A Comparison of Robotic, Laparoscopic and Open Partial Nephrectomy

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ABSTRACT

Introduction: Comparison of treatments for partial nephrectomy is limited by case selection. We compared robotic (RPN), laparoscopic (LPN), and open partial nephrectomy (OPN), controlling for tumor size, patient age, sex, and nephrometry score.

Methods: RPN, LPN, and OPN procedures between March 2003 and March 2010 were reviewed. All RPN and LPN were included, and 2 OPN were matched for each RPN in tumor size ($\pm$0.5cm), patient age ($\pm$10 y), sex, and nephrometry score. Perioperative outcomes were compared.

Results: Ninety-six partial nephrectomy procedures were reviewed: 27 RPN, 15 LPN, and 54 OPN. RPN, LPN, and OPN had similar median tumor size (2.4, 2.2, and 2.3cm, respectively), nephrometry score (6.0 each), and preoperative glomerular filtration rate (71.5, 84.6, and 77.0 mL/min/1.73m^2, respectively). Blood loss was higher for OPN (250 mL) than for RPN or LPN (100 mL), $P < .001$. Operative time was shorter in OPN (147 min) than in RPN (190 min) or LPN (195 min), $P < .001$. Median warm ischemia time was shorter for OPN (12.0 min) than for RPN (25.0 min) or LPN (29.5 min), $P < .05$. Cold ischemia time for OPN was 25.0 min. A 10% glomerular filtration rate decline occurred in 10 RPN, 5 LPN, and 29 OPN cases ($P = .252$). Median hospital stay for LPN and RPN was 2.0 d versus 3.0 d for OPN ($P < .001$). Urine leak occurred in 1 RPN and 3 OPN cases. Postoperative complications occurred in 4 RPN (3 were Clavien grade 2 or less), 1 LPN (grade 1), and 7 OPN (6 were grade 2 or less) cases.

Conclusion: Renal function preservation and complications are similar for each treatment modality. OPN offers faster operative and ischemia times at the expense of greater blood loss and hospital stay.

Key Words: Nephron-sparing surgery, Laparoscopy, Robotics, Nephrometry score.

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INTRODUCTION

In light of recent research demonstrating the significant impact of radical nephrectomy on renal function and survival, the indications for partial nephrectomy (PN) and other nephron-sparing techniques have increased.[1–3] It has been shown that open partial nephrectomy (OPN) for small renal masses has oncologic control comparable to that of radical nephrectomy.[4] With increased laparoscopic technology, partial nephrectomy via purely laparoscopic (LPN) or robotic (RPN) means has become readily available. Preliminary comparison between LPN and OPN demonstrate similar oncologic outcome and renal function preservation.[5–9] Similarly, LPN and RPN have equivalent outcomes.[10–13]

Comparisons between treatment modalities have been difficult, as the preoperative characteristics of patients undergoing a particular treatment modality are often influenced by age, medical comorbidities, tumor size, and tumor configuration. Recently, Kutikov and Uzzo[14] developed a RENAL nephrometry score to describe the likelihood of performing a radical versus partial nephrectomy, thereby suggesting a means to characterize the difficulty of performing a partial nephrectomy for a particular renal mass. This allows one to select cases that are similar in terms of difficulty of resection to compare treatment modalities. Furthermore, characterization of the efficacy of RPN is limited in that the outcomes have not been compared to OPN, but rather to LPN as a surrogate comparison. In this study, we compare patients treated for T1a renal masses undergoing RPN, LPN, and OPN, matching cases for age, sex, tumor size, and nephrometry score.

METHODS

Patients treated with RPN, LPN, or OPN for T1a renal masses at the Indiana University Medical Center between

2004 and 2010 were reviewed in this institutional review board-approved study. All consecutive cases of RPN and LPN for T1a renal masses performed by a single minimally invasive specialist were included, which represented initial minimally invasive partial nephrectomies for this particular surgeon. Patients with previous renal cancer, solitary kidneys, prior renal surgery, or clinical evidence of metastatic renal cancer were excluded. Patients who had multiple procedures for renal masses were included if the first procedure was a partial nephrectomy, with follow-up continuing until the second procedure.

