Factors associated with prolonged length of stay following robotic-assisted partial nephrectomy

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Introduction: *To prospectively analyze the association of clinical and operative variables on patient length of hospital stay (LOS) following robotic-assisted partial nephrectomy (RAPN) and develop an accurate clinical-based scoring system to predict prolonged LOS following RAPN.*

Materials and methods: *We analyzed 304 consecutive RAPNs performed by a single surgeon. Prolonged LOS was defined as greater than 3 days of hospitalization postoperatively. Preoperative clinical factors and operative variables were analyzed for association with LOS. After adjusting for multiple testing, $p \leq 0.004$ was considered statistically significant.*

Results: *LOS was 1 day in 17 (5.6%) patients, 2 days in 136 (44.7%) patients, 3 days in 89 (29.3%) patients, and more than 3 days in 62 (20.4%) patients. Lower preoperative hemoglobin ($p = 0.004$), total operative time ($p < 0.001$), estimated blood loss (EBL) ($p < 0.001$), intraoperative complications or conversion ($p < 0.001$), and renal mass size ($p < 0.001$) were associated with prolonged LOS. EBL and total operative time were most predictive of prolonged LOS and were used to create the BLOT (blood loss and operative time) predictive scoring system. Blot scores ranged from 0 to 5, to predict prolonged LOS. We observed prolonged LOS in 4.3%, 9.6%, 25.6%, 47.1%, 50.0%, and 100% of patients with scores of 0, 1, 2, 3, 4, and 5, respectively.*

Conclusions: *Operative time and estimated blood loss are most predictive of prolonged LOS following RAPN. Using these variables, the BLOT score accurately predicts prolonged LOS following RAPN.*

Key Words: length of stay, partial nephrectomy, renal cell carcinoma, robotic partial nephrectomy, robotic surgery

Introduction

Benefits of robotic-assisted partial nephrectomy (RAPN) compared to open partial nephrectomy (OPN) have been well-documented, including fewer complications and reduced length of hospital stay (LOS).[1,2] As costs of healthcare rise, more emphasis is going towards curtailing expenses while maintaining quality patient care. The benefits of RAPN may help offset the costs associated with robot purchasing, maintenance, and use.[3] Despite the proposed advantages of RAPN, a subset of patients may require prolonged hospitalization leading to increased cost to healthcare systems and patients.

Studies have demonstrated average hospital stays of 2 to 3 days after RAPN,[4,5] and prolonged length of hospital stay following RAPN has been defined as > 3 days.[6,7] Age, gender, comorbidities, and tumor size have been shown to potentially be predictive of LOS after RAPN; however, there is no reliable predictive tool for determining which patients will have a prolonged LOS following RAPN.[4]

We examined clinical and perioperative factors to determine their association with prolonged LOS and created a simple scoring system which is highly predictive of prolonged LOS (> 3 days) following RAPN.

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Materials and methods

Data collection

All consenting patients undergoing surgery for a suspicious renal mass at our institution are prospectively included in an institutional review board-approved registry. We collect clinical, pathologic, and demographic data, as well as biological specimens (tumor tissue, blood, urine). We retrospectively reviewed this registry from February 2008 to October 2017 and found 304 patients who underwent RAPN by a single very high volume surgeon (≥ 15 cases per year).[6]

We collected patient characteristics at baseline (age, sex, body mass index [BMI], preoperative creatinine, preoperative hemoglobin, preoperative estimated glomerular filtration rate [eGFR], hypertension, cardiovascular disease), tumor information (R.E.N.A.L. nephrometry score,[8] and Mayo Adhesive Probability [MAP] score[9]), and operative information (estimated blood loss [EBL], operative time, warm ischemia time (WIT), collection system entry, intraoperative complication or conversion to open partial nephrectomy or laparoscopic nephrectomy, and pathology [final renal mass size and diagnosis of renal cell carcinoma]).

