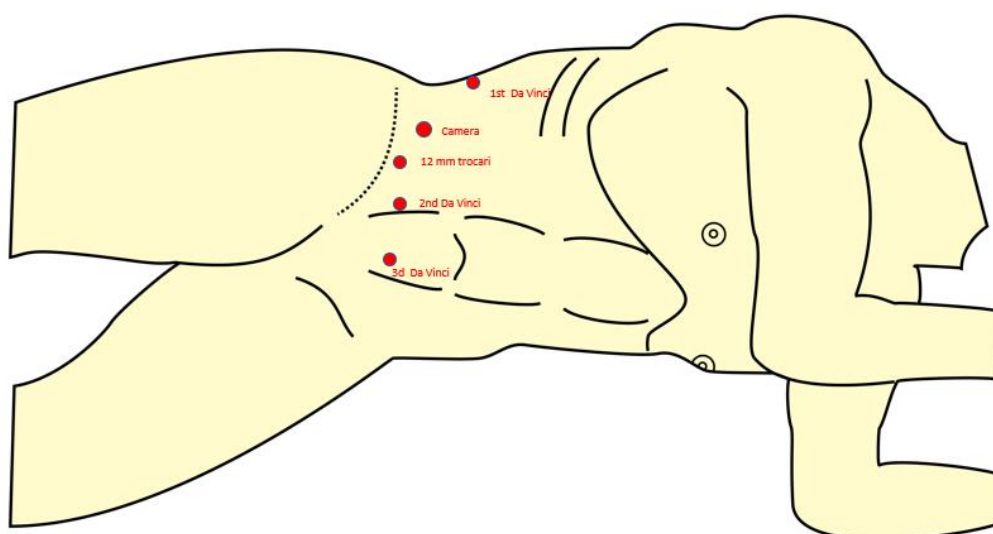


Figure 10: Schematic imaging for Trocar positioning for the retroperitoneal approach (image courtesy of Daniar Osmonov, MD)

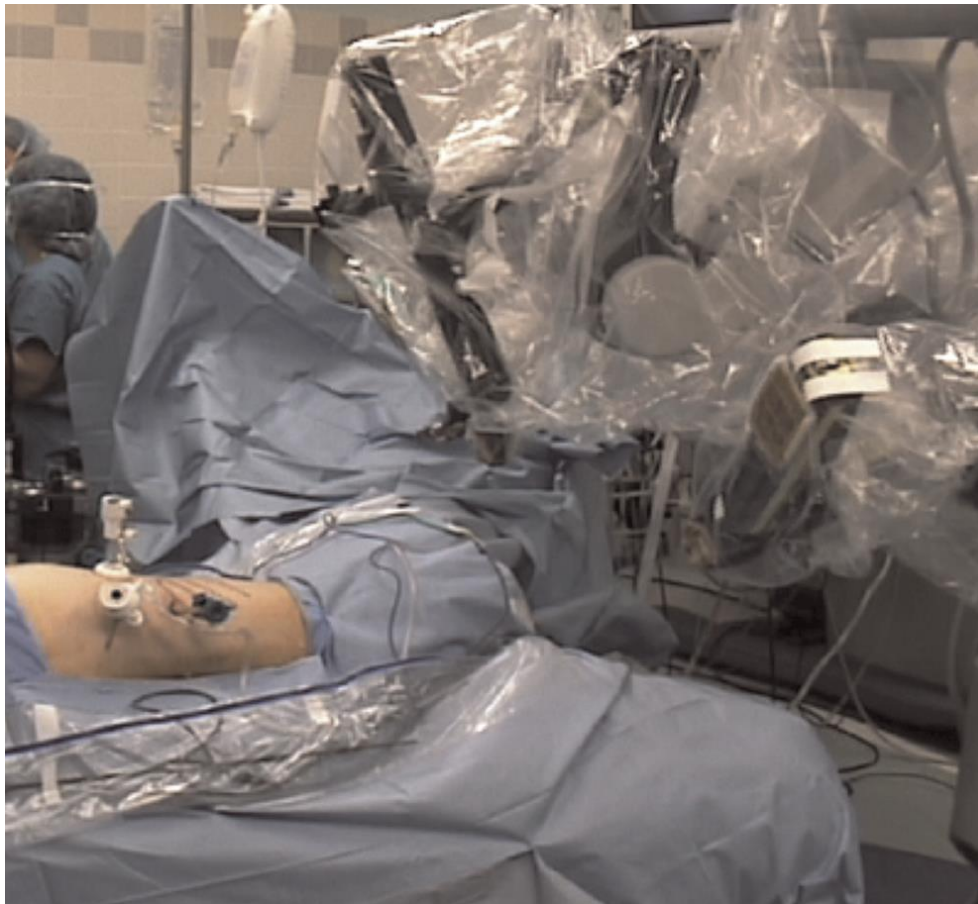


Figure 11: Docking of the robot during retroperitoneal surgery. The robot is docked over the patient's head, parallel to the spine. Reproduced from Swedish Urology archive.

Inspection of retroperitoneum. The peritoneum is bluntly dissected medially, followed by preparation and exposure of the renal hilum, the ureter. The renal artery is secured with a vascular loop. Complete mobilization of the kidney is routinely unnecessary so that the lateral aspect of the kidney fixation is left. Fascia renalis posterior and the fat capsule leaving the fat overlying the tumor are sharply resected to recognize the dissection margin better and follow the renal parenchyma restoration. For complete or partial endophytic tumors, a laparoscopic ultrasound probe is used.

When applicable, warm ischemia is initiated to excise the target tumor by clamping the renal vessels or selective clamping of the tumor artery, and early unclamping is routinely preferred⁴². Then, the renal collecting system was closed using an absorbable monofilament suture. Renorrhaphy was accomplished by a series of sutures using the sliding clip technique⁴³.

2.4.1.6.4. Complications of robotic partial nephrectomy

Complications are an essential parameter to assess the safety and complexity of any surgical intervention⁴⁴. In addition to general surgical complications, which are generally assessed using Clavien-Dindo classification (Table 4)⁴⁴, robotic partial nephrectomy may have additional complications related to the operation's nature more than the technique used. Robotic surgery-specific complications include conversion to radical nephrectomy because of intraoperative complication or difficulty in tumor resection as in hilar tumors conversion to open partial or radical nephrectomy in the previous operation or obesity cases⁴⁵. Injuries to the collecting system, intestine, liver, spleen, or postoperative bleeding are related to the PN regardless of operative technique⁴⁶.