Preoperative data included patient age, sex, race, glomerular filtration rate (GFR), which was estimated by the modified Modification of Diet in Renal Disease (MDRD) equation, comorbidities, and body mass index (BMI). Nephrometry score was calculated using the formula described by Kutikov and Uzzo.[14] Perioperative data included operative time, ischemia time, blood loss, complications, and margin status. Postoperative GFR was estimated from the patient's creatinine prior to discharge and at last follow-up from the latest available creatinine in the patient's chart.

For each RPN, 2 OPNs were matched in terms of patient age (within 10 y), sex, tumor size (within 0.5cm), and nephrometry score (within 2) from a pool of 320 cases performed between March 2003 and March 2010. Data from the open partial nephrectomy cases were limited to the matching parameters until adequate matches were found. These cases were performed predominantly by urologists who did not routinely perform minimally inva-

sive partial nephrectomy to increase the likelihood that similar masses would be selected for OPN. RPN and LPN cases were not directly matched, because they were performed by the same surgeon and the same mass attributes were used to select patients for these treatment modalities. Matching between these 2 groups would restrict the size of the comparison groups, mostly due to differences in sex and age. Thus, this led to some differences in the median age and sex distribution between the 2 groups, though no difference was seen in the mass size or nephrometry score. The preoperative characteristics of these 2 groups were compared to ensure that they were similar.

Statistical analysis was performed using SPSS, version 18 (Chicago, IL). Comparisons of medians between groups were made using Mann-Whitney U or Kruskal-Wallis tests. Comparisons of frequencies of nominal variables between groups were conducted using χ^2 or Fisher's exact tests to determine significance.

RESULTS

A total of 96 PN procedures were reviewed: 27 RPN, 15 LPN, and 54 OPN **(Table 1)**. RPN, LPN, and OPN were similar in terms of median tumor size (2.4, 2.2, 2.3cm, respectively, $P = .857$), age (62 y, IQR = 15; 49 y, IQR = 25; and 58 y, IQR = 18, respectively, $P = .093$), BMI (29.2, 26.9, 29.2 kg/m^2, respectively, $P = .648$), nephrometry score (6.0 in each group), and preoperative GFR (72.6, 84.6, 76.6 mL/min/1.73m^2, respectively, $P = .327$). Mean

Table 1.
Preoperative Comparison of Robotic, Laparoscopic, and Open Partial Nephrectomy

	RPN[a] (n=27)	LPN[a] (n=15)	OPN[a] (n=54)	P Value
Median age (IQR[a]) yr	62.1 (15.3)	49.4 (24.8)[b]	57.6 (17.6)	.093
Number of females (%)	8 (29.6)	10 (58.8)	16 (29.6)	.071
Median BMI (IQR) kg/m^2	31.4 (5.5)	27.8 (13.7)	29.6 (7.6)	.568
Median mass Size (IQR) cm	2.40 (0.6)	2.20 (1.9)	2.30 (1.1)	.899
Median nephrometry Score (IQR)	6.0 (4.0)	6.0 (1.0)	6.0 (2.0)	.716
Median preoperative GFR (IQR) mL/min/1.73m^2	71.5 (10.5)	84.6 (24.1)	77.0 (29.4)	.171
Number with diabetes (%)	5 (18.5)	1 (5.9)	6 (11.1)	.483
Number with hypertension (%)	17 (63.0)	6 (40.0)	27 (50.0)	.324
Previous cardiovascular disease/stroke (%)	1 (3.7)	1 (5.9)	2 (3.7)	.918

[a]RPN, robotic partial nephrectomy; LPN, laparoscopic partial nephrectomy; OPN, open partial nephrectomy; IQR, interquartile range; BMI, body mass index; GFR, glomerular filtration rate.

[b]Median age of LPN patients was significantly lower than that for RPN.

follow-ups for RPN, LPN, and OPN were 9.4 ± 7.6 mo, 25.8 ± 20.2 mo, and 21.1 ± 18.8 mo, respectively (*P* = .004, comparing RPN with the other groups).

