Identifying preoperative predictors of operative time and their impact on outcomes in robot-assisted partial nephrectomy

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ABSTRACT

Objective: To identify preoperative characteristics in patients with renal masses that influence operative time during robot-assisted partial nephrectomy (RAPN) and evaluate the relationship between operative time and length of stay, complication rates, and overall outcome.

Methods: We queried our institutional database to identify a cohort of patients who underwent RAPN by two experienced robotic surgeons between 2012 and 2019. A multivariable regression model was developed to analyze operative time, length of stay, and any grade complication within 30 days postoperatively using bootstrap resampling technique.

Results: A total of 392 patients were included. On multivariable analyses, prior abdominal surgery ($p=0.001$) was associated with 22 minute increase in operating room time; as well as adhesive perirenal fat (22 minutes, $p=0.001$). For each one unit increase in nephrometry score, there was a four minute increase in operating room time ($p=0.028$), and for each one cm increase in tumor size, there was an associated 12 minute increase in operating room time ($p<0.001$). For each one year increase in age, there was an associated 0.024 day increase in length of stay [(odds ratio (0.013-0.035)]; additionally, for every one cm increase in tumor size there was a 0.18 day associated increase in length of stay [OR (0.070-0.28)]. Each one hour increase in operating room time was associated with a 0.25 day increased length of stay [OR (0.092, 0.41)]. Only tumor size was found to be associated with any grade complication.

Conclusions: Patients with a history of abdominal surgery, larger complex tumors, and significant Gerota's fat undergoing robotic partial nephrectomy should anticipate longer operative times. Older patients with larger tumors and longer operative times can anticipate a longer length of stay. Tumor size appears to be the common determinant of all three outcomes: operative time, length of stay, and any grade Clavien complication.

INTRODUCTION

Over the last decade, robotic assisted laparoscopic partial nephrectomy has become the primary treatment modality for clinical T1 renal tumors[1–3]. The use of nephron sparing surgery leads to improved preservation of renal function, reduction of metabolic and cardiovascular sequelae, and acceptable oncologic outcome [2,4–9]. Although partial nephrectomy is the most commonly performed procedure for small renal tumors, the impact of predictable preoperative variables has not been well evaluated [10–14].

A number of surrogates have been postulated as important for perioperative outcomes following minimally invasive nephron sparing surgery. These include patient comorbidities, tumor size and complexity (nephrometry score), surgeon experience, operative time, estimated blood loss (EBL), perinephric to subcutaneous fat, hospital length of stay (LOS), as well as a host of other prognostic indicators [13–19]. Although numerous studies have evaluated these characteristics using a multitude of methodologies; to date, there is a dearth of evidence assessing how these factors may affect operative time and subsequently complication rates. We sought to examine this relationship and the relationship between operative time and length of stay for patients undergoing robotic partial nephrectomy at our institution.

MATERIAL AND METHODS

Data source

After obtaining approval from the Institutional Review Board, we queried our prospectively maintained partial nephrectomy database to examine the records of patients who underwent robotic partial nephrectomy for clinically localized renal tumors by two experienced fellowship trained surgeons using the da Vinci Si or Xi system (Intuitive Surgical Inc., Sunnyvale, California, USA) between 2012 to 2019. These two surgeons had performed over 500 partial nephrectomies by 2012 and were considered to be beyond their learning curve for the analyzed patients. We excluded any patients who underwent conversion to radical nephrectomy, had aberrant anatomy such as a horseshoe kidney, and those whom preoperative imaging (computed tomography or magnetic resonance imaging) could not be located and reviewed. All data and imaging were reviewed independently by three of the study's authors (N.K, J.Z, and R.N).

Operative technique

All patients underwent robotic partial nephrectomy via the transperitoneal approach using the da Vinci robotic system (Intuitive Surgical, Sunnyvale, CA, USA). Patients were placed in the flank position with typically a 12 mm Airseal port and an additional five mm assistant port along with four eight mm robotic ports. Details of the procedures followed similar steps as outlined in prior robotic partial nephrectomy technique literature [20].