Grade	Definition
Grade I	<p>Any deviation from the normal postoperative course without the need for pharmacological treatment or surgical, endoscopic, and radiological interventions</p> <p>Allowed therapeutic regimens are drugs as antiemetics, antipyretics, analgesics, diuretics, electrolytes, and physiotherapy. This grade also includes wound infections opened at the bedside</p>
Grade II	<p>Requiring pharmacological treatment with drugs other than such allowed for grade I complications</p> <p>Blood transfusions and total parenteral nutrition are also included</p>
Grade III -Grade IIIa -Grade IIIb	<p>Requiring surgical, endoscopic, or radiological intervention</p> <ul style="list-style-type: none"> -Intervention not under general anesthesia -Intervention under general anesthesia
Grade IV -Grade IVa -Grade IVb	<p>Life-threatening complication (including CNS complications) * requiring IC/ICU management</p> <ul style="list-style-type: none"> -Single organ dysfunction (including dialysis) -Multiorgan dysfunction
Grade V	Death of a patient
Suffix "d"	<p>If the patient suffers from a complication at the time of discharge, the suffix "d" (for "disability") is added to the respective grade of complication. This label indicates the need for a follow-up to evaluate the complication fully.</p>
<p>Brain hemorrhage, ischemic stroke, subarachnoidal bleeding, but excluding transient ischemic attacks. CNS, central nervous system; IC, intermediate care; ICU, intensive care unit.</p>	

Table 4: The Clavien-Dindo classification of surgical complications ⁴⁴

2.5. Objective

The study evaluates both surgical approaches, TRPN and RRPN, for localized renal masses performed in the department of urology at the University medical center Schleswig-Holstein, Campus Kiel.

Patients and Methods:

The study protocol was approved by our ethics committee (Medical Faculty's Ethics Committee of Christian-Albrecht- University of Kiel, D 487/20). All procedures applied are part of standard routine care, in line with European Urology Association guidelines, with ethical principles following the latest version of Helsinki's Declaration.

From our prospective data register at the university medical center of Schleswig Holstein, Campus Kiel, we reviewed 224 consecutive RPN for treatment of renal masses over five years between 2014 and 2019: in 163 patients via a transperitoneal approach and 61 patients via a retroperitoneal approach by three surgeons using a da Vinci® Si surgical system.

The choice of robot approach (RRPN vs. TRPN) was based on tumor location: RRPN was primarily selected for posterior tumors, TRPN was selected for, though not limited to, anterior tumors.

Patient demographics, operative, perioperative, and oncological and functional outcome data were analyzed retrospectively for all patients and arranged into an anonymized database.

1. Standard patient protocol

1. Preoperative

All the patients underwent preoperative preparation, including laboratory investigations (Complete blood picture count (CBC), renal function tests, and urinalysis), Clinical assessment, detailed medical history, radiological investigations (CT, MRT), and anesthesiologic fitness.

2. Operative:

Da Vinci Si robot (Sunnyvale, Intuitive Surgical Inc., CA) was used in TRPN and RRPN. All operations were carried out under general anesthesia. All relative operative data were collected.

3. Postoperative

- Laboratory investigations were performed 24 hours postoperatively, and according to clinical and laboratory findings, additional testing may follow.
- The intraoperative drain is usually removed on the second postoperative day.
- The patient was usually discharged between the 4th to sixth postoperative day.

2. Statistical analysis parameters

1. Preoperative data:

1. Patient demographics:

- Age
- Sex
- BMI (Body Mass Index)
- ECOG/WHO PS (Eastern Cooperative Oncology Group/World Health Organization Performance Status)

2. Comorbidities assessment:

- Charlson Comorbidity Index
- Solitary kidney.
- Renal insufficiency stage
- Diabetes
- Arterial Hypertension
- Peripheral vascular disease
- Cardiovascular disease
- Cerebrovascular disease
- Lung disease
- Second malignancy
- Stone disease
- Smoking
- Alcohol
- Anticoagulation medications
- Hypertension medications
- Diabetes medications
- Diuretics

3. Oncological assessment:

- Presence of multiple tumors
- Site of the tumor
- Clinical size of the tumor
- Imaging Studies
- PADUA Score
- Planned surgical approach
- TNM clinical classification

4. Laboratory investigations:

- Hemoglobin
- Hematocrit
- Creatinine
- eGFR (estimated Glomerular Filtration Rate)

2. Operative data:

- Operation date
- ASA (The American Society of Anesthesiologists physical status classification system) Score
- Operative technique and approach
- Operative time
- Indication for the operation (elective or emergency)
- Number of tumors
- Surgeon
- Console time
- Time to reach renal hilum
- Type of ischemia
- Clamping type and level
- Intraoperative ultrasound
- Intraoperative mannitol®
- Intraoperative fluorescence
- Ischemia time
- Early unclamping
- Collecting system injury
- Collecting system protective measures
- Adrenalectomy
- Lymphadenectomy
- Blood loss

3. Postoperative data

1. Laboratory investigations:

- Hemoglobin
- Hematocrit
- Creatinine
- eGFR (estimated glomerular filtration rate)

2. Oncological data:

- Multifocality
- Tumor size
- Histopathology
- Fuhrmann grade
- Sarcoma percentage
- Necrosis
- Perirenal fat invasion
- Sinus fat invasion
- Adrenal invasion
- Gerota's fascia invasion
- surgical margin status
- TNM pathological classification

3. Complications:

- Conversion
- Type of conversion (to OPN, or radical nephrectomy)
- Intraoperative of complications
- Intraoperative transfusion
- Postoperative complications
- Postoperative transfusion
- Clavien grade
- Nephrectomy
- Fever
- Infection
- Urinoma

Statistical Analysis:

Matched-pair analysis between the RRPN and TRPN groups was performed using an algorithmic approach in Python programming language. The programming library sklearn (<https://scikit-learn.org>) was applied with logistic regression as a modeling method. The matching process simulates randomization – as a result, we get two groups of equal size, which are balanced for specific parameters.

A total of 51 pairs were matched with propensity score precision down to 2 digits. The matching criteria used were age, Charlson comorbidity index, BMI, the grade of renal insufficiency, tumor diameter, and PADUA score.

