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ORIGINAL ARTICLE

Single-port versus multiport partial nephrectomy: a propensity-score-matched comparison of perioperative and short-term outcomes

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Abstract

The objective of this study was to compare the perioperative and short-term functional and oncological outcomes of single-port and multiport robotic-assisted laparoscopic partial nephrectomy using propensity-score analysis. We evaluated all patients who underwent robotic partial nephrectomy at our institution between January 2019 and October 2020. Patient demographics, intraoperative data, and postoperative outcomes were collected and analyzed. Propensity-score matching was performed on age, sex, body mass index, prior abdominal surgery, and nephrometry score using the optimal matching method. A post hoc sensitivity analysis was performed to examine the robustness of the results. In total, 48 and 238 patients underwent single-port and multiport robotic partial nephrectomy, respectively. Following propensity-score matching, 48 multiport cases were matched 1:1 to single-port cases. The single-port cohort had lower median opioid use at postoperative day 1 (4.6 vs 9.8 MME, $p = 0.0209$) and cumulative hospital stay (5.1 vs 9.3 MME, $p = 0.0357$). Single port also had a shorter median length of stay (1.4 vs 1.6 days, $p = 0.0045$), although the post hoc sensitivity analysis showed no difference between the groups [−0.13 (95% CI; −0.580, 0.315, $p = 0.5607$). There were no significant differences in operative time, estimated blood loss, ischemia time, transfusions received, or positive margin rates. In conclusion, based on our early experience, single-port robotic partial nephrectomy is a safe and acceptable alternative to multiport robotic partial nephrectomy, providing comparable perioperative and postoperative outcomes while reducing inpatient opioid use.

Keywords Single-port surgery · Partial nephrectomy · Propensity-score-matched analysis · Robotic surgery · Opioids

Introduction

In 2021, it is estimated that more than 76,000 new cases of kidney cancer will be diagnosed in the United States [1]. The incidence of renal cell carcinoma in the US rose, in part, due to more frequent use of cross-sectional abdominal imaging, which increased the probability of finding a small renal tumor in an otherwise asymptomatic patient [2]. Partial nephrectomy (PN) has become the preferred management strategy for most clinically localized renal tumors, if feasible, as it reduces the risk of chronic kidney disease (CKD) or progression of CKD compared to radical nephrectomy while providing similar oncologic outcomes [3]. The robotic approach to partial nephrectomy has become increasingly popular over the last decade. The rapid adoption of robotic-assisted partial nephrectomy (RAPN) was driven by improved perioperative outcomes after robotic partial nephrectomy, including shortened length of hospital stay, lower complication rates and estimated blood loss than open PN, and shorter warm ischemia time than laparoscopic PN [4].

Intuitive surgical recently released a purpose-built, single-site robotic platform, the da Vinci SP system, which received FDA approval in 2018 and has already been successfully used in many urological procedures [5, 6]. Studies

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have shown that the single-port (SP) system may allow for a shorter hospital stay, decreased postoperative pain, and improved scar cosmesis [7, 8]. To date, the literature on SP-RAPN is limited, consisting mainly of case series, initial experiences, and a few comparative studies [9–13]. In the present study, we report the results of the first and largest propensity score-matched study comparing the perioperative and short-term functional and oncological outcomes of patients undergoing single-port robotic-assisted partial nephrectomy and multiport (MP) robotic-assisted partial nephrectomy.

Materials and methods

Study population

We performed a retrospective review of our institutional review board-approved (Pro2016-0680), prospectively maintained nephrectomy database for patients who underwent SP or MP partial nephrectomy at our institution between January 1, 2019, and October 1, 2020. We included only cases performed by surgeons with both SP and MP-RAPN experience to minimize the bias of different surgeons. All three surgeons (MA, GL, MS) have extensive experience using the standard multiport da Vinci Xi system and received specialized training with the da Vinci SP platform. Patient selection criteria were non-standardized and varied between surgeons.