Blood loss was higher for OPN (250 mL, IQR = 300) than for RPN (100.0, IQR = 100) or LPN (100.0 mL, IQR = 150), *P* < .001 **(Table 2)**. Operative time was shorter in OPN (147 min) than in RPN (190 min) or LPN (195 min), *P* = .010. Median WIT was shorter for OPN (12.0 min) than for RPN (25.0 min) or LPN (29.5 min). Median cold ischemia time for OPN was 25.0 min. Among OPN, 32 (59%) patients underwent cold ischemia, 16 (30%) warm ischemia, and 6 (11%) no ischemia. Warm ischemia was used in 24 RPN (89%) and 9 (60%) LPN, while no ischemia was used in 3 RPN (11%) and 6 (40%) LPN.

Median hospital stays for RPN, LPN, and OPN were 2.0 d, 2.0 d, and 3.0 d, respectively, *P* < .001. Postoperative GFR was similar among the 3 groups (RPN: 66.4 mL/min/1.73m^2, IQR = 22.3; LPN: 75.1 mL/min/1.73m^2, IQR = 26.4; and OPN: 68.7 mL/min/1.73m^2, IQR = 24.6; *P* =

.098). Postoperative leaks were noted in 1 (3.7%) RPN, managed by prolonged Foley catheterization and flank drain for 10 d, and 3 (5.6%) OPN, managed by prolonged drain duration of 8 d, 14 d, and 41 d. Intraoperative complications occurred in 1 RPN (3.7%, bleeding requiring transfusion), 0 LPN, and 4 OPN (7.4%, splenic vein injury, hemorrhage, pleurotomy, and injury to renal pelvis requiring stented repair), *P* = .478. Two RPN were converted to LPN (1 due to machine malfunction and 1 due to inability to access mass with robotic arms). Postoperative complications occurred in 4 RPN (1 urine leak, 1 mild ileus, 1 urinary tract infection, and 1 stroke that resolved) and 7 OPN (3 urine leaks, 1 pneumothorax, 1 readmission for emesis, 1 wound dehiscence, and 1 temporary femoral neuropathy). Complication severity by Clavien grade was similar among the 3 treatment groups: 3 of 4 RPN, 1 of 1 LPN, and 6 of 7 OPN complications were ≤grade 2 **(Table 2)**.

Tumor was identified on the cut surface of the tumor specimen in 1 RPN. This tumor was on the hilar vessels

Table 2.
Perioperative Comparison of Robotic, Laparoscopic, and Open Partial Nephrectomy

	RPN[d] (n=27)	LPN[d] (n=15)	OPN[d] (n=54)	P Value
Median EBL[d], mL (IQR[d])	100 (100)	100 (150)	250 (300)[a]	<.001
Median Operative Time, min (IQR)	190 (60)	195 (90)	147 (64)[a]	<.001
Ischemia				
Warm ischemia time (IQR)	25.0 (7.0)[b]	29.5 (10.0)	12.0 (2.0)[a]	<.001
Number warm ischemia (%)	25 (92.6)	9(60.0)	16 (29.6)	<.001
Cold ischemia time	–	–	25.0 (18.0)	
Number cold ischemia (%)	0	0	32 (59.3)	<.001
Intraoperative Complications	1	0	4	.478
Postoperative Complications	4	1	7	.784
Grade 1	1	1	5	
Grade 2	2	0	1	
Grade 3b	0	0	1	
Grade 4a	1	0	0	
Urine Leak	1 (3.7)	0	3 (5.6)	.629
Conversion to Radical Nephrectomy	1[c]	0	0	.277
Malignancy (%)	17 (63.0)	11 (73.3)	44 (81.5)	.190
Positive Margin on Specimen	1	0	4	.478
Positive Margin on Deep Resection Margin	0	0	1	.675

[a]Significantly different from the other 2 treatment modalities.

[b]Significantly different from LPN.

[c]Mass at hilum such that additional tissue could not be taken, later found to be multifocal tumor. [d]RPN=robotic partial nephrectomy; LPN=laparoscopic partial nephrectomy; OPN=open partial nephrectomy; EBL=estimated blood loss; IQR=interquartile range.

precluding additional excision, and the case was converted to radical nephrectomy (final pathology revealed multifocality). Four OPNs had tumor at the specimen margin, with 3 cases having additional negative deep margins, and 1 angiomyolipoma (AML) with no additional sections taken. Malignancies were identified in 17 (63%) RPN, 11 (73%) LPN, and 45 (83%) OPN **(Table 3)**. Among those with malignancy, the majority were clear cell. Distribution of grade was similar among the 3 groups, though no grade 3 masses were present in the RPN group ($P = .132$). There were no recurrences or metastases in the patients treated for primary renal cell carcinoma.