A two-sample t-test and Mann-Whitney test for continuous and categorical parameters were employed to determine any significant differences for each matching characteristic between the two groups; the test showed that both groups are homogeneous. A p -value of < 0.05 considered significant. The implementation was performed in Python with the library scipy (<https://docs.scipy.org/doc/scipy/reference/stats.html>).

SPSS 25 was used for statistical analysis: a univariate analysis using two-sample t-test (mean and standard deviation for continuous variables), Mann-Whitney-test (median and range for continuous variables), and chi-square test (percentage for categorical variables) were employed to compare perioperative and postoperative data with statistical significance at $p < 0.05$.

A multivariate analysis with binary logistic regression was used to correlate between statistically significant variables and the approach.

Results:

After propensity score matching, 51 matched pairs were identified in both groups with a well-balanced distribution of preoperative demographic and tumor parameters (Table 5).

Parameter	TRPN*	RRPN**	p-Value
Patient Demographics			
Median age, years	68 (41-83)	68 (33-86)	0.79
Median BMI, kg/m ²	27.4 (19.9-43.5)	27.8 (16-44)	0.75
Female patients, n (%)	18 (35.3%)	20 (39.2%)	0.68
Median Charlson comorbidity index	2	2	0.96
Solitary kidney, n (%)	2 (3.9%)	2 (3.9%)	1.00
Median preop hemoglobin, g/dl	13.7 (9.7-16.4)	13.6 (8.4-16.3)	0.49
Median preop eGFR, ml/min	71 (21-106)	110 (101-117)	<0.001
Tumor characteristics			
Median tumor size, mm	26 (8.2-72)	27 (6.6-65)	0.57
Right-sided tumor, n (%)	30 (58.8%)	27 (52.9%)	0.83
Median PADUA score	9 (6-12)	8 (6-12)	0.44
PADUA (Fig. 15)			
• Low complexity, n (%)	16 (31.4%)	14 (27.5%)	0.88
• Intermediate complexity, n (%)	18 (35.3%)	20 (52.6%)	
• High complexity, n (%)	17 (33.3%)	17 (33.3%)	
Face			
• Anterior, n (%)	25 (49%)	6 (11.8%)	<0.001
• Posterior, n (%)	17 (33.3%)	39 (76.4%)	
• lateral, n (%)	9 (17.6%)	6 (11.8%)	
* TRPN: Transperitoneal Robotic-Assisted Partial Nephrectomy ** RRPN: Retroperitoneal Robotic-Assisted Partial Nephrectomy after propensity score matching.			

Table 5: Patients' Demographics and Radiological Characteristics of Renal Tumors.

The median age was 68 years old in both groups, with the age range between 33 and 86 years old in RRPN, wherein TRPN between 41 and 83 years old (Fig.12). The median BMI was 27.8 vs. 27.4 in RRPN vs. TRPN, respectively, with a BMI range between 16 and 44 in RRPN and between 19.9 and 43.5 in TRPN (Fig.13).

The median clinical tumor size was 26 mm vs. 27 mm in TRPN and RRPN, respectively. ($p= 0.57$), The median PADUA score was 9 in the TRPN group and 8 in RRPN ($p= 0.88$), with 33% highly complex tumors in both groups (Fig. 14). TRPN was used for anterior 49 % and R.R.P.N. for posterior tumors 76% ($p<0.001$), in 14 % tumor location was lateral (between anterior or posterior) (17.6 % T.R.P.N, 11.8% R.R.P.N., $p<0.001$). However, a difficult tumor localization was not a contraindication to perform either TPRN or RRPN.