R.E.N.A.L. and MAP scores were calculated as previously described.[8,9] R.E.N.A.L. scores were grouped 4-6, 7-9, and 10-12, respectively. MAP scores of 0-3 were considered low and scores of 4-5 were considered high. For patients with multiple renal masses, the size of the largest resected mass was used for analysis. Among patients who had more than one RAPN performed at our institution, we included only the first one in our study. All RAPN were performed in standard fashion as previously described utilizing sliding-clip renorrhaphy.[10,11] After RAPN, all patients were placed on our standard postoperative pathway: on postoperative day 1, patients have their urethral catheter removed, they are required to ambulate, and if not already started, patients are placed on a regular diet. Narcotic pain medications are used sparingly. Discharge criteria includes tolerating a regular diet but does not require return of bowel function.

Hospital LOS was recorded from the time of surgery completion with regards to days in the hospital. Surgery day was defined as postoperative day zero. Prolonged hospital LOS was defined as any stay greater than 3 postoperative days.[6,7]

Statistical analysis and development of predictive scoring system

Associations of preoperative and intraoperative characteristics with prolonged LOS following RAPN were estimated using logistic regression models. Odds ratios (OR) and 95% confidence intervals (CIs) for numeric factors were based on an increase in the predictor variable equivalent to the interquartile range (75^{th} percentile minus 25^{th} percentile) unless otherwise noted. EBL was transformed on the logarithm scale because of its skewed distribution; a log base of 2 was chosen so the regression coefficient and OR would correspond to a doubling in estimated blood loss. In single variable analysis of associations with prolonged LOS, we used the Holm stepdown method for adjusting for multiple testing ($p \leq 0.004$ considered as statistically significant).[12] All other statistical tests used a nominal 5% significance level ($p \leq 0.05$). Since we had fewer than 10 events per predictor variable, we used the least absolute shrinkage and selection operator (Lasso) with the Bayesian information criterion stopping criteria for variable selection with the logistic regression model[13,14] where the 17 predictor variables were standardized (mean = 0 and standard deviation = 1). Once the variables were selected via Lasso, we entered the selected predictor variables into a multivariable logistic regression model for the final prognostic model. Calibration of the model was assessed via estimation of observed and predicted probabilities of prolonged LOS. Discrimination was assessed using the area under the receiver operating characteristic curve (AUC). Internal validation was performed using 1000 bootstrap resamples. All analyses were performed using SAS (version 9.4, SAS Institute Inc., Cary, NC, USA).

Results

Preoperative and intraoperative patient characteristics are shown in Table 1. A total of 304 patients who underwent RAPN were included in the study. Length of stay was 1 day in 17 (5.6%) patients, 2 days in 136 (44.7%) patients, 3 days in 89 (29.3%) patients, and > 3 days in 62 (20.4%) patients.

Single variable associations of preoperative and intraoperative characteristics with prolonged LOS are also shown in Table 1. The only preoperative characteristic associated with prolonged LOS was lower hemoglobin levels (OR [14.6 versus 12.8 g/dL] = 0.63, $p = 0.004$) after adjusting for multiple testing ($p \leq 0.004$ was considered statistically significant based on 17 tests). Intraoperative variables associated with prolonged LOS after adjusting for multiple testing included EBL (OR [doubling] = 4.58, $p < 0.001$), total operative time (OR [226 versus 175 min] = 2.37, $p < 0.001$), intraoperative complications or conversion (OR [yes versus no] = 6.45, $p < 0.001$), and renal mass size (OR [4.0 versus 2.2 cm] = 1.88, $p < 0.001$).

TABLE 1. **Baseline characteristics and associations of preoperative and intraoperative characteristics with prolonged length of stay after robotic-assisted partial nephrectomy**

