Surgical Outcomes of Three vs Four Arm Robotic Partial Nephrectomy: Is the Fourth Arm Necessary?

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OBJECTIVE To compare the cost, efficacy, and safety of 3-arm versus 4-arm technique in robotic partial nephrectomy (RPN). Surgeons may either elect to utilize three vs four robotic instruments depending on preference. The purpose of this study is to compare the outcomes between the two techniques.

METHODS RPNs from June 2016 to August 2017 were retrospectively reviewed. Tumor features, surgical parameters, and operative outcomes were evaluated. The number of arms used was determined. Statistical analysis was performed with the Student's *t* test, chi-squared, and Mann-Whitney test.

RESULTS A total of 61 consecutive 3-arm RPNs and 59 consecutive 4-arm RPNs were evaluated. Mean tumor diameter and median nephrometry score were 3.4 cm (± 1.1 SD) and 7 (6-8 IQR) for the 3-arm group and 3.3 cm (±1.2 SD) and 6 (5-8 IQR) for the 4-arm group, respectively (size: $p = 0.7$, nephrometry: $p = 0.07$). Hospital length of stay, operative time, estimated blood loss, complication rate, blood transfusion rate, and readmission rate all demonstrated no statistically significant difference between 3-arm and 4-arm groups ($p > 0.05$). Mean ischemia time was shorter by 5.1 minutes in the 4-arm group ($p = 0.02$). Rate of margin positivity was higher in the 4-arm group (0% vs 10%, $p = 0.03$).

CONCLUSION RPN can be safely and effectively completed with 3-robotic arms. While there was increased ischemia time, the difference was small and likely not of clinical significance. The routine addition of the fourth robotic arm in RPN is not necessary. UROLOGY 123: 140–145, 2019. © 2018 Elsevier Inc.

KEYWORDS Robotics, Partial Nephrectomy, Kidney Cancer, Fourth-arm, Cost

Partial nephrectomy is the standard of care for the treatment of small renal masses.[1] While laparoscopic partial nephrectomy offers advantages over open surgery, it is a technically complex operation with a steep learning curve.[2] The introduction of the robotic partial nephrectomy (RPN) has diminished the learning curve of minimally invasive partial nephrectomy and as a result, has increased the prevalence of this operation amongst urologic surgeons.[3]

RPN is associated with less blood loss and length of stay compared to open surgery and less ischemia time and operative time compared to laparoscopic surgery.[2,4] The introduction of the da Vinci S robot in 2006 allowed surgeons to dock a fourth working arm that was not possible on the first generation model. Since that time, many RPN techniques have been described in the literature, most utilizing four robotic instruments (camera, left arm, right arm, assist arm),[5-7] however, some surgeons elect to utilize three arms (no assist arm).[8-10] The fourth arm is often used to retract the kidney and to allow two-handed hilar dissection. It further allows for the console surgeon to be more self-sufficient if their bedside assistant is less experienced.[5] It can, however, limit the working envelope of each instrument and contribute to instrument and arm collisions. There are also costs associated with the use of the additional arm/instruments.

At our institution, RPN is performed by several experienced robotic surgeons utilizing both the 3-arm and 4-arm techniques. We sought to compare the peri-operative and early post-operative outcomes of three and four arm robotic partial nephrectomies at a single institution.

MATERIALS AND METHODS

This is an Institutional Review Board approved single center retrospective review. Sixty-one (61) consecutive 3-arm RPN and 59 consecutive 4-arm RPN were reviewed retrospectively from June 2016 to July 2017. All cases were performed via the trans-peritoneal approach. Cases

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were searched by CPT code (50543) over this period of time. CPT codes for radical nephrectomy and nephroureterectomy (50545, 50548) were reviewed as well to ensure no errantly billed partial nephrectomy was missed. Five experienced academic urologists were included in this study. This institution averages approximately 130 robotic partial nephrectomies per year. Clinical indications for RPN included both malignant and benign processes. One patient in this cohort was excluded due to conversion to open surgery secondary to bowel injury on initial port placement. Patients that were converted to radical nephrectomy due to the inability to complete the renorrhaphy were excluded.

All cases were performed with the Da Vinci Si surgical system (Intuitive Surgical, Sunnyvale CA). A 12-mm trocar was used for the camera. Two or three 8-mm robotic ports were used depending on 3-arm or 4-arm technique. If 3 arms were used, a drape and robotic trocar seal for the fourth arm was not opened. Both techniques also utilized either one or two 12-mm trocars for the bedside assistant.