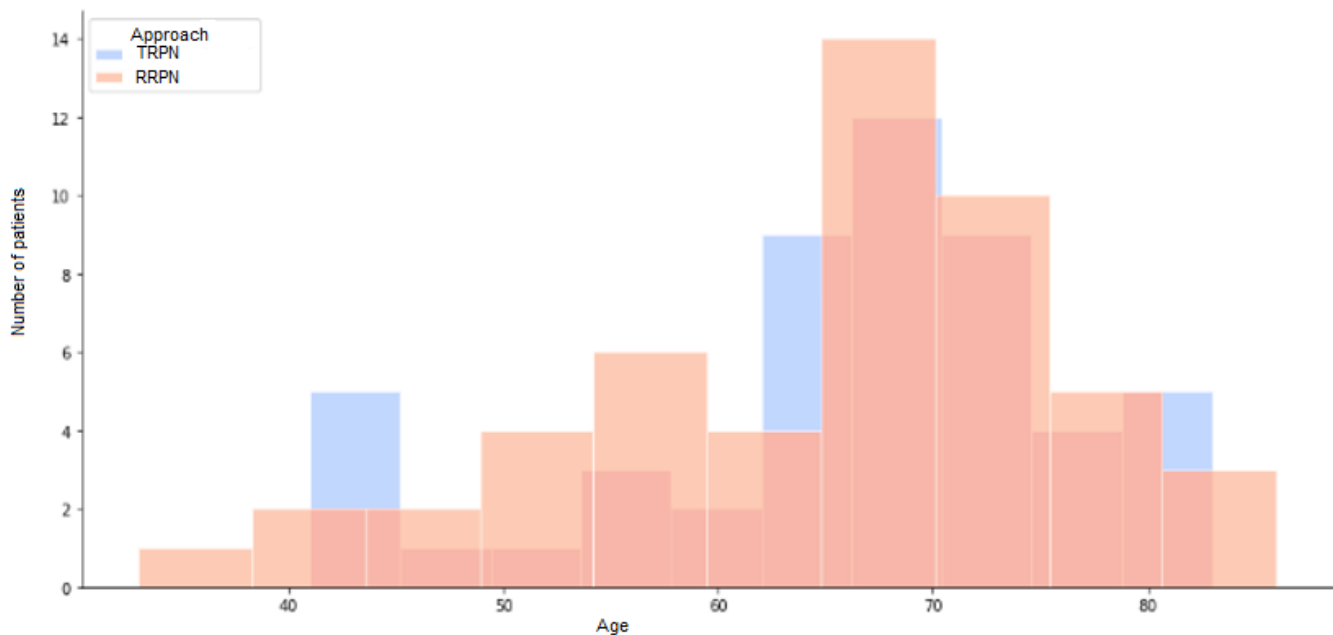


Figure 12: Age distribution in both groups

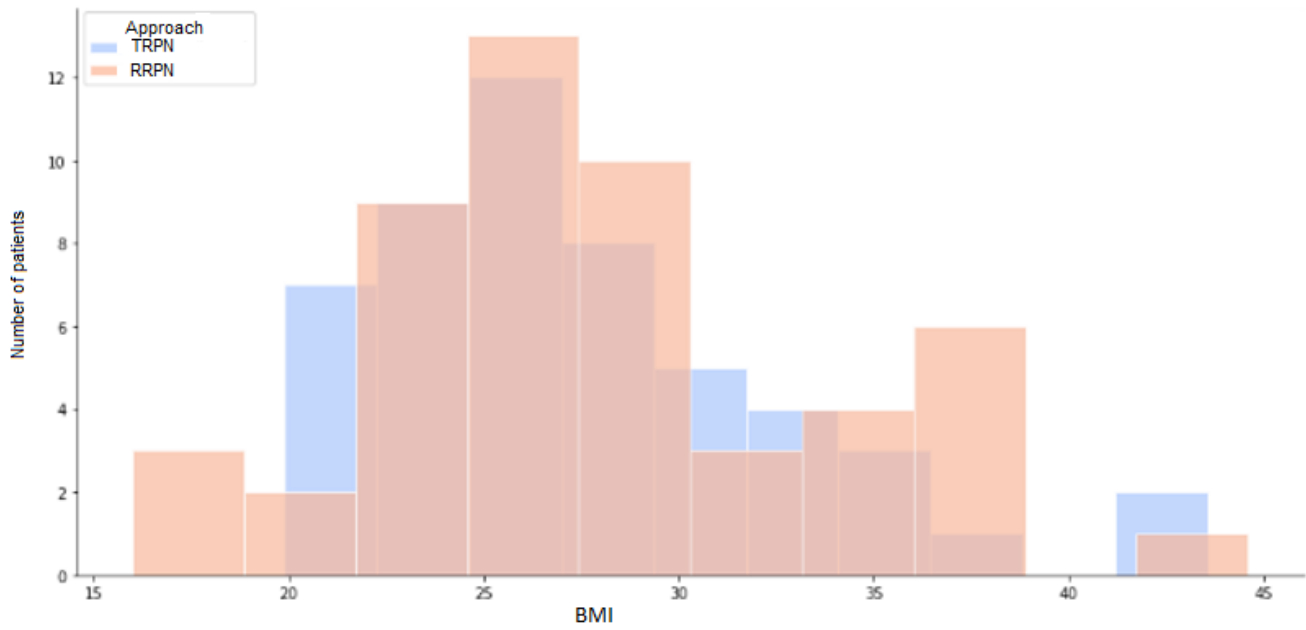


Figure 13: BMI (Body mass index) in both groups.

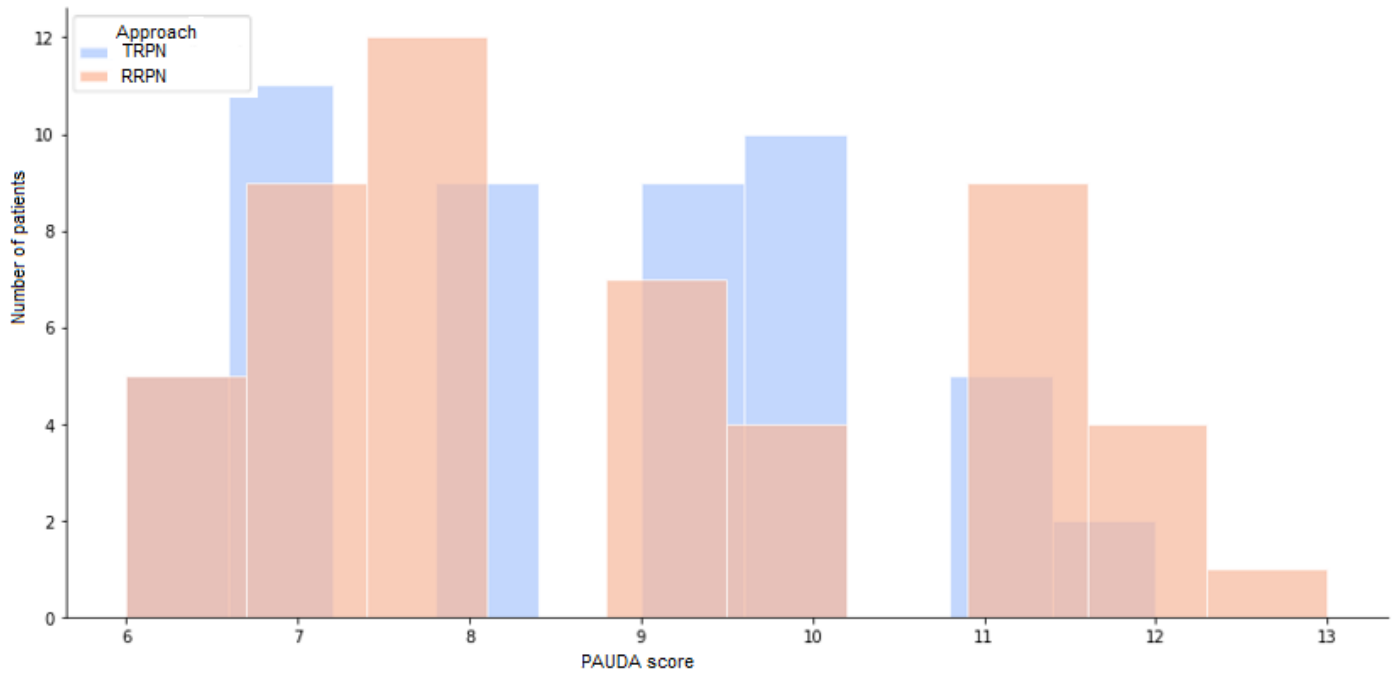


Figure 14: PADUA score in both group

The mean operative time was shorter in the RRPN group with 143 vs. 150 minutes ($p=0.63$). Off-clamp resection of the tumor was performed in two TRPN and two RRPN cases. Access to the renal hilum was significantly earlier in RRPN (Fig.15), with 21 minutes than 41 minutes in the TRPN group ($p<0.001$). The warm ischemia time was shorter for the retroperitoneal group with ten vs. 12 minutes ($p=0.07$) (Fig. 16). Early unclamping was done in 71% of RRPN cases than 48% of TRPN cases ($p=0.02$). The conversion was necessary for four patients (2 TRPN, 2 RRPN, $p=1.00$) with three robot-assisted nephrectomies and one open nephrectomy. Both groups show no difference in the negative surgical margins, 94.1% in TRPN, and 98% in RRPN ($p=0.30$).

