Robot-assisted Partial Nephrectomy with Segmental Renal Artery Clamping: A Single Center Experience

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Purpose: The aim of our study is to evaluate the feasibility and effectiveness of robotic partial nephrectomy performed with segmental clamping of tumor-feeding arteries.

Materials and Methods: Thirty-six patients with renal tumor who underwent robotic partial nephrectomy with segmental renal artery clamping were included in this study. Prospectively recorded patient demographics, mean operation time, estimated blood loss, warm ischemia time, length of hospital stay, pre- and postoperative renal functions and oncological outcomes were analyzed retrospectively. All complications were graded based on the modified Clavien-Dindo classification system. Surgical success was defined as no conversion from segmental artery clamping to the main renal artery clamping.

Results: Mean tumor size was 40 mm and, R.E.N.A.L nephrometry score was 6.74. Mean operation time, estimated blood loss and warm ischemia time were 162 min, 236 ml, and 16 min, respectively. Five postoperative complications were observed. There were no significant differences in terms of renal functional outcomes before and after surgery ($P = .18$). Of 36 patients, 34 were completed successfully; however, main renal artery clamping was required in two patients due to excessive bleeding from the tumor bed. The success rate of the segmental renal artery clamping technique was determined as % 94.4 (34/36) in our study.

Conclusion: Segmental renal artery clamping may be considered as a reliable and effective surgical method for vascular control during robotic partial nephrectomy. For this technique, tumor characteristics and intrarenal vascular anatomy should be precisely evaluated by the preoperative contrast-enhanced computerized tomography with 3-D reconstruction.

Keywords: partial nephrectomy; robotic surgery; renal functions; segmental renal artery; warm ischemia time

INTRODUCTION

Majority of renal masses are now diagnosed at early clinical stage due to the widespread use of cross-sectional imaging systems. Although open radical nephrectomy has historically been considered the treatment of choice, partial nephrectomy (PN) is now accepted as a standard of care especially for treating T1a and T1b renal tumors amenable to nephron-sparing surgery.[1] When compared with radical nephrectomy, PN can achieve preserved renal function, improved overall patient survival, and reduced cardiovascular events.[2]
Minimally invasive nephron-sparing options such as laparoscopic and robotic partial nephrectomy (RAPN) have gained acceptance during the past two decades. However, laparoscopic partial nephrectomy is a technically challenging procedure due to the steep learning curve and necessity of the intracorporeal suturing that limits its use to highly experienced laparoscopic surgeons.[3-5] More recently, the robotic surgery gives surgeons several advantages over traditional laparoscopy to overcome these drawbacks. These advantages include tremor filtering, motion scaling, and magnified three-dimensional vision with a fully articulating Endowrist making tumor excision easy even in posterior tumor location.
The most important step of PN is clamping of the main hilar vessels to minimize blood loss and improve intraoperative visualization. By this way, renal tumors can be resected more easily and then; secure renorraphy can be performed. However, renal hilar control causes warm ischemia and prolonged warm ischemia time (WIT) is associated with renal functional impairment induced by renal ischemia-reperfusion injury.[6] Because of this reason, WIT should be minimized as much as possible to prevent chronic kidney disease and cardiovascular events.[7-8] Several techniques have been described to reduce this injury such as zero ischemia, zero ischemia with microdissection technique and segmental renal artery clamping (SAC).[9-12] However, no consensus related to the impact of the type of renal ischemia on the postoperative renal function has been assigned, yet. Therefore, the present study aims to evaluate the safety and efficacy of SAC during RAPN focusing on operative, post-operative and functional outcomes in the 36 consecutive patients.

PATIENT AND METHODS

Study population and design

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Table 1. Preoperative characteristics and perioperative outcomes in patients with renal tumor underwent SAC RAPN.