Preoperative demographic parameters and tumor characteristics/histology were collected. Tumor complexity was measured using the RENAL nephrometry score.[11] Intraoperative details such as operating room time, estimated blood loss, warm ischemia time were recorded. Post-operative variables such as hospital length of stay, complications, need for blood transfusion, renal function, and need for re-admission were reviewed. Operative time was defined as the time from incision to all wound closures. Warm ischemia time was defined from when arterial occlusion is initiated to when the last clamp is removed. Post-operative complications were graded according to the Clavien-Dindo classification scale.[12] Renal function was evaluated by comparing pre-operative creatinine values to post-operative creatinine values taken at follow-up (6-12 weeks post-operatively). Re-admissions and blood transfusion were counted if they occurred within 30 days of the operation. Fourth arm utilization costs were calculated based on this institution's contracted purchase price from Intuitive Surgical. SPSS version 22 (International Business Machines Corporation, Armonk, NY, USA) was used to perform data analysis. Differences in means and medians of continuous variables were analyzed using the Student's t test and Mann-Whitney U test, respectively. Associations with categorical variables were assessed using the chi-squared test. All p values were two-sided and statistical significance was defined as $p < 0.05$.

RESULTS

A total of 61 consecutive 3-arm RPNs and 59 consecutive 4-arm RPN were evaluated. Of the 5 surgeons included in the study, 2 surgeons only performed 3-arm technique each with over 10 years of robotic experience, 2 only performed 4-arm technique with 7 and 10 years of robotic experience, and 1 surgeon performed both techniques with 5 years of robotic experience. The bedside assist in each case was one of three Physicians' Assistants that specialized in clinical urology and had at least 3 years of bedsiding experience (greater than 200 cases each). For the entire cohort, median age was 60.5 years (IQR 59-67), median BMI was 30 kg/m^2 (IQR 25.7-34.4), mean tumor size was 3.3 ± 1.2 cm, and the median nephrometry score was 7 (IQR 5-7) (Table 1). Four procedures were excluded from analysis. One patient sustained a bowel injury during initial trocar placement. Three patients were converted to radical nephrectomy due to the inability to complete the renorrhaphy (two in the 3-arm group

Table 1. Patient demographics and tumor characteristics

Patient and Tumor Characteristics	3-arm RAPN (n = 61)	4-arm RAPN (n = 59)	*p*-value
Median Age in Years (IQR)	61 (47-68)	60 (54-47)	0.803
No. male/female (%)	37(60%) / 24 (40%)	37 (63%) / 22 (37%)	0.853
Race			0.051
Caucasian (%)	51 (83%)	40 (67%)	
African-American (%)	4 (7%)	4 (7%)	
Hispanic (%)	2 (3%)	10 (17%)	
Asian (%)	3 (5%)	1 (2%)	
Unknown (%)	1 (2%)	4 (7%)	
Body mass index (kg/m^2), median (IQR)	30.7 (25.1–30.7)	29.7 (25.8–33.2)	0.830
Tumor size (cm), mean (SD)	3.4 (1.1)	3.3 (1.2)	0.647
R.E.N.A.L. score, median (IQR)	7 (6–8)	6 (5–8)	0.072
No. left/right (%)	28 (46%)/33 (54%)	36 (61%) / 23 (39%)	0.120
Final Pathology			0.302
Clear cell RCC (%)	47 (77%)	41 (70%)	
Papillary RCC (%)	1 (2%)	3 (5%)	
Chromophobe RCC (%)	6 (10%	6 (10%)	
Oncocytic neoplasm favor oncocytoma (%)	1 (2%)	5 (8%)	
Benign (%)	9 (15%)	3 (5%)	
Stage			0.365
pT1a	41(69%)	42 (74%)	
pT1b	12 (20%)	13 (23%)	
pT3a	6 (10%)	2 (4%)	

and one in the 4-arm group). There were no conversions to radical nephrectomy for hilar injuries.

Among the 3-arm and 4-arm cohort, no significant difference was observed in gender, age, body mass index, tumor laterality, and tumor size. Malignant histology and clear cell RCC histology represented 51/61 (83%) and 47/61 (77%) for the 3-arm group, and 51/59 (86%) and 41/59 (70%) for the 4-arm group, respectively ($p = 0.3$). Tumor complexity was measured using the RENAL nephrometry score.[11] The 3-arm cohort tended toward more complex tumors, but this was not statistically significant when compared to the 4-arm group. Mean tumor diameter was 3.4 cm ± 1.1 for the 3-arm group and 3.3 cm ± 1.2 for the 4-arm group ($p = 0.7$). The median nephrometry score was 7 (6-8 IQR) for the 3-arm group and 6 (5-8 IQR) for the 4-arm group ($p = 0.07$).