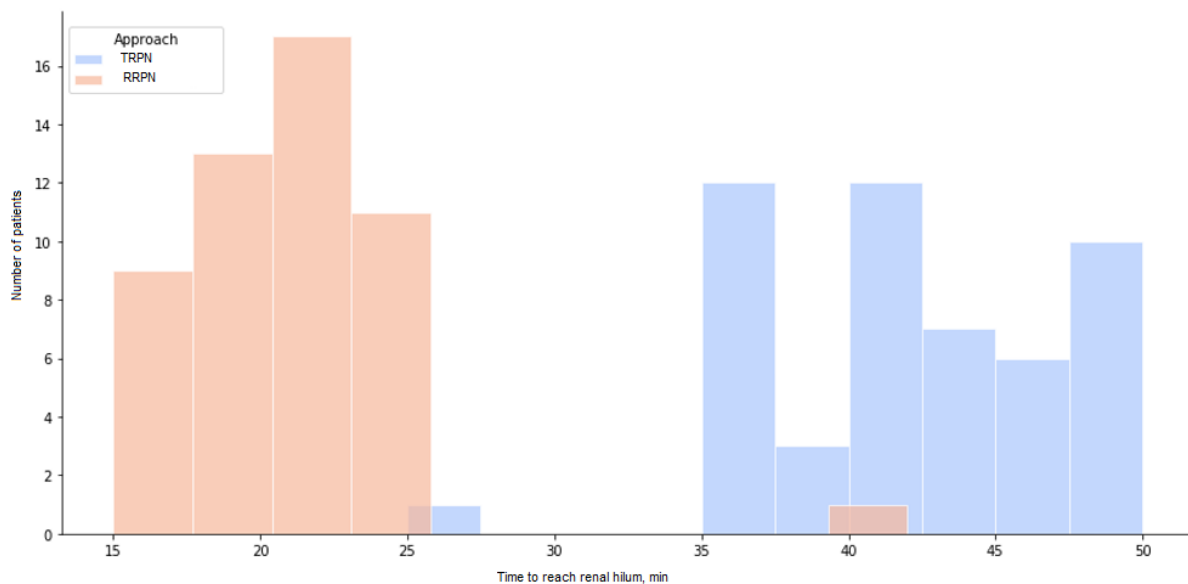


Figure 15: Time to reach the renal hilum (min) in both groups

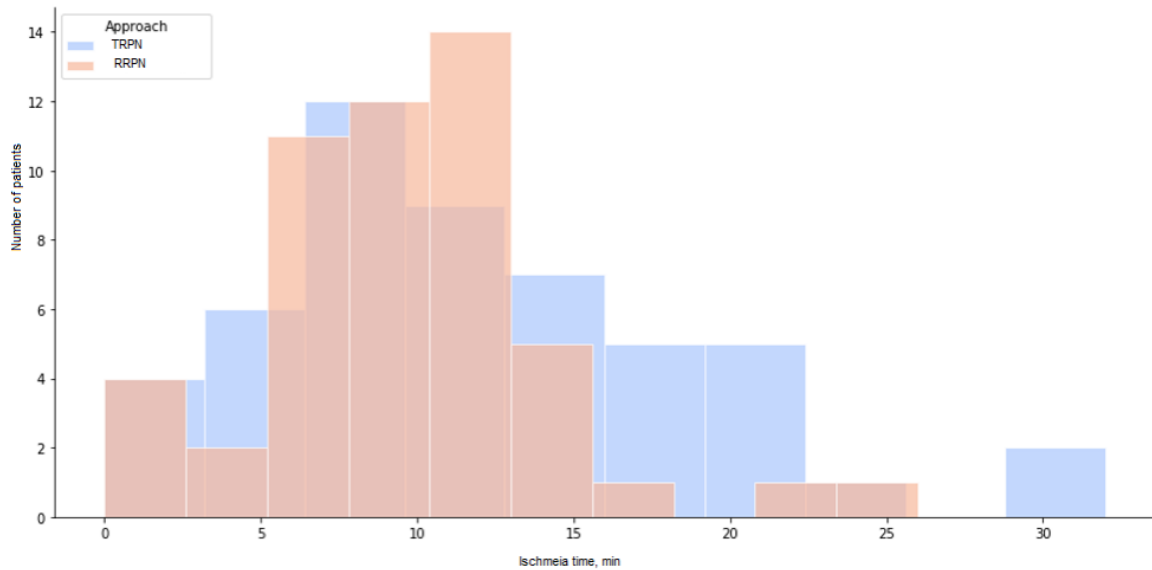


Figure 16: Ischemia time (min) in both groups

In the postoperative course, complications were documented in 28 patients with 39.2% in the TRPN group and 15% in the RRPN group ($p=0.008$), including major complications (Calvien-Dindo classification $> II$) in 25.5% vs. 4% ($p=0.01$) in TRPN vs. RRPN, respectively. The most frequent major complication was hemorrhage requiring intervention (TRPN 15.6 % vs. RRPN 0%, $p=0.39$) followed by urinoma (TRPN 2% vs. RRPN 0%, $p=0.15$). Moreover, postoperative blood transfusion rates were higher after TRPN (17.6% vs. 7.8%, $p=0.13$). The median Length of hospital stay was six days in both groups. ($p=0.11$). Renal functional results were comparable between both groups; median eGFR before discharge was 62 vs. 104 ml/min in TRPN and RRPN, respectively ($p= 0.01$) with no delta eGFR loss in both groups and with an increase of 1 ml/min in the TRPN group vs. 3 ml/min in the RRPN group ($p= 0.33$). Histopathology revealed malignancy in 74.5 % of the cases, with a clear cell renal carcinoma as the most common pathology (58.8 vs. 31%, $p=0.07$). A positive surgical margin was detected in 5.9% of the TRPN and 2% of the RRPN cases ($p=0.30$). Notably, the time to access the renal hilum was the only significant variable ($p<0.001$) on a multivariate binary logistic regression model. (Table 6)