Outcomes of interest

The outcomes of interest of this study were predetermined. The primary outcome of interest was operative time amongst patients undergoing robotic partial nephrectomy. Operating room time was reported in hours and minutes and is defined as time of first incision to completion of skin closure. The secondary outcomes examined the association between preoperative predictors of increased operative time and downstream perioperative outcomes such as length of stay and all grade complications. Length of stay was measured in days as day of admission to day of discharge when the patient physically exited the hospital. Complications were recorded within 90 days postoperatively.

Covariables

Patient, tumor, and perioperative characteristics were reported and compared. This included age, sex, body mass index (BMI), prior abdominal surgery, R.E.N.A.L nephrometry score, greatest tumor dimension on imaging, perirenal fat thickness, the presence/absence of adhesive perirenal fat, Charlson comorbidity index, and median ischemia time. Adhesive perirenal fat was retrospectively determined using the imaging scoring system known as the Mayo adhesive probability (MAP) score. All patients with a maximum MAP score of five were determined to have adhesive perirenal fat preoperatively [16,20]. All other variables were prospectively captured in our database. Patients with prior abdominal surgery were compared to those without a history of surgery, and patients determined to have adhesive perirenal fat preoperatively were compared to those without. The study cohort was further split into three groups based on operative time; the fastest group was classified as the 25th percentile or less, middle group was the 25th to 75th percentile, and the slowest group included 75th percentile or longer.

The cohort was then analyzed using these three operative time groups (slow, middle, fast) to compare the impact of patient and tumor characteristics.

Statistical analysis

Patient characteristics and unadjusted outcomes were compared using Fisher's exact and chi-square tests for categorical variables and t-statistics for continuous variables. Multivariable logistic regression models were built *a priori* using: age, BMI, sex, prior abdominal surgery, presence of adhesive perirenal fat, perirenal fat thickness, R.E.N.A.L nephrometry score, and greatest tumor dimension on imaging. We included operating room time in the multivariable model for LOS and any grade Clavien-Dindo complication [21]. In order to perform internal validation of our final model, we used nonparametric bootstrapping (n=1,000) with stratified resampling for sensitivity analyses. We then generated a logistic regression model with bias-corrected 95% confidence intervals (CIs) using the 1,000 bootstrapped samples.

All analyses were performed using Statistical Analysis System (SAS) version 9.4 software (SAS Institute, Cary, North Carolina, USA). All testing was two-sided, and the probability of a Type I error was set at 0.05.

RESULTS

Unadjusted analysis

Our study included 392 patients who underwent robotic partial nephrectomy (Table 1). Patients in the fastest 25th percentile had a median operation time of 146.5 minutes; patients in the middle 25th-75th percentile group had a median operative time of 206 minutes; and patients in the slowest 75th percentile group demonstrated median times of roughly 288 minutes (range 94-453 minutes). On unadjusted analysis, prior abdominal surgery (p=0.02), higher nephrometry score (p=0.001), larger tumor sizes (p=0.002), increased perirenal fat thickness (p=0.01), longer length of stay (p< 0.0001), ischemia time (p=0.0002), and increased estimated blood loss (p< 0.0001) were all statistically significant across the three groups (Table 1). Charlson comorbidity index was not significant (p=0.27).

Operative time

We examined operative time as a continuous variable measured in hours using a boot strapped multivariable logistic model with n=1,000 iterations (Table 2). After adjusting for the covariates, we found patients with prior abdominal surgery were associated with a 22 minute increase in operative time and adhesive perirenal fat was also associated with a 22 minute increase (p=0.001, both). These variables had the most significant impact on operating room time. With each one unit increase of nephrometry score there was a four minute increase in the operative time (p=0.028). Regarding surrounding renal fat, for each one cm increase in fat thickness there was a 0.8 minute increase in operative time (p=0.0028). Lastly, for every centimeter increase in tumor size there was a 12 minute increase in the operative time (p<0.001).