A standardized postoperative care pathway was used in all cases. Immediately following the procedure, patients received 1 g intravenous acetaminophen. For 48 h after the procedure, 975 mg acetaminophen was administered at fixed intervals every 6 h. When necessary, rescue analgesia for breakthrough pain was provided: 50 mg oral tramadol, as frequently as every 6 h (moderate pain), 5 mg oral oxycodone, as frequently as every 6 h (severe pain), or 2 mg intravenous morphine, as frequently as every 4 h (severe pain for patients unable to tolerate oral medication). Ambulation was encouraged beginning postoperative day 0. The foley catheter was removed on postoperative day 1, and the patient was discharged home if pain was controlled with oral medication and regular diet was tolerated.

The surgical technique for retroperitoneal cases closely mimicked the multiport technique as described by Feliciano et al. [14] After balloon dilation of the retroperitoneal space, GelPort (Applied Medical, Rancho Santa Margarita, CA, USA) was placed at the incision. An assistant trocar was also placed through the GelPort. The remaining technical steps followed the multiport technique. For transperitoneal cases, the surgical technique followed the approach described by Kaouk et al. [15] A single 3-cm incision was made in the abdomen and carried down to the peritoneum. GelPort was placed at the incision, and an assistant trocar was placed alongside the robotic trocar in the GelPort. The remaining steps followed the standard approach for transperitoneal partial nephrectomy.

Data collection

Demographic and clinical variables examined were age, sex, race, BMI, current smoking status, presence of diabetes, hypertension, cardiovascular disease, end-stage renal disease, prior abdominal surgery, and preoperative renal function. Renal function was stratified based on the National Kidney Foundation Kidney Disease Outcome Quality Initiative (NKF-KDOQI) classification method for CKD.

Tumor characteristics were analyzed using nephrometry score, tumor location, presence of a solitary kidney, sidedness, and greatest tumor size. The RENAL nephrometry score was calculated using preoperative contrast-enhanced axial imaging [16].

Perioperative and postoperative values analyzed were operative time, estimated blood loss, length of hospital stay, transfusions, surgical margin status, pain scores, opioid usage, intraoperative and postoperative complications, and hospital readmission within 30 days of discharge. Postoperative pain scores were measured using an 11-point (0–10) verbal numeric rating scale. Pain scores were assessed four hours postoperatively, on the morning of postoperative day 1, and at the time of discharge. Opioid use was standardized to morphine milligram equivalents and measured on postoperative days 0 and 1, and cumulative use during the postoperative inpatient period. Complications were assessed using the modified Clavien–Dindo classification system, with major complications considered to be Clavien grade ≥ III [17]. The highest graded complication was used for statistical analysis in cases with multiple complications.

Surgical approaches compared rates of selective clamping, entrance to the collecting system, and surgical approach (transperitoneal vs retroperitoneal).

Follow-up data included length of time to the most recent follow-up visit, renal function, and evidence of recurrence. Renal function was determined using the NKF-KDOQI classification system. Recurrence was screened using routine imaging studies (chest X-ray or CT, and abdominal CT or MRI).

Statistical analysis

Descriptive statistics were reported for the entire sample and then stratified by SP or MP before and after propensity-score matching. The Shapiro–Wilk test was used to assess the normality of continuous variables. Normally distributed variables were reported as mean (SD) and non-normally distributed variables as median (IQR). Categorical variables are presented as counts (%). To evaluate baseline differences between the SP and MP cohorts before matching, the two-sample t test or Wilcoxon rank-sum test were used for continuous variables as appropriate. Further, chi-square tests were used for categorical variables, and if expected cell counts were below 5, Fisher's exact test was performed.

Propensity-score matching and diagnostics were performed using Proc PSMATCH SAS 9.4 to ensure that the SP and MP patients were similar. Propensity scores were calculated using a logistic regression model with SP or MP as the response. Patients were matched on age (<65 vs ≥ 65 years), sex (male vs female), BMI, prior abdominal surgery (yes vs no), and nephrometry score. These variables were chosen because of their clinical relevance and association with both the treatment and outcomes or outcomes only [18, 19]. For matching, a 1–1 optimal matching algorithm on the logit of the propensity score was utilized. To ensure high-quality matches, exact matched values were used for age, sex, and prior abdominal surgery. Matching covariate balance was assessed using standardized mean differences for all subjects, subjects in the support region, and matched subjects.