No, of patients.		36
Age (years, mean [SD])		57 (± 12)
Gender, n (%)	Male	29 (% 81)
	Female	7 (% 19)
Tumor side, n (%)	Right	18 (50)
	Left	18 (50)
Body mass index (±SD)		31 (± 4)
Tumor size, mm (±SD)		40 (± 14)
R.E.N.A.L score (±SD)		6.74 (± 1,8)
Mean Operation time (min) (±SD)		162 (± 44)
Mean warm ischemia time (min) (±SD)		16 (± 7)
Estimated blood loss (mL) (±SD)		236 (± 149)
Mean hematocrit decline (%), (±SD)a		3.98 (± 2.08)
Mean decrease in postoperative eGFR (mil/min/1.73 m^2), (±SD)		b4.88(± 17.1)
Drain removal time (days), (±SD)		2,5 (± 1)
Length of hospital stay (days), (±SD)		3,2 (± 1,3)
Intraoperative complication, n, (%)		1 (3)
Postoperative complications, n, (%)		5 (14)

[a]*P* <.01, CI%95: 3,06 - 4.90.
[b]*P* .18, CI%95: -2.57 - 12.20.

Between February 2013 and August 2018, 42 consecutive patients underwent RAPN. Thirty-six of these operations (86 %) with clinical T1-2 renal tumors were perform with segmental renal artery clamping technique and included in this study. All procedures were carried out by the single surgeon who performed several hundred robotic surgeries since 2005 before attempting SAC RAPN. Segmental renal artery clamping technique was attempted for vascular control in almost all patients during the study period when it was feasible. Tumors that were excised under main renal artery clamping, patients with a solitary kidney, multifocal tumors, patients with radiological evidence of locally advanced disease, patients with incomplete records or follow-up < 6 months were excluded. Patients' characteristics and follow up data were enrolled in our database prospectively.

Preoperative preparation

Preoperative evaluation included medical history, physical examination, routine laboratory studies, including serum creatinine, urinalysis and chest X-ray. All patients underwent a preoperative radiologic evaluation with contrast-enhanced computed tomography (CT) with 3-dimensional reconstruction to delineate precise segmental branches of the renal artery. Target arteries were defined as the feeding segmental arterial branches of the main renal artery entering directly into the tumor which were preoperatively determined by 3-D models of CT (**Figure 1**).

Outcome assessment

Tumor size was reported as the largest single dimension of the lesion as measured on the CT. Pathological staging was performed according to the 2009 IUCC/ American Joint Committee on Cancer tumor-node-metastasis staging system.[13] All tumors were scored according to R.E.N.A.L. nephrometry score.[14] Prospectively recorded patient demographics, mean operation time, estimated blood loss (EBL), WIT, length of hospital stay, pre- and postoperative renal functions and oncological outcomes were analyzed retrospectively. Preoperative creatinine levels and estimated glomerular filtration rates (eGFR) calculated with the Modification of Diet and Renal Disease[15] formula were compared with the postoperative creatinine and eGFR levels at the 1st month follow up. All complications within 30 days of the procedure were recorded prospectively and graded based on the modified Clavien-Dindo classification system.[16] Surgical success was defined as no conversion from segmental artery clamping to the main renal artery clamping.

Surgical Technique and follow-up

All operations were performed by using da Vinci SI robotic surgical system (Intuitive Surgical, Inc., Sunnyvale, CA). Written informed consent was obtained from all the patients in this study which was approved by the institutional review board. A five-port transperitoneal approach was used for left-sided tumors. An additional 5 mm port was used for liver retraction for right-sided tumors (**Figure 2**). Following the endotracheal intubation under general anesthesia, a ureteral catheter was placed in patients whose tumor was too close to the collecting system. Then, the patient was placed in a 60° modified flank position, and the pneumoperitoneum was achieved with a Veress needle at Palmer's point[17] for left renal tumors and 2 cm cranial from the midpoint between the umbilicus and anterior superior iliac spine for right renal tumors. The colon was reflected medial-