Peri-operative outcomes and complications for the two cohorts are summarized in Table 2. Comparing these two cohorts, hospital length of stay, operative time, EBL, surgical complication rate, blood transfusion rate, and readmission rate all demonstrated no statistically significant difference between 3-arm and 4-arm partial nephrectomy ($p > 0.05$). Mean warm ischemia time was shorter by 5.1 minutes in the 4-arm group ($p = 0.02$). Rate of margin positivity was lower in the 3-arm group (0% vs 10%, $p = 0.03$).

Details of the complications are listed in Table 3. Two patients in the 3-arm group developed a grade-III complication (angioembolization of a pseudoaneurysm) while one patient in the 4-arm group developed deep vein thrombosis (DVT) requiring inferior vena cava (IVC) filter. A total of three grade-IV complications occurred (2 in the 3-arm group, and 1 in the 4-arm group). All three were Intensive Care Units (ICU) admissions (3-arm: diaphragmatic injury requiring chest tube and observation, 4-arm: uncontrolled diabetes mellitus requiring ICU for insulin drip, and post-operative hypotension admitted to ICU for observation). There were no grade-V complications in this study.

At our institution, the ProGrasp is commonly used as the fourth arm. The unit cost of the ProGrasp for the Da Vinci Si is $2200. The instrument can be used for 10 cases before expiring, making the per-case cost $220. The disposable cannula seal for the fourth arm costs $15 per seal. The sterile drape for the fourth arm costs $45. Out our institution, the total additional cost to utilize the fourth arm is $280.

Table 3. Complications

Complication	Cohort 3-Arm	4-Arm
Clavien Grade 1	**3**	**0**
Gross hematuria	2	0
Blood loss anemia	1	0
Clavien Grade 2	**1**	**2**
Urinary Tract Infection	1	1
Acute Kidney Injury	0	1
Clavien Grade 3	**2**	**1**
Angioembolization	2	0
DVT requiring IVC filter	0	1
Clavien Grade 4	**2**	**1**
Diaphragm Injury	0	1
Hypotension	1	0
Uncontrolled DM	1	0
Clavien Grade 5	**0**	**0**

DISCUSSION

Minimally invasive partial nephrectomy compared with open partial nephrectomy has lower perioperative complication rate, shorter hospital stay, and less blood loss, with comparable ischemia time and renal function preservation.[13] Improvements in the technique of RPN have allowed for treatment of large and complex tumors to be safe and effective.[14,15] In one study evaluating renal surgery in the state of Maryland, minimally invasive partial nephrectomy went from less than 5% in 2000 to 60% in 2011, and that number continues to rise.[16] Similar data exist on the national level.[17] This all comes, however at added overall cost.[18,19]

Many RPN techniques have been described, including both 3-arm and 4-arm technique. This is usually dependent on surgeon comfort and preference. Our institution

Table 2. Surgical outcomes and complications

Surgical Characteristics	3-arm RAPN (n = 61)	4-arm RAPN (n = 59)	*P*-value
Mean LOS in hours (SD)	56.4 (17.9)	62.1 (34.5)	0.268
Mean OR Time in minutes (SD)	176.6 (34.1)	184.3 (46.9)	0.308
Margin Status			0.027
Negative (%)	59 (100%)	53 (90%)	
Positive (%)	0 (0%)	6 (10%)	
Mean Ischemia Time in Minutes (SD)	25.6 (7.5)	20.5 (9.9)	0.020
Mean EBL in mL (SD)	227.2 (180.8)	202.7 (156.1)	0.429
Complications (%)	8 (13%)	4 (7%)	0.249
Clavien III-V Complications (%)	4 (7%)	2 (3%)	0.434
Blood Transfusion	4 (6%)	1 (2%)	0.178
Mean change in serum Cr (SD)	-0.04 (0.3)	0.01 (0.4)	0.503
Readmissions (%)	7 (12%)	2 (3%)	0.164

performs both 3-arm and 4-arm technique. The fourth arm is primarily used in retraction and dissection of the hilum, but it is typically not used to actively dissect the renal tumor or perform renorrhaphy. We sought to evaluate whether routine use of the fourth arm conferred a clinical benefit and at what cost.