After matching, we tested for differences in additional baseline and clinical variables and our outcomes of interest. The paired nature of the data was accounted for in the analysis [20]. For continuous variables, either a paired t test or the Wilcoxon signed-rank test was employed. Furthermore, differences in categorical variables were tested using McNemar's test (asymptotic or exact as appropriate; 2 categories) or the exact Bowker's test of symmetry (3+ categories). A post hoc sensitivity analysis was performed using repeated-measures linear regression.

All analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Two-sided p values less than 0.05 were considered statistically significant.

Results

In total, 286 patients (SP-RAPN, $n = 48$; MP-RAPN, $n = 238$) underwent partial nephrectomy. Propensity-score matching resulted in 48 patients in each PN cohort.

Demographics and clinical characteristics

Before propensity score matching, there were several differences between the two cohorts, with the SP-RAPN group more likely to be female (54.2 vs 36.1%, $p = 0.0196$), have no smoking history (68.8 vs 63.0%, $p = 0.0051$), have undergone prior abdominal surgery (68.8 vs 52.5%, $p = 0.0391$), and have undergone a retroperitoneal approach to their PN (60.4 vs 28.6%, $p < 0.0001$). Post-match analysis showed that the two cohorts were more closely aligned. However, after matching, the SP-RAPN cohort continues to have a higher rate of retroperitoneal approach (60.4 vs 31.3%, $p = 0.0060$) and the MP-RAPN group was more likely to have CKD preoperatively (33.4 vs 12.5%, $p = 0.0352$). Table 1 summarizes the demographic and clinical variable outcomes.

Perioperative and pathological outcomes

Table 2 displays the comparative perioperative and pathological results for both groups. A lower median opioid use was observed in the SP-RAPN cohort for postoperative day 1 (4.6 vs 9.8 MME, $p = 0.0209$) and cumulative hospital stay (5.1 vs 9.3 MME, $p = 0.0357$). The SP-RAPN group also had a shorter mean postoperative length of stay (1.4 vs 1.6 days, $p = 0.0045$). Although not listed in the table, there were no instances of a case requiring conversion. There were no significant differences in operative time, estimated blood loss, ischemia time, transfusions received, or positive margin rates.

Complications

There were no major intraoperative complications in the SP-RAPN group and two in the MP-RAPN group. In one MP-RAPN case, a small serosal tear in the bowel was observed and repaired without further issues (Clavien Class IIIb). The second MP-RAPN case was a patient with a history of urethral strictures who developed poor urine output intraoperatively. After failed endoscopic placement of a new catheter, a suprapubic tube was placed (Clavien Class IIIb).

There were no major complications during the postoperative hospital stay in the MP-RAPN cohort and one in the SP-RAPN group. On postoperative day two, the SP-RAPN patient, who had been on chronic anticoagulation with warfarin secondary to aortic valve replacement, became hypotensive and hemoglobin decreased to 7.1 from a baseline of 12.3. The patient immediately received two liters of crystalloid intravenous fluids and two units of packed red blood cells. An abdominal CT angiogram revealed subcapsular perinephric hematoma requiring embolization by interventional radiology (Clavien Class IIIa).

There was one readmission secondary to a major complication in both the MP-RAPN and SP-RAPN cohorts. The MP-RAPN patient returned with gross hematuria due to a pseudoaneurysm, requiring embolization by interventional radiology (Clavien Class IIIa). The SP-RAPN patient presented with gross hematuria and chest pain. Upon readmission, an ST-segment elevation was noted on an electrocardiogram, consistent with an acute myocardial infarction. The patient underwent cardiac catheterization with stent placement (Clavien Class IVa). This patient's gross hematuria was due to a pseudoaneurysm at the surgical site and required embolization by interventional radiology.