Length of stay

Length of stay measured in days was then analyzed using a multivariable regression model (Table 3). After adjusting for the covariates, we found for each one year increase in age there was a 0.024 day increase in length of stay [95% confidence interval (CI) (0.013-0.035)]. Additionally, for every one cm increase in tumor size there was a 0.18 day associated increase in length of stay [95% CI (0.070-0.28)]. Each one hour increase in operating room time was associated with a 0.25 day increased length of stay [95% CI (0.092-0.41)]. The other covariates including BMI, sex, prior abdominal surgery, adhesive perirenal fat, nephrometry score, and perirenal fat thickness were not significant to impact hospitalization time. Figure 1 demonstrates the unadjusted association between length of stay and operative room time. As the operating room time increased, there was a gradual rise in the associated length of stay.

Complications

Any grade Clavien-Dindo complication modeled was similarly examined using a multivariable logistic regression model with n=1,000 bootstrap iterations (Table 4). After adjusting for potential confounding variables only increased tumor dimension was statistically significant. There was a 1.4 times greater odds (p=0.009) associated with any grade complication for each one cm increase in tumor size. Although adhesive perirenal fat neared statistical significance (p=0.6), no other analyzed variable was demonstrated to be associated with increasing complication risk.

DISCUSSION

Our experience with robotic partial nephrectomy for localized renal masses suggests the following: 1) if the surgical patient has one or more of the following including a large complex mass, significant perirenal fat, or prior abdominal surgery, the surgeon should anticipate significantly longer operative times; 2) longer operative times are associated with increased length of stay for this procedure; 3) larger tumor size is associated with increased complication rates. Because modifications to mitigate operative time appear most critical when these preoperative variables are identified the exercise of identifying the presence or absence of these factors before partial nephrectomy should be readily available, simple to do, and useful.

Operative time has long been recognized as an important surrogate in perioperative outcomes across all surgical subspecialties [22–27]. However, prior studies have not found an association between tumor characteristics (specifically nephrometry score) and longer operating room time for robotic partial nephrectomy [28]. Interestingly, our study found that tumor size and complexity appear to be the largest determinates which impact operative time, length of stay, and overall complication rate. Explanation of this relationship may be multifactorial; first, partial nephrectomy with larger tumors may consistently require more of the allowable 30 minutes for renal reconstruction, increasing operative time as well as increasing complication risk secondary to increased rates of bleeding and urinary extravasation; second, because clamp time is relatively predictable (< 30 minutes in almost all cases), we would anticipate that most of the accumulated operative time may in fact be related to the preparation of the tumor prior to ischemia. This may be secondary to increased renal mobilization to visualize tumor edges and surrounding parenchyma for anticipated suture placement as well as more expansive use of quality intraoperative ultrasound. These various iterations demonstrate why tumor size itself may be the biggest predictor of time and morbidity from the procedure.

The presence of adhesive perirenal fat and increased perirenal fat thickness leads to increased operative complexity and time during robotic partial nephrectomy [16–20,29,30]. The Mayo adhesive probability score is an image based scoring system ranging from zero to five that helps to identify patients with "sticky" perirenal fat which results in increased operative complexity during robotic partial nephrectomies [20]. Similarly, our findings found adhesive fat and perirenal thickness are major predictors of operative time for these surgeries. Interestingly, BMI itself was not predictive of longer operating room time in contrast to the fat characteristics of the kidney itself. Our study demonstrates the nuances of managing obese patients unique to robotic kidney surgery. Objective measures such as distance from fascia to skin, amount of visceral fat, perirenal fat thickness, in addition to subjective factors such as laxity of the abdomen, presence of a significant pannus, and the shape of the flank can all impact operating room time. Although outside the scope of the present study, it appears that retroperitoneal fat more so than extra-fascial obesity may be the more important driver of difficulty when considering robotic partial nephrectomy.