Parameter	TRPN*	RRPN**	p-Value
Intraoperative Parameters			
Global ischemia, n (%)	30 (61%)	47 (94%)	<0.001
Median warm ischemia time, mins	12 (0-32)	10 (0-26)	0.07
Early unclamping, n (%)	23 (47.9%)	34 (70.8%)	0.02
Mean Time to reach Hilum, min	41 (25-50)	21 (15-42)	<0.001
Intraoperative transfusion, n (%)	0 (0%)	2 (3.9%)	0.31
Conversion, n (%)	2 (3.9%)	2 (3.9%)	1.00
-To robotic nephrectomy, n	2	1	
-To open nephrectomy, n	0	1	
Postoperative course			
Overall complications, n (%)	20 (39.2 %)	8 (15.1%)	0.008
Postoperative transfusion, n (%)	9 (17.6%)	4 (7.8%)	0.13
Major surgical complication (Clavien \geq 3), n (%)	13 (25.5 %)	2 (4%)	0.01
Urinoma, n (%)	2 (3.9%)	0 (0%)	0.15
Median Length of hospital stay, days	6 (4-20)	6 (4 -21)	0.11
Laboratory and pathology results			
Mean hemoglobin D1, g/dl	10.9 (6.5-13.8)	10.9 (7.4- 14.4)	0.97
Mean eGFR before discharge, ml/min	62.8 (15-102)	104 (101-107)	0.01
Median loss of eGFR, ml/min	4 (-36 - 40)	1 (-28 - 33)	0.33
Median pathological tumor size, mm	25.5 (2-178)	30 (7-70)	0.19
Negative surgical margin, n (%)	48 (94.1%)	50 (98%)	0.30
* TRPN: Transperitoneal Robot-Assisted Partial Nephrectomy ** RRPN: Retroperitoneal Robot-Assisted Partial Nephrectomy after propensity score matching			

Table 6: Operative and postoperative parameters.

Discussion:

Both RRPN and TRPN are effective and imperatively efficient in comparison to open surgical access. However, RRPN tends to be more appropriate than the TRPN to excise tumors on the dorsal renal surface⁴⁷, allowing easier access to the renal hilum, as the renal artery lies anterior to the renal vein on the dorsal aspect of the kidney⁴⁸; RRPN also reduces the necessity to mobilize the bowel or the kidney. The transperitoneal approach has its limitations in the presence of adhesions following prior abdominal surgery⁴⁹. In a multicenter cohort study, the retroperitoneal approach was preferred in patients with previous abdominal surgery (11.2% vs. 5.4%); the presence of dorsal tumors in those patients was similarly prevalent in patients without prior abdominal surgery (38.8% vs. 43.3%, $P = 0.286$)⁵⁰. Another recent cohort study of the retroperitoneal approach in 110 obese patients with body mass indices (BMI) > 30 kg/m² showed shorter operation time, warm ischemia time, and less blood loss than TRPN⁵¹.

We have presented 224 patients undergoing RRPN (n= 63) and TRPN (n= 161) for cT1 tumors. We found that RRPN shows a comparable operative time, warm ischemia time, and Length of hospital stay with a shorter time to reach the renal hilum ($p < 0.001$) and fewer complication rate ($p = 0.008$).

Localized renal tumors (cT1) can be either accessed via a retroperitoneal approach (mainly posterior tumors) or transperitoneal approach (mainly anterior tumors) depending on the preference of the surgeon, based primarily on the experience of the surgeon and the surgical characteristics of the patient⁴¹. In our cohort, only 11.8 % of anterior tumors were in the RRPN group; On the opposite, 33.3 % of posterior tumors in the TRPN group ($p < 0.001$). 76% of the RRPN group were posterior tumors.

Our study reveals the retroperitoneal approach's advantage to reach the renal hilum, as it is anatomically more accessible, with reduced time for mobilizing the bowel or the kidney, in contrast to the transperitoneal approach. The RRPN group showed a shorter operating time with 143 vs. 150 minutes ($p = 0.06$). In earlier studies, the operative time showed a more significant variation with 120 vs. 153 minutes (Choo et al.) and 217.2 vs. 231.7 (Stroup et al.) in RRPN vs. TRPN, respectively 41,52. However, the time needed to access the renal hilum has not previously been described; in our cohort, it was significantly shorter in the RRPN group with a mean of 21 minutes compared to 41 minutes in the TRPN group ($p < 0.001$).

The warm ischemia time was shorter in the retroperitoneal group with ten vs.12 minutes ($p=0.07$) in our patients. In previous studies, the warm ischemia time also varied between 10.8 minutes for the retroperitoneal approach vs.11.1 minutes ($p = 0.98$) by Abaza et al. and 27 vs. 30 minutes ($p<0.01$) reported by Sharma et al.^{53,54}. Our results, however, dispute those by Tanaka et al., Hughes-Hallett et al., and Maurice et al. have shown longer warm ischemia time in the RRPN groups⁵⁵⁻⁵⁷.

The rates of early unclamping procedures were significantly higher for 71% of the cases in RRPN compared to 48% of the cases in TRPN ($p=0.02$), showing that the retroperitoneal approach may offer better exposure and easier control of the renal artery as well as ease of tumor resection and bleeding control.

Although our results show approximately 23% more early unclamping in RRPN than TRPN, warm ischemia time in the RRPN group was 2 mins shorter, however without clinical significance. Compared to other studies, however, our average warm ischemia time was very short in general (10 vs.12 mins in the resp. groups), which may explain why early unclamping has not shown a significant reduction in warm ischemia time. This raises the need for a prospective randomized study to assess the approach's role and other possible factors affecting early unclamping and warm ischemia time.

The median Length of hospital stay was six days in both groups ($p=0.119$). The Length of hospital stay is significantly shorter for RRPN in early studies like in Hughes-Hallett et al., i.e., 2.5 vs. 4.6 days ($p<0.01$)⁵⁶, and Gin et al. 1.5 vs. two days ($p=0.001$)⁵⁸, adding more favorability to the retroperitoneal approach.