No mortalities were reported for either group, and there was no statistical difference between the rates of

Table 1 Characteristics of renal cancer patients before and after propensity-score matching

	Total sample	Before matching			After matching		
	$n=286$	SP ($n=48$)	MP ($n=238$)	p value	SP ($n=48$)	MP ($n=48$)	p value
Age; median (IQR)	62 (53, 70)	59.5 (51.5, 70)	62 (53, 70)	0.2237	59.5 (51.5, 70)	62 (51.0, 69.5)	NA
< 65	162 (56.6%)	31 (64.6%)	131 (55.0%)		31 (64.6%)	31 (64.6%)	
≥ 65	124 (43.4%)	17 (35.4%)	107 (45.0%)		17 (35.4%)	17 (35.4%)	
Sex (female)	112 (39.2%)	26 (54.2%)	86 (36.1%)	**0.0196**	26 (54.2%)	26 (54.2%)	NA
Race				0.1583			0.5313
Arabic	2 (0.7%)	0 (0.0%)	2 (0.8%)		0 (0.0%)	0 (0.0%)	
Asian	9 (3.2%)	1 (2.1%)	8 (3.4%)		1 (2.1%)	1 (2.1%)	
Black/African American	12 (4.2%)	2 (4.2%)	10 (4.2%)		2 (4.2%)	2 (4.2%)	
White	258 (90.2%)	42 (87.5%)	216 (90.8%)		42 (87.5%)	45 (93.8%)	
Other	5 (1.8%)	3 (6.3%)	2 (0.8%)		3 (6.3%)	0 (0.0%)	
BMI; median (IQR)	28.9 (25.2, 33.0)	27.4 (24.9, 31.8)	29.2 (25.4, 33.3)	0.3056	27.4 (24.9, 31.8)	28.8 (25.4, 33.7)	NA
Smoking status				**0.0051**			0.0642
Current	23 (8.0%)	6 (12.5%)	17 (7.1%)		6 (12.5%)	5 (10.4%)	
Former	78 (27.3%)	7 (14.6%)	71 (29.8%)		7 (14.6%)	16 (33.3%)	
Never	183 (64.0%)	33 (68.8%)	150 (63.0%)		33 (68.8%)	27 (56.3%)	
Never assessed	2 (0.7%)	2 (4.2%)	0 (0.0%)		2 (4.2%)	0 (0.0%)	
ESRD	41 (14.3%)	6 (12.5%)	35 (14.7%)	0.6908	6 (12.5%)	9 (18.8%)	0.5488
DM	54 (18.9%)	8 (16.7%)	46 (19.3%)	0.6674	8 (16.7%)	8 (16.7%)	1.0000
HTN	176 (61.5%)	28 (58.3%)	148 (62.2%)	0.6168	28 (58.3%)	33 (68.8%)	0.3593
CVD	16 (5.6%)	2 (4.2%)	14 (5.9%)	1.0000	2 (4.2%)	2 (4.2%)	1.0000
Prior abdominal surgery	158 (55.2%)	33 (68.8%)	125 (52.5%)	**0.0391**	33 (68.8%)	33 (68.8%)	NA
Pre-op GFR category				0.3288			**0.0352**
No CKD	222 (77.6%)	42 (87.5%)	180 (75.6%)		42 (87.5%)	32 (66.7%)	
Stage 3a	48 (16.8%)	4 (8.3%)	44 (18.5%)		4 (8.3%)	14 (29.2%)	
Stage 3b	12 (4.2%)	2 (4.2%)	10 (4.2%)		2 (4.2%)	2 (4.2%)	
Stage 4	1 (0.4%)	0 (0.0%)	1 (0.42%)		0 (0.0%)	0 (0.0%)	
Stage 5	0 (0.0%)	0 (0.0%)	0 (0.0%)		0 (0.0%)	0 (0.0%)	
Missing	3 (1.1%)	0 (0.0%)	3 (1.3%)		0 (0.0%)	0 (0.0%)	
Nephrometry score; median (IQR)	8 (6, 9)	7 (6, 10)	8 (6, 9)	0.3642	7 (6, 10)	7 (5, 9)	NA
Approach				**< 0.0001**			**0.0060**
Transperitoneal	189 (66.1%)	19 (39.6%)	170 (71.4%)		19 (39.6%)	33 (68.8%)	
Retroperitoneal	97 (33.9%)	29 (60.4%)	68 (28.6%)		29 (60.4%)	15 (31.3%)	
Location				0.2590			0.6616
A	109 (38.1%)	19 (39.6%)	90 (37.8%)		19 (39.6%)	18 (37.5%)	
P	117 (40.9%)	23 (47.9%)	94 (39.5%)		23 (47.9%)	20 (41.7%)	
X	60 (21.0%)	6 (12.5%)	54 (22.7%)		6 (12.5%)	10 (20.8%)	
Hilar tumor				0.2099			0.3833
Yes	79 (27.6%)	17 (35.4%)	62 (26.1%)		17 (35.4%)	12 (25.0%)	
No	203 (71.0%)	31 (64.6%)	172 (72.3%)		31 (64.6%)	36 (75.0%)	
Missing	4 (1.4%)	0 (0.0%)	4 (1.7%)		0 (0.0%)	0 (0.0%)	
Solitary kidney	11 (3.9%)	0 (0.0%)	11 (4.6%)	0.2208	0 (0.0%)	1 (2.1%)	1.0000
Side being operated on				0.6357			0.6291
Left	140 (49.0%)	22 (45.8%)	118 (49.6%)		22 (45.8%)	25 (52.1%)	
Right	146 (51.0%)	26 (54.2%)	120 (50.4%)		26 (54.2%)	23 (47.9%)	
Entered collecting system	181 (63.3%)	26 (54.2%)	155 (65.1%)	0.1507	26 (54.2%)	32 (66.7%)	0.2379
Selective clamp	72 (25.2%)	9 (18.8%)	63 (26.5%)	0.2609	9 (18.8%)	13 (27.1%)	0.4545
ASA score				0.8600			0.5413