Length of stay is an increasingly scrutinized surrogate for cost efficient care. Similar to our findings, prior studies have demonstrated the relationship between operative time and length of stay for partial nephrectomy [31,32,33]. The fastest operative time patients were hospitalized one less day on average than the slowest operative time patients (2.2 vs 3.3 days). Adding an hour of surgery increased hospital stay by one quarter of a day. Moreover, prior literature has demonstrated an association between longer length of stay and increased complication rates [33]. In an era in which Medicare reimbursement may be classified as "outpatient," "outpatient in a bed," and "inpatient," shifts between categories may be based on one half day of stay in either direction. These subtle differences can have huge cost implications and are important nuances to understand when assessing timing for patient discharge. Additionally, as length of stay is increasingly being used as a benchmark for evaluating quality of care, identifying preoperative variables that may impact this determination are important.

These findings should be considered in the context of several limitations. First, the retrospective methodology of this study creates intrinsic limitations consistent with any observational study [34]. To our knowledge, however, no longitudinal administrative data exists that collects all of the variables which we are interested in such as nephrometry score, adhesive perirenal fat, and operative time. We also utilized bootstrap resampling technique to provide internal validation of our model and as certain variables may have non normal distribution [35,36]. Furthermore, our study relied on data collected in our prospective database which relies on the electronic medical record. These data are obtained from a robust electronic medical record system used for clinical documentation and billing purposes. To minimize this risk, we had three authors independently collect the data and one author recheck the database to reduce the possibility of data collection errors. Furthermore, we did not specifically examine anterior versus posterior tumors and their relation to operating time and length of stay. Given these factors are included in the nephrometry score, this would likely confound our results.

Our renal database, although constantly being refined, does not reliably reflect all the technical evolutions of robotic partial nephrectomy dating back to 2012. Although these nuances can certainly influence operative time, the focus of our analysis was to identify and analyze clear and objective preoperative factors which can be utilized to create of roadmap of surgical expectations. The da Vinci Xi robotic system was introduced in 2014 during our study period. Both the da Vinci Si and Xi systems were used in this study although our database does not include this information. The benefits of the da Vinci Xi system would likely be minimal given the experience of the surgeons in this study. Moreover, in our study, length of stay was measured in days rather than hours and minutes. Our model is neither granular nor statistically powerful enough to account for patient factors and their changes on length of stay in terms of hours. Nevertheless, one increased day in the hospital is a significant period of time and our model accounts for these changes in association with operating room time. These limitations not withstanding this work represents the first to identify and quantify specific variables that affect operative time for robotic partial nephrectomy and underscore their impact on both length of stay and overall complication rates.

Operative time in robotic partial nephrectomy is important. The impact between operative time and length of stay is consistently demonstrated. Our findings highlight several factors, especially renal tumor and perirenal fat characteristics, are measurable with quantifiable objective impact on outcome. The ability to predict operative time, length of stay and complication rate is useful both for patient counseling as well as surgical planning such as operative schedule management, operative room support, and/or modification of resident or fellow participation. As hospitals and third party payers attempt to create fair measures to compare surgeons on a global scale, identifying predictive variables for each operation lays the groundwork to establishing benchmarks that are individualized and achievable.

CONCLUSION

In patients undergoing robotic partial nephrectomy, prior abdominal surgery, larger and more complex tumors, and patients with increased Gerota's fat with or without inflammation can anticipate increased operative time. Tumor size itself appears to be the biggest predictor of operative time, length of stay, and complication rates. It is important to integrate and quantify these important preoperative variables into operative planning in order to create fair and reasonable expectations for both patient and surgeon in regard to overall outcome.