The German health care system requires a minimum length of hospital stay to ensure full compensation of the medical intervention costs; early discharge would harm the intervention's profitability. The comparison will not equate with health systems that encourage early patient discharge; in other words, the parameter" length of hospital stay" is not comparable in different health care systems.

Complication rates reported for RRPN and TRPN vary in the literature; thus, Mittakani et al. reports overall complication rates of 53.1% for RRPN. vs. 46.9% for TRPN ($p= 0.88$); major complications rates (Clavien-Dindo classification >II) in RRPN were 28.6% vs. 12.2% in TRPN⁴⁰, By contrast, Kim et al. have found overall complications rates as low as 7% in RRPN vs. 10% in T.R.PN. ($p=0.37$)⁵⁹. Similarly, to Mittakani, Tanaka et al., resp. Choo et al. also report higher complication rates in RRPN than in TRPN: 10% vs. 6.25%, $p=0.72$, resp. 14% vs. 4%, $p=0.28$ ^{52,55}.

In contrast to most of the studies mentioned above, our study shows a higher rate of complications in the TRPN group (39.2%) than the RRPN group (15.1%) ($p=0.08$). As the rate of major complications was 25.5% in the TRPN group and only 4% in the RRPN group ($p=0.012$).

In our study, the conversion was necessary for only four patients (two TRPN, two RRPN, $p=1$) with three radical robotic-assisted nephrectomies and one OPN representing only 1 % in each arm; Hughes-Hallett et al. reported conversion to an open approach in 2.3% of RRPN vs. 8.4% of TRPN, $p=0.23$ ⁵⁶, Mittakanti et al. reported a conversion rate of (2.1% RRPN vs. 3.8% TRPN) most to radical nephrectomy but one to open partial nephrectomy⁴⁰.

The limitations of our study lie in its retrospective nature, particularly inherent selection bias. Moreover, we could only assess the results of a limited number of surgeons; although they come from different surgical backgrounds, they all started their learning curve in the transperitoneal approach. It was not before they had developed advanced robotic surgery skills then they started the retroperitoneal approach, which might affect the rate of complications, conversion rates, and the operative time. More studies are required, particularly a prospective multicenter randomized controlled trial comparing the two approaches regarding operative, perioperative variables, survival, and oncological outcomes.

Summary:

Robot-assisted partial nephrectomy is a minimally invasive treatment option for localized kidney tumors. It can be performed either via the more routinely used transperitoneal approach or the retroperitoneal approach.

We used a matched-pair analysis to evaluate and compare the retroperitoneal (RRPN) perioperative variables and the transperitoneal (TRPN) robot-assisted partial nephrectomy.

We carried out a retrospective review of 224 patients who underwent robot-assisted partial nephrectomy between 2014 and 2019; 63 patients and 161 patients underwent retroperitoneal and transperitoneal approaches, respectively. A matched-pair analysis was performed on 51 pairs of patients. The matching criteria used were age, Charlson comorbidity index, BMI (Body Mass Index), the grade of renal insufficiency, tumor diameter, and PADUA score.

In the group with retroperitoneal access, the time to reach the renal hilum ($p < 0.001$), the overall complication rate ($p = 0.008$), and the major complication rate ($p = 0.01$) were significantly lower compared to the transperitoneal group.

The operative time was 143 vs. 150 minutes ($p = 0.63$), in RRPN vs. TRPN, respectively. Warm ischemia time was 10 minutes in RRPN vs. 12 minutes in TRPN ($p = 0.07$). Early unclamping was used in 71% in RRPN vs. 48% in TRPN ($p = 0.02$). The Length of hospital stay was six days in both groups ($p = 0.11$). The cases' complexity, the rate of positive surgical margins, and postoperative kidney function were comparable in both groups ($p > 0.05$).

Conclusion:

The advantages of RRPN lie in the shorter time to reach the renal hilum and the lower complication rates; the comparability with the other parameters proves the safety and feasibility of the retroperitoneal access for localized kidney tumors.

The retroperitoneal approach should be part of the robot surgical training to enable surgeons to master both approaches to treat localized renal tumors. Further prospective randomized studies are needed to identify objective selection criteria for the optimal choice of surgical access.

Author	Our Study		Laviana et al ⁶⁰		Maurice et al ⁵⁷	Choo et al ⁵²		Paulucci et al ⁶¹	Mittakanti et al. ⁴⁰
Study Design	Retrospective, Matched-paired		Retrospective, matched-paired, bicenter		Retrospective, matched-paired, multicenter	Retrospective, matched-paired		Retrospective, matched-paired	Retrospective, matched-paired
Sample size (n), RRPN (n) vs TRPN(n)	224 51 vs 51		355 78 vs 78		610 74 vs 296	107 43 vs 43		519 157 vs 157	544 166 vs 166
Conversion rate, %	2 vs 2 (p=1)		NR*		NR*	0 vs 1% (to RN***)		NR*	2.1 vs 3,8 (to RN***), 1 RP** patient to Open
Operative Time, min	143 vs. 150 (p=0.63)		167 vs 191.1 (p=0.001)		176 vs 176 (p=0.93)	120 vs 153(p = 0.028)		157 vs 185 (p<0.001)	162 vs 191 (p<0.001)
Warm Ischemia Time, min	10 vs 12 (p=0.07)		20.8 vs 21.9		21 vs 19 (p=0.01)	23 vs 25.5 (p= 0.28)		17 vs 17 (p=0.61)	18 vs 18 (p=0.66)
Complications, %	15.1 vs 39.2 (p=0.008)		24.4 vs 35.9 (p=0.106)		12.2 vs 14.2 (p=0.65)	NR*		11.5 vs 12.1 (p=0.86)	53,1 vs 46,9% (p=0.88)
Major complications % (Clavien-Dindo grade>II)	4 vs 25.5 (p=0.012)		5.1 vs 6.4 (p=0.739)		5.4 vs 3 (p=0.30)	0		5.1 vs 3.2 (p=0.29)	28,6 vs 12,2% (p=0.88)
Tumor location, %	RP** posterior 76%, anterior 11.8%	TP ** posterior 33.3%, anterior 49%	RP** posterior 92.3%	TP** posterior 85.9%	NR*	RP** Posterior 44%, anterior 14%	TP ** Posterior 19%, anterior 42%	Posterior 100%	NR*
	p<0.001					(p<.0001)			
Tumor size, cm	3 vs 2.5(p=0.199)		NR*		2.4 vs 2.5(p=0.59)	2.8 vs 2.7 (p =0.77)		2.9 vs 3 (p=0.741)	3.1 vs 3.3 (p=0.3)
Hospital Stay, days	6 vs 6 (p=0.11)		1.8 vs 2.7 (p<0.001)		2.2 vs 2.6 (p=0.01)	NR*		1 vs 2 (p=0.017)	1,7 vs 1,9 (p=0.006)
Positive margins, %	2 vs 5.9 (p=0.30)		3.9 vs 2.6 (p=0.65)		1.4 vs 1.7% (p=1.0)	0 vs 2		3.9 vs 2.4 (p=0.501)	2,8 vs 1,9 (p=0.48)