Table 1 (continued)

	Total sample	Before matching			After matching		
	$n=286$	SP ($n=48$)	MP ($n=238$)	p value	SP ($n=48$)	MP ($n=48$)	p value
1	6 (2.1%)	1 (2.1%)	5 (2.1%)		1 (2.1%)	0 (0.0%)	
2	133 (46.5%)	25 (52.1%)	108 (45.4%)		25 (52.1%)	20 (41.7%)	
3	140 (49.0%)	21 (43.8%)	119 (50.0%)		21 (43.8%)	27 (56.3%)	
4	7 (2.5%)	1 (2.1%)	6 (2.5%)		1 (2.1%)	1 (2.1%)	
Type of tumor				0.2860			1.0000
RCC	225 (78.7%)	35 (72.9%)	190 (79.8%)		35 (72.9%)	35 (72.9%)	
Benign	61 (21.3%)	13 (27.1%)	48 (20.2%)		13 (27.1%)	13 (27.1%)	
Greatest tumor size; median (IQR)	2.9 (1.9, 4.0)	2.4 (1.6, 3.8)	2.9 (2.0, 4.0)	0.1163	2.4 (1.6, 3.8)	2.2 (1.6, 3.1)	0.2075
Tumor grade (RCC Only)				0.4905			0.7729
1	8 (3.6%)	1 (2.9%)	7 (3.7%)		1 (2.9%)	5 (14.3%)	
2	136 (60.4%)	23 (65.7%)	113 (59.5%)		23 (65.7%)	22 (62.9%)	
3	42 (18.7%)	5 (14.3%)	37 (19.5%)		5 (14.3%)	3 (8.6%)	
4	5 (2.2%)	2 (5.7%)	3 (1.6%)		2 (5.7%)	0 (0.0%)	
DNA	34 (15.1%)	4 (11.4%)	30 (15.8%)		4 (11.4%)	5 (14.3%)	

Bold values indicate statistical significance at $p < 0.05$.