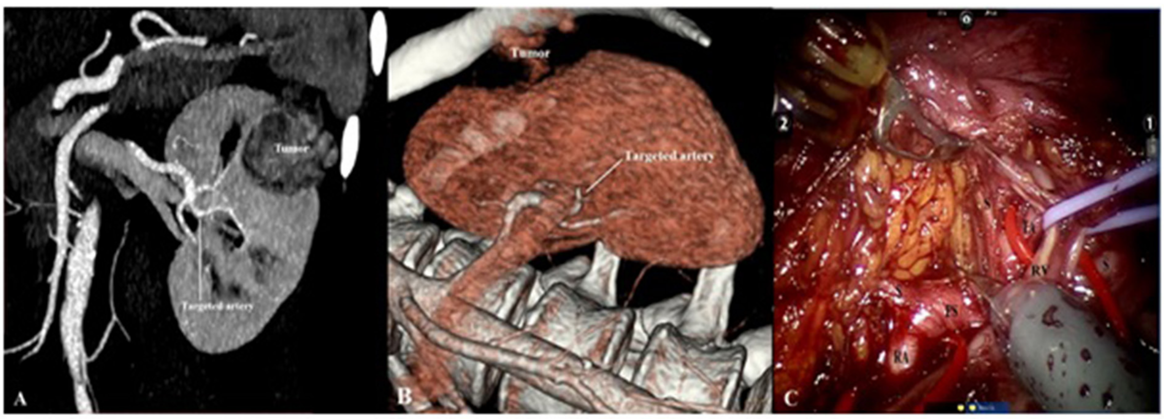

Figure 1. Vascular segmentation of renal artery A(left). Preoperative assessment of renal vascular anatomy. B(right). Segmental branches of renal artery feeding the tumor on 3-D CT imaging. C) Peroperative appearance of renal vasculature. (RA=Renal artery, PS=Presegmental artery, S=Segmental artery, RV= Renal vein, TA= Targeted artery)

Table 2. Pathological features and oncological outcomes

Tumor location, n (%)	Upper	9 (24)
	Middle	10 (27)
	Lower	17 (49)
Tumor growth pattern, n (%)	Endophytic	19 (53)
	Exophytic	17 (47)
Malign histology (RCC), n (%)	30 (83)	
Subtypes of malign tumors, n (%)	Clear cell type	15 (42)
	Papillary type	7 (19)
	Chromophobe type	8 (22)
Pathologic stage of malignant tumors, n	pT1a	19
	pT1b	9
	pT2a	1
	pT3a	1
Benign histology, n (%)		6 (17)
Subtypes of benign tumors, n (%)	Angiomyolipoma	3 (8)
	Oncocytoma	2 (6)
	Benign cyst	1 (3)
Positive surgical margin, n (%)		1 (3)
Local recurrence, n		0
Mean follow up (months), (±SD)		36 (22)

ly. Main renal vein, renal artery, and targeted segmental arteries were separately dissected and encircled by vascular loops in all cases. The renal capsule was scored using monopolar shears. Two 15-cm long 3-0 polyglyconate barbed sutures on a 26 mm ½ circle needle were placed in the abdominal cavity for renal parenchymal repair. Metal and plastic bulldog clamps of different size (Scanlan International, St. Paul, MN) depending the size of the renal arterial branch were used in order to control segmental branches of the main renal artery supplying the tumor. Cold excision of the tumor was performed with robotic hot shears. It was also necessary to clamp additional segmental arteries when there was arterial bleeding from tumor bed. If the pelvicaliceal system was opened up, it was repaired by uninterrupted 4-0 polyglactin suture. Afterward, tumor bed was sutured continuously with two preplaced barbed sutures. Subsequently, bulldog clamps were released (early unclamping). In case of pulsatile arterial bleeding, vessels were controlled in a figure of eight fashion by using 4-0 polyglactin suture. Renal parenchyma was further approximated using 0-0 polyglactin sutures on CT-1 needle with sliding-clip renorrhaphy technique.[18] A Jackson-Pratt drain was placed in all patients. In follow-up, all patients received comprehensive metabolic panel every 3 months for two years and then yearly. An abdominal ultrasound and chest radiography were done at 3rd months. Abdominal and thorax CT were performed at 6th months and yearly thereafter, if necessary.

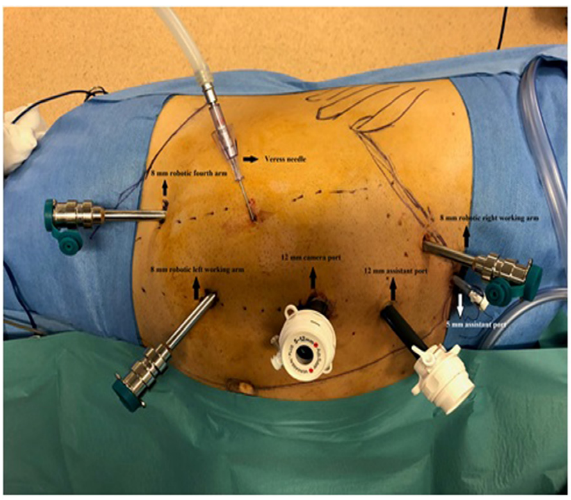

Figure 2. Port placement for right robotic partial nephrectomy.