The primary use of the fourth arm is to aid in renal hilum dissection and retraction thus making the surgery more efficient and safe. It also allows for easier manipulation of a drop-in ultrasound probe and placement of the bulldog clamps by the console surgeon. All of these maneuvers confer greater independence to the console surgeon and allows for a less experienced bedside assistant.[5] However, this was not born out in the data as complications, operative time and blood loss were similar. It is possible that surgeons will elect to use the fourth arm if the tumor is more complex or challenging. However, the 3-arm group trended toward increased complexity (median RENAL score of 7 vs 6 for 3-arm and 4-arm cohorts, $p = 0.07$) minimizing this purported advantage. Likewise, the mean tumor size of the 3-arm group was slightly larger. Together, these measures indicate that there was not a strong selection bias between the two cohorts based on tumor characteristics.

The parameters that intuitively would not be related to the fourth arm are margin status and warm ischemia time given that the fourth arm is not used actively for these portions of the case. These two parameters were the only ones that demonstrated a difference between the two cohorts. Ischemia time was longer by approximately five minutes in the 3-arm cohort and rate of margin positivity was higher in the 4-arm cohort. The fourth arm can be used to retract the kidney during excision of a difficult to reach the tumor, however, this can often lead to the clashing of the instruments. Many surgeons will stow or remove the fourth arm during clamp time. It is not clear whether the addition of the fourth arm contributed to the shortened ischemia time. Ischemia time is dependent on the surgeon technique, tumor complexity, trainee involvement, and degree to which ischemia is achieved. While not statistically significant, the lesions in the 3-arm group trended towards greater complexity ($p = 0.072$). Given the minimal use of the fourth arm during clamp time, the difference in ischemia time is more likely related to these additional factors and not the additional arm itself. However, this cannot be determined with certainty. The impact of the additional 5 minutes of ischemia time is unclear, however, there is evidence to demonstrate that it is likely insignificant and that the amount of vitalized parenchyma remaining is a more principal factor.[20]

Robotic surgery has consistently demonstrated increased cost owing largely to the cost of the surgical robotic system, its maintenance, and its disposables.[21] While compared to open surgery, RPN does have increased cost, but the improved outcomes and greater utilization of nephron sparing surgery are an accepted trade off.[22] The increased cost of the robotic approach is primarily due to the price and maintenance of the robot and its disposables.[23] When ignoring the initial purchase cost of the robot, the cost of open partial nephrectomy and RPN are similar.[24] Therefore, minimizing the use of the robot to three arms presents an opportunity for cost savings. The actual amount saved by not using an instrument use and robotic drape depends on the service and supply contract of the institution, but a robotic instrument typically costs $2000-2500 and offers 10 uses. The robotic arm drape also typically costs approximately $50. Use of an additional trocar requires a cannula seal (a box of 10 costs $150). Immediate cost savings of the 3-arm technique is approximately $300, and this does not include repair and maintenance costs of the fourth arm.[6] Overall, robotic cost analysis is a complex entity and will vary greatly from institution to institution.[18] Specifically, at our institution, the per case cost of using the fourth arm is $280. The advent of new technology and marketplace competition may drastically change the cost analysis in the future.

While cost is a vital component in surgery, often surgeons will not deviate from their techniques for cost alone. Many surgeons utilized the fourth arm because that is how they were trained to perform RPN. They may also place the fourth arm simply because it is there. We sought to demonstrate that exclusion of the fourth arm is not a patient safety concern and there may be added value of the 3-arm technique beyond cost such as significantly less arm collision and less incisional pain for the patient.[8]

This study has several strengths. All surgeons were experienced likely beyond the learning curve for RPN. All bedside assistants were experienced advanced practice providers that minimize variation of this critical role. This is a single site study which minimizes operating room variables. Our study also has several limitations. Primarily, this study is retrospective in nature. Tumor size or complexity may guide a particular surgeon to use the fourth arm, which introduces selection bias. Since only one surgeon performed both techniques, a cohort bias exists precluding an intra-surgeon comparison of outcomes. A randomized prospective trial with one or more surgeons performing both techniques would likely remove these biases, however, it is not practical. Ideally, the surgeons would have an equal distribution of cases. While this study is larger than many RPN analyses, an increased sample size might elucidate additional significant variables. This study was performed at a large academic center responsible for training many residents and fellows. Surgical training introduces uncontrolled variances in operative time and technique. The use of experienced bedside assistants is a resource that other institutions may not have and can affect the need for the fourth arm.

CONCLUSION

RPN can be safely performed utilizing either 3 or 4 robotic arms depending on surgeon preference. Comparing these groups, there was no difference in tumor size or complexity between these two cohorts. With the exception of ischemia time and margin positivity, there were no

statistical differences in surgical outcomes between the 3-arm and 4-arm technique. The difference in ischemia time was minimal and not likely to affect renal function. Margin positivity was higher in the 4-arm group and likely not due to the addition of the arm. For surgeons experienced in robotic surgery routine addition of the fourth robotic arm in RPN is not necessary.