Characteristic	Median (IQR) or n (%) n = 304	Single variable associations with prolonged length of stay OR (95% CI)	p value
Preoperative characteristics			
Age (years)	63 (55, 75)	1.02 (0.72-1.48)	0.90
Sex			0.34
Female	119 (39.1%)	1.00 (reference)	
Male	185 (60.9%)	1.33 (0.75-2.42)	
Body mass index (kg/m^2)	28.8 (25.6, 32.9)	1.37 (1.01-1.84)	0.038
Hypertension			0.59
No	112 (36.8%)	1.00 (reference)	
Yes	192 (63.2%)	1.18 (0.66-2.15)	
Cardiovascular disease			0.087
No	240 (78.9%)	1.00 (reference)	
Yes	64 (21.1%)	1.74 (0.91-3.26)	
Creatinine (mg/dL)	1.0 (0.8, 1.1)	1.19 (0.94-1.50)	0.14
GFR < 60 mL/min/1.73m^2			0.25
No	255 (83.9%)	1.00 (reference)	
Yes	49 (16.1%)	1.52 (0.73-3.03)	
Hemoglobin (g/dL)	13.8 (12.8, 14.6)	0.63 (0.46-0.86)	0.004
R.E.N.A.L score	8 (6, 9)	1.52 (0.99-2.40)	0.065
MAP score			0.18
MAP 0-3	219 (73.7%)	1.00 (reference)	
MAP 4-5	78 (26.3%)	1.51 (0.81-2.75)	
Intraoperative characteristics			
Collection system entry			0.17
No	106 (35.6%)	1.00 (reference)	
Yes	192 (64.4%)	1.54 (0.85-2.92)	
Total operative time (minutes)	198 (175, 226)	2.37 (1.66-3.46)	< 0.001
Warm ischemia time (minutes)	18 (14, 22)	1.38 (1.03-1.91)	0.039
Estimated blood loss (mL, doubling)	300 (300, 500)	4.58 (2.88-7.71)	< 0.001
Intraoperative complications or conversion			< 0.001
No	287 (94.4%)	1.00 (reference)	
Yes	17 (5.6%)	6.45 (2.37-18.54)	
Renal mass size (cm)	3.0 (2.2, 4.0)	1.88 (1.31-2.75)	0.001
Renal cell carcinoma			0.31
No	74 (24.3%)	1.00 (reference)	
Yes	230 (75.5%)	1.44 (0.74-2.98)	

IQR = interquartile range; OR = odds ratio; CI = confidence interval
GFR = glomerular filtration rate; MAP = Mayo Adhesive Probability.
Prolonged length of stay was defined as a hospital stay longer than 3 days after robotic-assisted partial nephrectomy. Information was not available for the following variables: MAP score (n = 7), collection system entry (n = 6). Unadjusted odds ratios and 95% confidence intervals were estimated from single variable logistic regression models.
The p values ≤ 0.004 were considered as statistically significant after a Holm stepdown adjustment for multiple testing.

TABLE 2. **Multivariable associations of preoperative and intraoperative variables with a length of stay > 3 days after robot-assisted partial nephrectomy with estimated blood loss as a numeric variable on the logarithm (base = 2) scale**

	Multivariable associations with length of stay longer than 3 days following RAPN		
Variable	**β (SE)**	**OR (95% CI)**	**p value**
Total operative time (1 minute increase)	0.00918 (0.0042)	1.009 (1.001-1.018)	0.028
Estimated blood loss (doubling)	1.3376 (0.2629)	3.81 (2.33-6.55)	< 0.001

β = regression coefficient; SE = standard error; OR = odds ratio; CI = confidence interval

TABLE 3. **Observed and predicted length of stay (LOS) > 3 days based on model with estimated blood loss as a numeric variable**

Risk score decile	No. of patients	Predicted probability (%) of prolonged LOS, median (range)	Observed prolonged LOS, n (%)
1	30	4.5 (0.6 to 6.0)	2 (6.7%)
2	30	7.3 (6.0 to 8.1)	4 (13.3%)
3	31	8.9 (8.2 to 9.7)	3 (9.7%)
4	30	10.4 (9.8 to 11.3)	0 (0.0%)
5	32	12.3 (11.4 to 13.5)	3 (9.4%)
6	29	14.6 (13.6 to 17.3)	4 (13.8%)
7	31	20.6 (17.4 to 23.1)	6 (19.4%)
8	30	26.8 (23.3 to 29.6)	8 (26.7%)
9	31	36.1 (29.8 to 45.0)	11 (35.5%)
10	30	60.2 (45.3 to 97.9)	21 (70.0%)