Statistical analysis

All statistical analyses were performed using SPSS Statistics version 24 (IBM, Armonk, NY, USA) software. The sample mean was used to determine the average of the quantitative variables met the normal distribution according to the Kolmogorov-Smirnov test. Paired sample *t*-test was used to compare descriptive statistics for the before and after the intervention. The confidence interval was taken 95%, and a $P < 0.05$ was considered as statistically significant.

RESULTS

Table 1 summarizes patient demographics and early postoperative characteristics. The mean age was 57 (± 12) years. The mean body mass index, R.E.N.A.L. nephrometry scores, and tumor size were 31 (± 4), 6.74 (± 1.8) and 40 mm (± 14), respectively. The mean operation time was 162 min (± 44) and the mean warm ischemia time was 16 min (± 7). The mean targeted arteries dissection time was measured as 17 (± 10) min. Estimated blood loss was 236 ml (± 149). The mean decline in hematocrit was %3.98 (± 2,08), and this was statistically significant ($P < .01$). Mean pre- and post-operative eGFR values (ml/min/1.73 m^2) were 89.88 and 85. The mean reduction in eGFR at 1 month after surgery was not statistically significant ($P = .18$). Drain removal time and length of stay were 2.5 and 3.2 days, respectively. Of 36 patients in whom SAC was performed, 34 were completed successfully, while in 2 patients the main renal artery clamping was required due to excessive bleeding from the tumor bed. Therefore, the success rate of the SAC technique was determined as % 94.4 (34/36) in our study.

A renal vein injury occurred during dissection of the renal hilum and was successfully sutured by the 4-0 polyglactin sutures. Five postoperative complications were observed and recorded as Clavien grade 1-2 and 3-b. These complications were one sub-ileus that eventually resolved spontaneously, two postoperative bleeding necessitating blood transfusions, one pneumothorax requiring chest tube, and one urinoma requiring percutaneous drainage. Pathological characteristics of patients are listed in **Table 2**. Final pathological examination of 36 resected tumors revealed 30 malignant tumors (% 83) and 6 benign tumors (% 17). Pathology results showed 15 cases of clear cell carcinoma, 7 papillary carcinoma, 8 chromophobe RCC, 3 angiomyolipomas, 2 oncocytomas, and 1 renal cyst. Pathologic classifications of malignant tumors showed 19 cases of T1a, 9 T1b, 1 T2a and 1 T3a. The positive surgical margin was reported in one patient on the final pathology. However, no tumor recurrence occurred in the mean follow-up of 36 (± 22) months.

DISCUSSION

Partial nephrectomy is now considered as the gold standard surgical technique in the treatment of T1a, and when technically feasible in T1b renal tumors.[19] Renal function after PN can be impaired as a result of either ischemic injury induced by vascular clamping and loss of vascularized renal parenchyma. In order to achieve negative surgical margin, resection of some normal