DISCUSSION

In this series, 96 PN (27 RPN, 17 LPN, and 54 OPN) cases were reviewed, controlling for tumor size, nephrometry score, patient age and sex. Comparison of the RPN and OPN groups reveal similar distribution of low, medium, and highly complex lesions, while LPN had no high complexity lesions. Median tumor size varied by 0.2cm, suggesting similar masses were used for comparison. Intraoperatively, OPN had advantages in operative time and ischemia time, at the expense of increased blood loss, which was, in part, due to differences in operative technique. Postoperatively, urine leaks were low in all groups

Table 3.
Oncologic Comparison of Primary Renal Malignancies by Treatment Modality

	RPN[a] (n=17)	LPN[a] (n=11)	OPN[a] (n=45)	P Value
Median follow-up y (IQR)	5.1 (11.6)	29.0 (41.2)	16.8 (32.8)	.062
Type (%)				.317
Clear	10 (58.8)	9 (81.1)	34 (77.3)	
Chromophobe	6 (35.3)	1 (9.1)	5 (11.4)	
Papillary	0	0	2 (4.5)	
Other	1 (5.9)	1 (9.1)	3 (6.8)	
Grade (%)				.132
1	1 (5.9)	2 (20.0)	3 (7.1)	
2	16 (94.1)	6 (60.0)	29 (69.0)	
3	0	2 (20.0)	10 (23.8)	
Metastasis	0	0	0	
Recurrence	0	0	0	

[a]RPN=robotic partial nephrectomy; LPN=laparoscopic partial nephrectomy; OPN=open partial nephrectomy; IQR=interquartile range.

(3.7% RPN, 0 LPN, and 5.6% OPN), and GFR was similar. Tumor at the specimen margin was also low, occurring in 3.7% RPN, 0 LPN, and 7.4% OPN (all but 1 case, an AML, had additional negative margin biopsies).

While our series compares RPN, LPN, and OPN, similar comparisons in the literature typically compare RPN with LPN and LPN with OPN. When comparing RPN and LPN, both techniques offer low morbidity and good success **(Table 4)**. In a multi-institutional study comparing RPN (129 cases) and LPN (118 cases), postoperative complications were similar with urine leak and hemorrhage in 3 and 2 RPN, and 4 and 1 LPN.[10] Similar to our series, warm ischemia time (WIT) was shorter for RPN than for LPN (19.7 min versus 28.4 min). In contrast, blood loss was significantly lower in RPN (155 mL versus 196 mL). Two other single-institution, large series were consistent with our findings: no difference in blood loss, complications, and margins, but a decrease in WIT with RPN.[11,12] In contrast to these studies, Haber et al.[13] comparing 75 RPN and 75 LPN, noted no significant difference in WIT (RPN = 18.2min and LPN = 20.3min). Blood loss was significantly higher in RPN than LPN (323 mL versus 222 mL). A decline in postoperative GFR occurred in 9% of patients in both groups, and complications were seen in 13% RPN and 16% LPN. In summary, RPN and LPN have similar reported perioperative morbidity reported in the literature as well as in this series, though RPN may offer faster ischemia times. However, these series do not account for tumor location or configuration.

In comparison to OPN, our series showed a decrease in blood loss and hospital stay with RPN and LPN at the expense of longer operative and ischemia times. Complications and margins were otherwise similar. While comparison of RPN to OPN is limited in the literature, there are several studies that compare LPN to OPN **(Table 5)**. The largest comparison (771 LPN versus 1,028 OPN) also shows reduced WIT for OPN versus LPN (30.7 min versus 20.1 min).[5] As in our series, positive margins (2.85% LPN versus 1.6% OPN) and complications were similar. In contrast to our findings, blood loss was similar for OPN and LPN (300 mL versus 376 mL), with a 5% transfusion rate for both groups. Furthermore, both the size and configuration of the tumors differed significantly (OPN were larger and more often endophytic), thereby limiting the comparison. A separate large series of OPN reported a shorter operative time (155 ± 59 min), but similar ischemia time (20.1 ± 10.9 min) and blood loss (median = 350 mL).[15] A higher (15.3%) transfusion rate was reported. A similarly low positive margin rate of 1.5% was observed. Pempangkosol et al.[7] compared 85 LPN (2.4 ± 1.1cm)