Table 2 Partial nephrectomy surgical outcomes

	SP ($n=48$)	MP ($n=48$)	p value
Operating time (min); median [IQR]	102.0 [79.0, 127.5]	96.5 [83.0, 121.0]	0.8796
Estimated blood loss (mL); median [IQR]	50.0 [30.0, 100.0]	60.0 [50.0, 100.0]	0.4923
Postoperative length of stay (days); median [IQR]	1.0 [1.0, 1.0]	1.0 [1.0, 2.0]	**0.0045**
Received transfusion	0 (0.0%)	0 (0.0%)	NC
Intraoperative minor complication	0 (0.0%)	0 (0.0%)	NC
Intraoperative major complication	0 (0.0%)	2 (4.2%)	0.5000
Postoperative minor complication	0 (0.0%)	2 (4.2%)	0.5000
Postoperative major complication	1 (2.1%)	0 (0.0%)	1.0000
30-day readmission	3 (6.3%)	3 (6.3%)	1.0000
Minor complication	2 (66.7%)	2 (66.7%)	NC
Major complication	1 (33.3%)	1 (33.3%)	NC
Need to re-operate within 30 days	1 (2.1%)	1 (2.1%)	1.0000
Mortality within 30 days	0 (0.0%)	0 (0.0%)	NC
Mortality at any time	0 (0.0%)	0 (0.0%)	NC
Surgical margin status			1.0000
Focally positive	3 (6.3%)	4 (8.3%)	
Negative	45 (93.8%)	44 (91.7%)	
Opioid use POD 0; median [IQR]	4.8 [2.0, 8.6]	4.0 [2.0, 10.9]	0.8143
Opioid use POD 1; median [IQR]	0.0 [0.0, 7.5]	5.0 [0.0, 15.0]	**0.0209**
Cumulative opioid use; median [IQR]	5.1 [2.0, 18.6]	9.3 [4.0, 31.8]	**0.0357**
Pain score 4 hours post-operation; median (IQR)	2.0 (0.0, 4.0)	2.0 (0.0, 4.0)	0.7099
Pain score POD 1; median (IQR)	1.0 (0.0, 2.0)	2.0 (0.0, 3.0)	0.3129
Pain score on discharge; median (IQR)	0.0 (0.0, 2.0)	0.0 (0.0, 2.0)	0.2452
	SP ($n=33$)	MP ($n=33$)	p value
Ischemia time (min); median [IQR]	17.0 [14.0, 24.0]	16.0 [11.0, 20.0]	0.0801

Bold values indicate statistical significance at $p < 0.05$.

intraoperative complications, postoperative complications, or 30-day hospital readmission. Detailed results, including the number of minor complications in each cohort, are presented in Table 2.

Follow-up outcomes

There were no statistical differences between groups in the length of time to the most recent follow-up, evidence of recurrence, or change in the NKF-KDOQI CKD stage. The early functional and oncological results are shown in Table 3.

Sensitivity analyses

While our findings showed that the SP-RAPN group had a significantly shorter postoperative length of hospital stay and opioid use at postoperative day 1 and cumulative inpatient stay, there remained key differences between the SP-RAPN and MP-RAPN cohorts that could not be resolved by propensity-score matching. Namely, the surgical approach (transperitoneal vs retroperitoneal) and preoperative renal function differed between the groups. A sensitivity analysis was performed to ensure that the differences were not due to these baseline characteristics. Linear regression models were constructed using generalized estimating equations and the robust variance estimator clustered on the matched pair. Table 4 shows that after accounting for these baseline differences, the estimated mean difference for both postoperative day 1 opioid use [-5.22 (95% CI -10.185, -0.264, $p=0.0390$)] and cumulative opioid use [-8.39 (95% CI -15.822, -0.951, $p=0.0271$)] remained significantly lower for the SP-RAPN cohort, while postoperative length of stay showed no difference [-0.13 (95% CI -0.580, 0.315, $p=0.5607$)].