functional renal parenchyma during RAPN is inevitable; however, total or partial warm ischemia remains as the major modifiable factor for preservation of postoperative renal reserve. In our opinion, the main goal should be minimizing warm ischemia during RAPN.
Though total hilar control provides optimal intraoperative visualization with the bloodless surgical field, prolonged warm ischemia time causes renal functional impairment by renal ischemia-reperfusion injury. For this reason, selective artery clamping of tumor-feeding branches of the renal artery has gained popularity as an interesting strategy to limit ischemia to the targeted tumor area. In this manner, general warm ischemia can be avoided, and renal functions can be effectively protected. A single center series, from Frukawa et al., compared postoperative renal functional outcomes of SAC with the main artery clamping. They showed that SAC had significantly less renal functional decrease at 1 week after surgery. However, in that study, changes in renal functional results were similar at first month in both techniques.[20] Similarly, Shao et al. have also demonstrated that patients who underwent RAPN with SAC technique have a better early renal functional recovery when compared with main renal artery clamping.[21] At the present study, local warm ischemia time was 16 minutes and mean decline in postoperative renal functions were not statistically significant at the 1st month of follow up. Even though patients included in this study had relatively higher R.E.N.A.L nephrometry scores and endophytic tumor growth pattern, our findings were similar when compared to those reported in the literature.[22]
Although some studies have shown promising perioperative results for SAC, the real benefit of this technique remains debatable. The possibility of the more significant blood loss should be taken into account because of excessive hilar dissection and uninterrupted main renal artery. Thus, the main renal artery and vein should be wholly mobilized and encircled with a vessel loop in case severe bleeding. In 2015, Zhou et al. published a systematic review of 7 retrospectively designed studies conducted to compare SAC versus main renal artery clamping. There were no differences among groups in terms of mean operation time, surgical complications and length of stay. Although estimated blood loss was significantly higher with SAC technique, no significant difference was noted in blood transfusion rate among groups according to this meta-analysis.[23] In our study, only one renal vein injury occurred during hilar dissection which was successfully repaired by suturing. Though the mean decline in postoperative hematocrit was statistically significant within the cohort, only two patients received blood transfusions at postoperatively. Clavien grade 3 or higher complications were observed in two patients (% 5.5). Postoperative complications of our study are similar to those reported series for SAC during RAPN in the literature ranging from % 7-16.[22-25]
It's not clearly demonstrated in the current literature whether the increase in intraoperative blood loss has any negative impact on oncological outcomes of SAC. The largest RAPN series have reported PSM rates from % 0 to % 10.[26-29] In our study, one patient who had an utterly endophytic tumor with high R.E.N.A.L. nephrometry score had positive surgical margin but, no local recurrence has occurred during follow up. Finally, we think that increase in intraoperative blood loss during RAPN performed with SAC technique has no negative impact on the oncologic outcomes according to our results.
In our study, SAC was successfully performed in all but two patients. These two had to be converted to main renal artery clamping due to uncontrolled bleeding during dissection. Renal tumors of these patients had completely endophytic growth pattern and RENAL nephrometry scores of these tumors were 8 and 10. In endophytic and laterally located tumors as in these cases, multiple segmental arteries may supply the tumor which is difficult to control. Total clamping of the main renal artery might be more suitable for these patients. Therefore, we strongly recommend to study on intrarenal vascular anatomy before SAC attempt during RAPN. A contrast-enhanced CT with 3-D modification is the best tool to visualize arterial branches of the main renal artery before surgery. This imaging modality provides a preoperative mapping of renal vascular anatomy which is facilitating dissection plans from the main renal artery to target segmental branches feeding the tumor. Intraoperative ultrasonography using a drop-in probe can also be beneficial to visualize accurate surgical margin. It can be used to assess for specific segmental or interlobar arteries supplying the tumor. However, it was not used since not available in the current cohort.
At the present study, the success rate of the SAC technique was % 94.4 (34/36). This success rate is similar to those previously reported retrospective studies of robotic and laparoscopic partial nephrectomy series using SAC technique ranging from % 77-100.[20,21,30]
Our study has some limitations that need to be considered. First, this study is a single center, single surgeon experience. The cohort has insufficient power to detect definitive conclusion on the surgical outcomes. Second, no control group was included in this study to compare outcomes of the SAC with the other techniques such as off clamp and total ischemia. The last limitation of this study is the interpretation of the renal functions. All patients included in this study have a normal contralateral kidney that limits the ability to interpret eGFR changes. Though almost all studies choose comparison of the eGFR values to analyse the pre and post-operative renal functional changes, renal scans might be a more accurate way to evaluate functional changes. Nevertheless, this single-center study suggests that SAC of tumor-feeding arteries is a reliable surgical method of vascular control during RAPN.

CONCLUSIONS

Segmental artery clamping seems safe and effective surgical technique in order to minimize warm ischemia time during RAPN. It may be an alternative surgical method of vascular control. However, higher RENAL nephrometry scores and tumor growth pattern might have negative impact on surgical success rates. Therefore, preoperative mapping of renal vascular anatomy and tumor characteristics should be precisely determined before surgery.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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