Prognostic score = -15.0030 + 0.00918 * minutes of operative time + 1.3376 * log2 (estimated blood loss, mL)

TABLE 4. **Multivariable associations of preoperative and intraoperative factors with prolonged length of stay (LOS) after robotic-assisted partial nephrectomy**

	Multivariable associations with prolonged LOS		
Factor	**β (SE)**	**OR (95% CI)**	**p value**
Total operative time (1 minute increase)	0.0102 (0.0041)	1.010 (1.002-1.018)	0.028
Estimated blood loss (categorical)			< 0.001
Low (< 400 mL)		1.00 (reference)	
Moderate (400-1000 mL)	1.2809 (0.3464)	3.60 (1.86-7.30)	
High (> 1000 mL)	3.2834 (0.8622)	26.67 (5.72-195.10)	

β = regression coefficient; SE = standard error; OR = odds ratio; CI = confidence interval. Prolonged length of stay was defined as a hospital stay longer than 3 days after robotic-assisted partial nephrectomy. Associations with prolonged length of stay were estimated from a multivariable logistic regression model.

Model development and risk-scoring system

The Lasso procedure selected only two of the 17 predictor variables shown in Table 1 for inclusion in our prognostic model: total operative time and EBL (log scale). The multivariable associations of total operative time and EBL with prolonged LOS are shown in Table 2. From the model in Table 2, we calculated the risk score as -15.0030 + 0.5570 * hours of operative time + 1.3376 * $\log_2$ (estimated blood loss) and estimated the probability of prolonged LOS as $e^{score} / (1 + e^{score})$. The ability of the risk score to discriminate those patients with a prolonged LOS from those without a prolonged LOS was good with an AUC of 0.769 (95% CI 0.694 to 0.843). Calibration was also reasonable with no evidence of major differences between observed and expected probabilities of prolonged LOS, Table 3.

To simplify the scoring algorithm and also account for the natural imprecision of the EBL measurement, we refit the multivariable logistic regression model with total operative time as a numeric predictor variable and EBL as a categorical predictor variable. EBL was categorized as low (< 400 mL), moderate (400 to 1000 mL) or high (> 1000 mL). The final logistic regression model for predicting prolonged LOS had an AUC of 0.749 (95% CI 0.673 to 0.824) and is shown in Table 4.

A simplified scoring algorithm for predicting prolonged LOS is presented in Table 5 with possible scores ranging from 0 to 5. For simplified risk scores of 0, 1, 2, 3, 4, and 5, the percent of patients who had a prolonged LOS was 4.3%, 9.6%, 25.6%, 47.1%, 50.0%, and 100%, respectively, demonstrating good calibration, Table 6. The simplified risk score also had good discriminative ability for differentiating between those with and without prolonged LOS (AUC = 0.734, 95% CI, 0.667 to 0.800). We performed

TABLE 5. **Simplified scoring algorithm for predicting prolonged length of stay following robotic-assisted partial nephrectomy**

Factor	Points
Total operative time	
< 165 minutes	0
165 to 240 minutes	1
> 240 minutes	2
Estimated blood loss	
< 400 mL	0
400 to 1000 mL	1
> 1000 mL	3

Prolonged length of stay was defined as a hospital stay longer than 3 days after robotic-assisted partial nephrectomy. Points assigned for total operative time were calculated by subtracting the minimum total operative time observed in our dataset (106 minutes) from the total operative time, multiplying that number by the regression coefficients from the model shown in Table 5, and rounding to the nearest integer. Total operative time was evaluated in 15 minute increments for purposes of point assignment. Points assigned for estimated blood loss were calculated by rounding the regression coefficient in Table 5 to the nearest integer. The revised risk score was calculated by adding together the number of points for total operative time and estimated blood loss for a possible score ranging from 0 to 5.