Discussion

In the two decades since Winfield et al. described laparoscopic partial nephrectomy, urologists have continued to push the boundaries of minimally invasive surgery to improve surgical outcomes [21]. The evolution of minimally invasive surgery has seen the number and size of instruments and incisions decrease to reduce the morbidity associated with port placement, ultimately culminating in single-site surgery. Indeed, Fan et al. demonstrated laparo-endoscopic single-site (LESS) partial nephrectomy had less postoperative pain, shorter hospital length of stay, and better cosmetic outcomes than conventional laparoscopic partial nephrectomy [22]. Despite the advantages of LESS surgery, it is a technically challenging approach and showed inferior trifecta outcomes compared to standard MP-RAPN [23]. The da Vinci SP system overcomes some of the technical difficulties of previous single-site systems, like instrument clashing and motion restriction. Moreover, our findings show the SP system provided equivalent perioperative, pathological, and early functional and oncological outcomes compared to the multiport platform. Additionally, the SP cohort was found to have significantly lower opioid use on postoperative day 1 ($p=0.0209$) and cumulative inpatient stay ($p=0.0357$).

Our primary analysis also initially showed that the SP-RAPN cohort had a shorter length of hospital stay than the MP-RAPN cohort. Sensitivity analysis, however, showed no significant difference in the length of stay between the groups. This finding may be secondary to the two remaining differences between the cohorts after matching (preoperative renal function and surgical approach (transperitoneal vs retroperitoneal). The MP-RAPN group had worse preoperative kidney function; CKD is associated with longer hospital stays and increased morbidity and mortality after surgery [24, 25]. The SP-RAPN group was more likely to undergo

Table 3 Functional and oncological outcomes

	SP ($n=46$)	MP ($n=46$)	p value
Time from surgery to most recent follow-up (weeks); mean (SD) median [IQR]	22.4 (17.9) 21 [5.0, 32.0]	28.5 (30.5) 19.0 [3.0, 32.0]	0.6389
Evidence of recurrence at most recent follow-up	0 (0.0%)	1 (2.2%)	1.0000
Preoperative GFR CKD stage to discharge GFR CKD stage			0.1537
Improved	3 (6.5%)	5 (10.4%)	
Stayed the same	40 (87.0%)	32 (66.7%)	
Worsened	3 (6.5%)	9 (18.8%)	
	SP ($n=25$)	MP ($n=25$)	p value
Preoperative GFR CKD stage to most recent follow-up CKD stage			1.0000
Improved	1 (4.0%)	1 (4.0%)	
Stayed the same	22 (88.0%)	20 (80.0%)	
Worsened	2 (8.0%)	4 (16.0%)	

Table 4 Sensitivity analysis

	Estimated mean difference and 95% confidence interval	*p* value
Postoperative length of stay		
Treatment (ref = MP)		
SP	− 0.13 (− 0.580, 0.315)	0.5607
Approach (ref = transperitoneal)		
Retroperitoneal	− 0.05 (− 0.530, 0.423)	0.8256
Pre-Op GFR CKD stage (ref = no CKD)		
Stage 3a	0.29 (− 0.222, 0.798)	0.2686
Stage 3b	− 0.24 (− 0.855, 0.368)	0.4354
Opioid use postoperative day 1		
Treatment (ref = MP)		
SP	− 5.22 (− 10.185, − 0.264)	**0.0390**
Approach (ref = transperitoneal)		
Retroperitoneal	0.27 (− 4.319, 4.859)	0.9083
Pre-Op GFR CKD stage (ref = no CKD)		
Stage 3a	0.33 (− 4.977, 5.640)	0.9026
Stage 3b	0.76 (− 9.018, 10.543)	0.8785
Cumulative opioid use		
Treatment (ref = MP)		
SP	− 8.39 (− 15.822, − 0.951)	**0.0271**
Approach (ref = transperitoneal)		
Retroperitoneal	1.79 (− 5.288, 8.862)	0.6206
Pre-Op GFR CKD stage (ref = no CKD)		
Stage 3a	− 2.93 (− 11.675, 5.810)	0.5109
Stage 3b	0.50 (− 18.054, 19.051)	0.9580

Bold values indicate statistical significance at $p < 0.05$.

RAPN with a retroperitoneal approach, which is associated with a shorter length of stay [26]. Additionally, the lack of a significant difference in length of hospital stay may be due to our institution's already short length of stay (1.4 and 1.6 days for the SP and MP groups, respectively).