** NR: Not Reported, ** RP: Retroperitoneal approach, TP: Transperitoneal approach, *** RN: Radical Nephrectomy -In all Fields, Retroperitoneal vs. Transperitoneal, respectively. The Gray Box shows significant differences.

Table 7: Review of the literature comparing data of matched-paired analysis between RRPN vs. TRPN.

Author	Stroup et al. ⁴¹		Arora et al. ⁶²	Abaza et al. ⁵⁴	Sharma et al. ⁵³	
Study Design	Retrospective, bicenter		Retrospective	Retrospective, matched-paired	Retrospective	
Sample size (n), RRPN (n) vs TRPN(n)	404, 141 vs 263		690, 99 vs 394	137, 30 vs 107	119,25 vs 40	
Conversion rate, %	NR*		4 vs 5.4 (to RN ^{***}) (p=0.6)	1.4 (to TP ^{**})	127.8 vs 141.2 (P = 0.09)	
Operative Time, min	217.2 vs 231.7 (p=0.001)		160 vs 170 (p=0.6)	127.8 vs 141.2 (p= 0.09)	10.8 vs 11.1 (P = 0.98)	
Warm Ischemia Time, min	22.8 vs 23.1 (p=0.313)		17 vs 17 (p=0.6)	10.8 vs 11.1 (p = 0.98)	Overall (3,6)	
Complications, %	11.3 vs 13.7 (p=0.537)		NR*	Overall (3,6)	0%	
Major complications % (Clavien-Dindo grade>II)	2.8 vs 2.7%		1.8 vs 1.2 (p=0.6)	0%	NR*	
Tumor location, %	RP ^{**} posterior 65.3%	TP ^{**} anterior 65%	NR*	NR*	RP ^{**} posterior 100%	TP ^{**} posterior 8%, anterior 55%
	(P<0.001)				(p<0.01)	
Tumor size, cm	2.9 vs 3.1 (p=0.122)		3 vs 3,2 (P=0.2)	3.0 vs 3.5 (P = 0.1)	NR*	
Hospital Stay, days	2.2 vs 2.5 (p=0.296)		1 vs 3 (P<0.001)	0.7 vs 0.9 (P = 0.01)	2.3 vs 3 (p<0.01)	
Positive margins, %	2.8 vs 4.2 (p=0.173)		2.1 vs 2 (P=0.95)	0 vs 0	4 vs 2(p=0.85)	
<p>** NR: Not Reported, ** RP: Retroperitoneal approach, TP: Transperitoneal approach, *** RN: Radical Nephrectomy -In all Fields, Retroperitoneal vs. Transperitoneal, respectively. The Gray Box shows significant differences.</p>						

Table 8: Review of the literature with a comparison of data between RRPN vs. TRPN.

Review of literature comparison tables

Author	Tanaka et al. ⁵⁵		Hughes-Hallett et al. ⁵⁶		Hu et al. ⁶³	Gin et al. ⁵⁸	
Study Design	Prospective, nonrandomized. Single Center		Retrospective Multicenter		Retrospective, Multicenter	Retrospective, Multicenter	
Sample size (n), RRPN (n) vs TRPN(n)	26, 10 vs 16		103, 44 vs 59		227, 227 vs 0	191, 75vs 116	
Conversion rate, %	0		2.3 vs 8.4 to open (p=0.2353)		3 % (to RN ^{***})	NR*	
Operative Time, min	193 vs 239 (p= 0.07)		148.5 vs195.3 (p<0,01)		165	156 vs 191(p= 0.003)	
Warm Ischemia Time, min	24,7 vs 24.3 (p=0.548)		22.1 vs 19.1 (p=0,086)		19	24 vs 26 (p= 0.2)	
Complications, %	10 vs 6.25 (p=0.727)		9,1 vs 10 (p=1.000)		12.3	9 vs17 (p=0.008)	
Major complications % (Clavien-Dindo grade>II)	6.25 vs 0		NR*		NR*	4 vs 3 (p=0.008)	
Tumor location, %	RP** posterior 50%, anterior 0%	TP ** posterior 6,25%, anterior 43.7%	RP** posterior 75%, anterior 14%	TP ** Posterior 0%, anterior 83%	Posterior 70% anterior 6.3%	RP** posterior 69%, anterior 19%	TP** posterior 14%, anterior 65%
	(p= 0.01)	(p =0.014)	NR*		NR*	(p<0.0001)	
Tumor size, cm	2.2 vs 3.3 (P=0.0534)		2.84 vs 3.07(p=0.3977)		NR*	2.5 vs 3.2 (p <0.001)	
Hospital Stay, days	NR		2.5 vs 4.6 (p<0.01)		2	1.5 vs 2 (p=0.001)	
Positive margins, %	10 vs 0% (p=0.1971)		6.8 vs 5% (p=0.0.6598)		3.5	8 vs 6 (p=0.6)	

** NR: Not Reported, ** RP: Retroperitoneal approach, TP: Transperitoneal approach, *** RN: Radical Nephrectomy
-In all Fields, Retroperitoneal vs. Transperitoneal, respectively.
The Gray Box shows significant differences.

Table 9: Review of the literature with a comparison of data between RRPN vs. TRPN.

Compliance with ethical standards**Conflict of interest**

The authors declare that they have no conflict of interest.

Human and animal rights

All procedures in this study involving human participants comply with the institutional Ethics Committee's ethical standards and the 1964 Helsinki Declaration and its later amendments.

Informed consent

Informed consent was obtained from all individual participants in this study.

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