Table 4.
Review of Comparisons Between Robotic and Laparoscopic Partial Nephrectomy

Series	N	OR[a] Time (min)	WIT[a] (min)	EBL[a] (mL)	Complications
Benway et al[10]	129 RPN	189	19.7	155	3 leak, 2 hemorrhage
	118 LPN	174	28.4	196	4 leak, 1 hemorrhage
Wang[11]	40 RPN	140	19	137	1 leak, 2 hemorrhage
	62 LPN	156	25	173	1 leak, 2 hemorrhage
Kural et al[12]	11 RPN	185	27.5	286.4	
	20 LPN	226	35.8	387.5	
Haber et al[13]	75 RPN	200	18.2	323	1 leak, 3 hemorrhage
	75 LPN	197	20.3	222	0 leak, 4 hemorrhage

[a]OR=operating room; WIT=warm ischemia time; EBL=estimated blood loss; RPN=robotic partial nephrectomy; LPN=laparoscopic partial nephrectomy.

Table 5.
Review of Comparisons Between Laparoscopic and Open Partial Nephrectomy

Series	N	OR[a] Time (min)	WIT[a] (min)	EBL[a] (mL)	Complications
Gill et al[5]	771 LPN	201	30.7	300	24 leaks, 4.2% hemorrhage
	1,028 OPN	206	20.1	376	24 leaks, 1.6% hemorrhage
Pempangkosol et al[7]	85 LPN	225	29.5	437	1 leak, 2 hemorrhage
	58 OPN	275		427	1 leak, 2 hemorrhage
Schiff et al[8]	66 LPN	144		236	2 leaks, 1 hemorrhage
	59 OPN	239		363	1 leak
Marszalek et al[9]	100 LPN	85	23	323	4 leak, 6 hemorrhage
	100 OPN	150		222	2 leak, 1 hemorrhage

[a]OR=operating room; WIT=warm ischemia time; EBL=estimated blood loss; RPN=robotic partial nephrectomy; LPN=laparoscopic partial nephrectomy; OPN=open partial nephrectomy.

with 58 OPN (2.9 ± 0.9cm). In contrast to our series, overall complications were observed in 7.8% LPN versus 25% OPN, though each had 3 intraoperative complications, 1 urine leak, and 2 postoperative hemorrhages that required transfusion. Also differing from our series, a comparison of 66 LPN (2.2cm) and 59 OPN (3.4cm) observed shorter operative times for LPN (144 ± 38.4 min versus 239 ± 57.8 min), while blood loss was similar for both (236 ± 382 mL LPN versus 363 ± 241 mL OPN).[8] Positive margin rates were again similarly low, but overall complications were reduced in LPN (9% LPN versus 19% OPN), which contrasted our findings. Postoperative hemorrhage and leak were similar for LPN (1 hemorrhage and 2 leaks) and OPN (1 urine leak). While comparisons suggest an advantage for OPN in terms of ischemia time as in our series, with other perioperative aspects being sim-

ilar, the postoperative complications are variable and may reflect differences in patient or tumor characteristics.

To account for differences in patients selected for minimally invasive partial nephrectomy versus OPN, we matched cases by size and configuration. In a similar manner, Marszalek et al.[9] compared 100 LPN with 100 OPN, matched for age, sex, and tumor size **(Table 5)**. Median operative time was shorter, intraoperative complications were more frequent (10% versus 3%), and postoperative complications were less frequent for LPN (14% versus 19%). GFR decline was higher in the postoperative period for LPN, but was similar in both groups at last follow-up (10%). In contrast, our matched series of RPN and OPN, operative time (190 min versus 147 min) and WIT (25 min versus 12 min) were longer for RPN, while

blood loss was less for RPN (100 mL versus 250 mL). Comparison of WIT however is limited, as this does not include cold ischemia time for the OPN group. Positive margin rates, postoperative renal function, and complications were similar.