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Abbreviation Key

Estimated blood loss (EBL)

Length of stay (LOS)

Bias corrected odds ratio (bcOR)

Confidence interval (CI)

Kilograms (kg)

Centimeters (cm)

Body mass index (BMI)

Mayo adhesive probability (MAP)

Table 1. Patient demographic, tumor, and perioperative characteristics

	Fastest 25th%ile		Middle 25th - 75th%ile		Slowest 75th%ile		*p value*
n	104		190		98		
Median operative time, min (SD)	146.5 (18)		206 (23)		288 (39)		
Age, years (SD)	59 (13)		62 (12)		61 (12)		0.20
Female (%)	32 (30.8)		66 (34.7)		64 (65.3)		
BMI, kg/m^2 (SD)	31 (7.1)		33 (10)		32 (7.3)		0.40
Prior abdominal surgery							0.02
Yes (%)	42 (40.4)		98 (51.6)		56 (57.1)		
No (%)	62 (59.6)		92 (48.4)		42 (42.9)		
Nephrometry score (%)	<u>4-6</u>	<u>7-10</u>	<u>4-6</u>	<u>7-10</u>	<u>4-6</u>	<u>7-10</u>	0.001
	83 (79.8)	21 (20.2)	132 (69.5)	58 (30.5)	55 (56.1)	43 (43.9)	
Tumor greatest dimension, cm (SD)	2.9 (1.9)		3.1 (1.4)		3.7 (1.5)		0.002
Perirenal fat thickness, cm (SD)	2.2 (0.9)		2.4 (0.9)		2.7 (1.1)		0.01
Adhesive perirenal fat							0.13

Yes (%)	73 (70.2)		122 (64.2)		74 (75.5)		
No (%)	31 (29.8)		68 (35.8)		24 (24.5)		
Charlson comorbidity index							0.27
0-3	38		58		42		
4-7	10		29		21		
8-11	1		1		2		
Median ischemia time, min (SD)	15		16		19		0.0002
Length of stay, days (SD)	2.2 (1.1)		2.6 (1.2)		3.2 (1.9)		<0.0001
Estimated blood loss, ml (SD)	106 (55)		164 (148)		218 (223)		<0.0001
Clavien-Dindo complication (%)	1-2	3a-3b	1-2	3a-3b	1-2	3a-3b	0.06
	4 (3.8)	6 (5.8)	17 (8.9)	5 (2.6)	8 (8.2)	3 (3.1)	

Abbreviations: standard deviation (SD), kilograms (kg), centimeters (m), body mass index (BMI), centimeters (cm), milliliters (ml)

Table 2. Association of patient demographic, tumor, and perioperative factors on operating room time

	Coefficient	Additional operating room time (min)	95% adjusted CI	p-value
Age, years	-0.005	-0.3	(-0.14, 0.0038)	0.25
BMI, kg/m^2	0.0029	0.17	(-0.010, 0.016)	0.43
Sex	-0.20	-12	(-0.42, 0.019)	0.07
Prior abdominal surgery	0.36	22	(0.15, 0.56)	0.001
Adhesive perirenal fat	0.37	22	(0.15, 0.59)	0.001
Nephrometry score	0.068	4	(0.0073, 0.13)	0.028
Perirenal fat thickness, cm	0.013	0.8	(0.0015, 0.025)	0.0028
Greatest tumor dimension, cm	0.20	12	(0.12, 0.29)	<0.001

Abbreviations: odds ratio (OR), confidence interval (CI), kilograms (kg), body mass index (BMI), centimeters (cm)

*Bias corrected OR with 1,000 bootstrap iterations

Table 3. Association of patient demographic, tumor, and perioperative factors on length of stay