One major advantage of the SP system is decreased postoperative pain, which theoretically eliminates or reduces the need for opioid use after surgery. Our results support this assertion, with the SP group requiring significantly fewer narcotics postoperatively, although reported pain scores remained equivalent between the cohorts. This finding is particularly consequential given the incidence of persistent opioid use after surgery, especially in the US, with its high rates of opioid abuse, and deserves further investigation [27].

The retroperitoneal approach was used more frequently with the single-port robot than with the multiport robot. This finding is likely in part due to one of the key advantages of the single-port robot. In our experience, we have found that the single-port system is well suited to smaller spaces such as the retroperitoneum. Similar observations have been made in other urological procedures, as extraperitoneal prostatectomy has been popularized with the single port robot [28]. This is also true in head and neck cancers, as the single-port robot has revolutionized trans-oral robotic surgery given its maneuverability in tight spaces such as the oral cavity [29].

When using the multiport system, trocar placement within the retroperitoneum can be challenging for surgeons inexperienced with this approach. The single-port robot makes working within the retroperitoneum more feasible and accessible. With only a single incision site, it is easier to place the trocar and stay within the retroperitoneum. Our approach continues to evolve with retroperitoneal cases. We now utilize an incision at McBurney's point, allowing us to switch between a retroperitoneal and transperitoneal approach based on tumor location (Supplementary Fig. 1). This incision also reduces the potential risk of hernia associated with an umbilical incision. Additionally, in patients with multiple previous abdominal surgeries, we can approach through this incision retroperitoneally as well. Just as the single-port system has transitioned most single-port prostatectomy cases at our institution to an extraperitoneal approach, our analysis suggests that retroperitoneal partial nephrectomy with the single port will become more widely adopted.

Our study has several recognized limitations. First, this was a nonrandomized study with non-standardized patient selection criteria, which introduces the possibility of selection bias. Given patient selection was surgeon driven, we attempted to minimize potential bias by matching the SP-RAPN group to demographically similar MP-RAPN patients. Second, our median follow-up length of 22.4 (SP) and 28.5 (MP) weeks is insufficient to accurately evaluate oncological outcomes. Third, some studies have found retroperitoneal partial nephrectomy resulted in lower pain scores and shortened length of hospital stay than a transperitoneal approach [26, 30]. Given the greater number of retroperitoneal cases in the SP group, this may be a potential limitation of our study, as it may have biased the results of the SP group. However, data from other studies are equivocal [3, 30]. Another limitation is the greater number of females in the SP group, which may potentially have led to shorter operative and warm ischemia time, due to the lower perirenal body fat generally found in female patients. Finally, it should be noted that these cases were performed by three highly skilled robotic surgeons with significant experience with the da Vinci SP and Xi systems. Thus, given the complexities inherent in learning a new surgical approach, novice robotic surgeons may encounter longer learning curves.

Despite these limitations, the present study is the first and largest to examine the surgical, functional, and oncological outcomes of SP-RAPN compared to those of MP-RAPN using propensity-score matching to account for potentially confounding variables.

Conclusion

Single-port partial nephrectomy is a safe and acceptable alternative to MP-RAPN, providing comparable perioperative results, complication rates, and noninferior early oncological and functional outcomes. In this study, the SP approach was associated with lower opioid use on postoperative day 1 and cumulative inpatient stay. Additionally, the SP cohort utilized the retroperitoneal approach more often. The rates of positive surgical margins, complications, and readmissions were comparable between the groups. Matched or randomized multi-institutional studies with longer follow-up periods are needed to validate these promising early findings and may also focus on patient-assessed cosmesis and cost–benefit analysis in transitioning to an SP system.

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Declarations

Conflict of interest Robert Harrison, Mubashir Billah, Fahad Sheckley, Tina Lulla, Christina Caviasco, Angeline Sanders, and Gregory Lovallo have no conflicts of interest or financial ties to disclose. Michael Stifelman is on the scientific advisory board of Intuitive Surgery and has an educational agreement with Ethicon. Mutahar Ahmed is a consultant for CONMED and Intuitive Surgical.

Informed consent All procedures were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000. Informed consent was obtained from all patients for being included in the study. The authors affirm that human research participants provided informed consent for publication of the images in Supplementary Fig. 1.

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