Our series is unique in its matched comparison, including nephrometry score as a measure of tumor configuration in addition to tumor size, patient sex, and age.[14] It is also unique in providing a matched comparison of RPN and OPN and in its inclusion of all 3 modalities of partial nephrectomy. Recently, Scoll et al.[16] characterized a series of 100 RPN by the nephrometry score. This series included tumors > 4cm and noted 6% to have a nephrometry score of 10, which was highly complex (score 10 to 12), and 45.7% to have moderate complexity (score 7 to 9). Similar to our series, there were very few masses with highly complex Nephrometry Scores (10 to 12, noted in its original description). They report a positive margin rate of 5.7%, median estimated blood loss (EBL) of 50 mL, a WIT of 25min, and 1 postoperative transfusion.

Tumor configuration and size has been described in other series to influence outcome. Nadu et al.[17] compared 53 central tumors against 159 peripheral tumors, determining that central tumors were more likely to have delayed bleeding, but was not predictive of ischemia time, complications, blood loss, urine leak, or margin status. In a multi-institutional study, 41 hilar lesions had a higher WIT than 405 nonhilar lesions treated with RPN (26 min versus 19 min).[18] Positive margins and urine leaks were slightly higher in the hilar lesions (2.4% versus 1.5% for both outcomes), though this was not statistically significant. Chan et al.[19] determined treatment modality, tumor size, tumor depth, and estimated preserved renal volume to be predictive of postoperative function on a renal scan on univariate analysis only.

Tumor size and endophytic configuration were predictive of urine leaks in another study.[20]

The nephrometry score provides a method for more consistently characterizing renal masses, including the size, depth, proximity to the collecting system and hilum. The above studies have varying conclusions, which may be a result of differences in categorizing the lesions. Though not yet validated for perioperative outcomes, the nephrometry score offers the potential to compare similar renal masses in terms of case complexity across different treatment modalities.

There are limitations to this series, of which we report some of the more significant limitations. First, the nephrometry score does not account for lesions that are upper pole or posterior, which add a degree of difficulty to a transperitoneal RPN or LPN. When compared to OPN, Zorn et al.[21] observed a trend toward higher complications with LPN for upper pole tumors.

A second limitation is that different surgeons performed OPN than the surgeon performing the LPN or RPN cases, creating differences in operating time, ischemia time, and outcomes due to different surgical technique. Furthermore, the surgeons performing OPN had previous experience performing OPN, which is compared to the initial series of minimally invasive partial nephrectomy by a single surgeon. However, if one were to compare OPN and RPN from the same surgeon, selection of more difficult tumors for OPN only is more likely, thus comparing OPN and RPN from the same surgeon would introduce other factors that could create bias.

A third limitation is that the nephrometry score, which was initially developed from a series of open and laparoscopic radical and partial nephrectomies, may not be valid for series of smaller renal masses treated by partial nephrectomy alone. Since most of the masses included in this study were < 4cm, a dimension of the nephrometry score, mass size, is removed from the categorization of the renal masses. Given this constraint on mass size, the maximum nephrometry score in this series was 10 for most masses. Thus, the definition of low-, medium-, and high-complexity lesions must be revised from the initial description by Kutikov and Uzzo. Thus, in our series, low-, medium-, and high-complexity lesions are represented in the context of a partial nephrectomy. Further validation of the nephrometry score in a large cohort, as it relates to partial nephrectomy outcomes, is needed.

A final limitation arises from the size of our cohort. While we were able to identify statistically significant differences between the treatment modalities, the study is not adequately powered to detect more subtle differences. Additionally, we did not match LPN with OPN or RPN, due to cohort size constraints. It was assumed that LPN cases would be similar to RPN, since the same surgeon performed both LPN and RPN, with LPN representing mostly cases that were done prior to use of the robot. Analysis reveals that the groups were very similar in terms of nephrometry score and tumor size, but there were slight age and sex differences.

CONCLUSION

In this series, we compared a cohort of patients treated with OPN, LPN, and RPN who were similar in age, sex, tumor

size, and nephrometry score. In these patients, perioperative morbidity, renal function, and oncologic outcome were similar with each treatment modality. OPN offered faster operative and ischemia times at the expense of greater blood loss and hospital stay. This study demonstrates the potential utility of the nephrometry score in providing a means to compare outcomes of different treatment modalities for renal masses. It also stresses the importance of further validation of the nephrometry score to predict outcomes and thus guide future therapies.

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