	Coefficient	95% adjusted CI	p-value
Age, years	0.024	(0.013, 0.035)	<0.001
BMI, kg/m^2	-0.0029	(-0.022, 0.015)	0.76
Sex	0.24	(-0.052, 0.53)	0.11
Prior abdominal surgery	0.041	(-0.27, 0.35)	0.80
Adhesive perirenal fat	0.25	(-0.046, 0.55)	0.097
Nephrometry score	0.037	(-0.037, 0.11)	0.98
Perirenal fat thickness, cm	0.0045	(-0.011, 0.020)	0.56
Greatest tumor dimension, cm	0.18	(0.070, 0.28)	0.001
Operating room time	0.25	(0.092, 0.41)	0.002

Abbreviations: odds ratio (OR), confidence interval (CI), kilograms (kg), body mass index (BMI), centimeters (cm)

*Bias corrected OR with 1,000 bootstrap iterations

Table 4. Association of patient demographic, tumor, and perioperative factors on any grade complication

	Bias corrected OR	95% adjusted CI	p-value
Age, years	1.0	(0.96, 1.0)	0.97
BMI, kg/m^2	1.0	(0.95, 1.1)	0.96
Female sex	1.6	(0.69, 3.8)	0.27
Prior abdominal surgery	1.7	(0.79, 3.5)	0.18
Adhesive perirenal fat	2.9	(0.98, 8.7)	0.06
Nephrometry score	1.1	(0.92, 1.3)	0.30
Perirenal fat thickness, cm	1.0	(0.98, 1.1)	0.16
Greatest tumor dimension, cm	1.4	(1.1, 1.9)	0.009
Operating room time	0.78	(0.52, 1.2)	0.22

Abbreviations: odds ratio (OR), confidence interval (CI), kilograms (kg), body mass index (BMI), centimeters (cm)

*Bias corrected OR with 1,000 bootstrap iterations

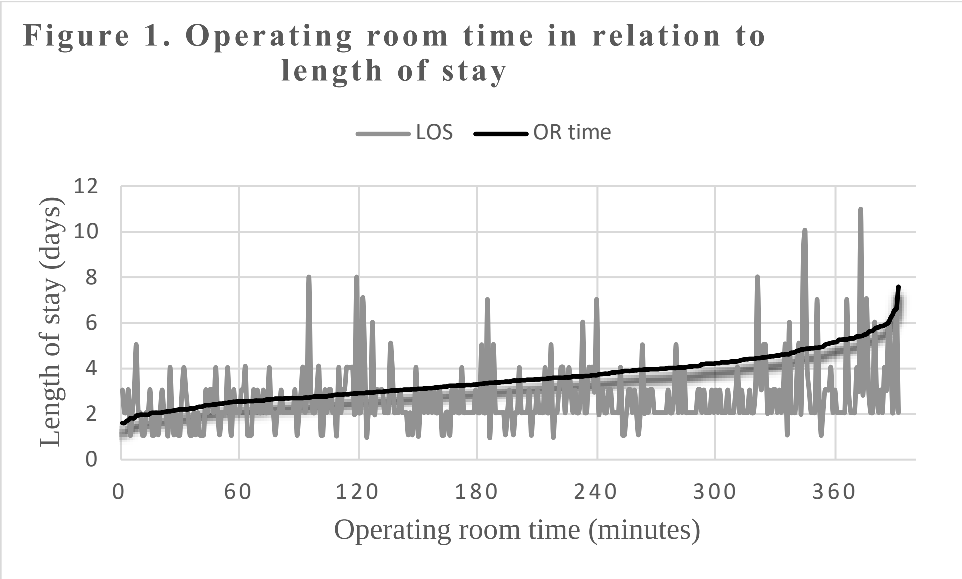

Figure Legend

Figure 1. Line chart showing association of operative room time on length of stay for robotic partial nephrectomy

Abbreviation Key

Estimated blood loss (EBL)

Length of stay (LOS)

Bias corrected odds ratio (bcOR)

Confidence interval (CI)

Kilograms (kg)

Centimeters (cm)

Body mass index (BMI)

Mayo adhesive probability (MAP)