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EDITORIAL COMMENT

We congratulate the authors for asking a very pragmatic clinical question (does the addition of a fourth arm during robotic partial nephrectomy improve clinical outcomes) and designing a study that attempts to answer that question. Indeed, as surgeons who frequently perform this procedure, we have often debated the relative merits of "adding or routinely using a fourth arm." The results of the current study suggest no advantage. So is the debate over? Can the good-natured argument frequently awash in testosterone and beer be put to rest? As Lee Corso would say..."not so fast my friend."

The current study suggests a negligible difference in the majority of surgical endpoints including overall operative time, estimated blood loss, complications, and length of hospitalization. The only statistically significant differences were seen in warm ischemia time (25.6 vs 20.5 minutes, $P = .02$) and margin positivity (0% vs 10%, $P = .03$), the former favoring a 4-arm approach and the later favoring a 3-arm approach. These findings are not unexpected. However, the retrospective nature of the study design limits the generalizability of its findings. As the decision to utilize a 3-arm vs a 4-arm approach was based on surgeon preference, the margin difference likely reflects surgeon experience, tumor complexity not reflected by nephrometry score, or other difficult to enunciate confounders. And while ischemia time was significantly different, this finding is not clinically meaningful and again more likely a statistical anomaly rather than a statistical fact.

What is not reflected in this study and may be challenging to prove statistically are the intangibles that a 4-arm approach can offer. First, we have yet to meet a patient who has complained about the aesthetics of an extra port...so let's get that out of the way. Anecdotally, addition of a fourth arm affords dynamic liver retraction when the right kidney is severely retrohepatic, helps stabilize the kidney when a posterior hilar mass is being approached transperitoneally, takes some of the frustration out of dealing with copious perirenal fat, and can be a "kidney saver" when a complex hilum is encountered. Certainly, an experienced surgeon can accomplish all of the above using a 3-arm

approach. An experienced surgeon should likewise practice surgical humility. Perhaps these intangibles may best serve the surgeon in their learning curve. Novice or expert, the ease of port configuration, and the flexibility of port exchange with the newest Xi platform should lower our threshold for adding a fourth arm and leaving our pride at the scrub sink.

Ultimately, the current study has significant limitations and cannot be used to judge the superiority of a 3-arm vs a 4-arm approach. The question the authors ask is nevertheless completely relevant. As surgeons, we must be mindful to practice cost effectiveness and to seek opportunities to improve quality and efficiency through elimination of waste. We must likewise avoid becoming so inflexible with our approach that pragmatism is disregarded. We challenge the authors, and all of us who perform robotic partial nephrectomy with regularity, to consider a prospective, randomized trial that helps to better answer the debate. Until that time, the bar argument will continue.

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AUTHOR REPLY

We whole-heartedly agree that the statistically different outcomes in warm ischemia time and margin positivity noted in this study are more likely an anomaly rather than statistical fact. We appreciate and acknowledge the "intangibles" of surgical technique, but to claim them as an advantage requires scientific proof. The commenters offer no evidence of this aside from anecdote. We have never encountered an issue retracting the liver with a 3 mm subxiphoid port which is decidedly less morbid than 8 mm robotic arm port. We likewise have no trouble manipulating the kidney with 1 arm once appropriately dissected. While it is rare for a patient to complain of the cosmesis of a single port over other ports, port-site hernias are a real and significant complication, even for 8 mm ports. Any port reduction offers a benefit, and the commenters cannot claim noninferiority without data to substantiate it.

We are unaware how a static and uncontrolled fourth arm acts as a "kidney saver," but if an acute renal hilar injury occurs, we feel the fourth arm is unlikely to salvage an otherwise lost renal unit. The hilum should be dissected with grace and care regardless of the number of arms. We likewise have found no advantage of the Xi platform in our surgical technique or port placement.

Safely and effectively performing a surgical procedure with reduced cost and less morbidity is to the benefit of the patient and the health care system. The commenters evocation of it being a matter of "pride" and "humility" is nonsensical. Perhaps the commenters ought to leave their credit cards at the scrub sink when justifying the use of the fourth arm without evidence of improving outcomes?

We acknowledged that the retrospective nature of this study is a limitation, however, what other "significant limitations" do the commenters feel nullify our findings? They stress avoidance of inflexibility and a disregard of pragmatism, however, that is precisely the theme of our findings. We ask surgeons to not be "inflexible" and not to "disregard pragmatism" in their consideration that the 3-arm technique is safe, effective, cost conscious, and perfectly feasible.

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