TABLE 6. **Predicted versus observed prolonged length of stay according to simplified risk score**

Simplified score	No. of patients	Prolonged LOS Predicted, %	Observed, n (%)	95% CI
0	23	3.5%	1 (4.3%)	0.0% to 16.0%
1	135	9.9%	13 (9.6%)	4.6% to 15.0%
2	117	24.9%	30 (25.6%)	18.1% to 34.0%
3	17	49.8%	8 (47.1%)	23.3% to 72.1%
4	4	74.9%	10 (83.3%)	60.0% to 100%
5	8	89.9%	10 (83.3%)	60.0% to 100%

LOS = length of stay; CI = confidence interval.

Prolonged length of stay was defined as a hospital stay longer than 3 days after robotic-assisted partial nephrectomy. The predicted percentage of patients with prolonged length of stay was estimated from a logistic regression model with the simplified risk score as the only predictor variables. The observed percentage of patients with prolonged length of stay was 50% (2/4) for a score of 4 and 100% (8/8) for a score of 5. Due to small sample sizes, scores of 4 and 5 were combined together for the observed percentage of patients with prolonged length of stay and 95% confidence interval. The 95% confidence interval for the observed percentage of patients with prolonged length of stay was estimated from 1000 bootstrap resamples of the original data.

internal validation of the simplified risk score with 1000 bootstrap resamples, which resulted in a corrected AUC of 0.735 (95% CI 0.667 to 0.801).

Discussion

Nephron-sparing surgery has become standard of care for localized suspicious renal masses < 4 cm, when feasible.[15] The use of RAPN has continued to grow over the last decade due to its peri and postoperative advantages and oncologic equivalence to OPN and laparoscopic partial nephrectomy (LPN), as well as its significantly decreased learning curve compared to LPN.[16] For surgeons, the triad of negative margins, short warm ischemia time (WIT), and lack of high grade complications has been a widely used tool for to measure successful outcomes of PN.[17] However, more demand from hospital administrators and payers is being put on surgeons for consistent financial outcomes and more rigorous economic expectations. This includes an expected shorter LOS to decrease hospital costs when RAPN is performed. To aid in shorter LOS, clinical care pathways are being utilized as a way to standardize care and set patient expectations.[18] Even with standardizations in place, predicting which patients will deviate from the mean in terms of LOS can be challenging and was thus the goal in our study. We were able to employ two factors found to be most predictive of LOS after RAPN, EBL and operative time, to create the BLOT score, which accurately risk stratifies patients for prolonged LOS.

The only patient characteristic we found to be associated with prolonged LOS was lower preoperative hemoglobin, though this was not selected for when creating our prediction model. There has been mixed data on patient factors, sometimes referred to as nonmodifiable factors, and their association with LOS. Larson et al specifically looked at factors associated with LOS of 4 days or more after RAPN and found higher Charlson comorbidity index, nephrometry score, and complications in patients with LOS ≥ 4 days.[7] Bazzi et al evaluated a more rigorous cutoff, examining factors associated with an overnight hospitalization (LOS ≤ 1 days) and found multiple patient and operative factors associated with longer hospital stay (higher age, higher ASA, female gender and lower estimated glomerular filtration rate), though there were no differences between groups on multivariate analysis, and these factors together were unable to be used to develop a predictive model for LOS.[4] Our study did not find host factors to be necessary in the prediction of LOS.

We found operative factors of increased EBL, longer operative times, and intraoperative complications or conversion to be associated with prolonged LOS, though only EBL and operative time were selected using the Lasso procedure during creation of our scoring system. Factors which could contribute to increased EBL or operative time (larger mass size, higher nephrometry or MAP score, etc.) did not contribute to the prediction of prolonged LOS once EBL and operative time were included in the model. Since both EBL and operative time are, to an extent, surgeon-dependent, and our study was conducted at a high volume institution, this highlights the potential benefit of centralization of RAPN to high volume centers. This has been suggested by Khandwala et al, who demonstrated improved outcomes and decreased costs when RAPNs are performed by very high volume surgeons.[6] This finding also mirrors the improved outcomes seen with centralization of other uro-oncology surgery, most notably with cystectomies.[19] Additionally, data has suggested the cost-equalizing effect gained from reduced complications and shorter LOS after RAPN may not be generalizable to low-volume hospitals.[3]

After review of our findings, we considered that surgeon experience may play a role in our findings, and thus compared our first 100 patients to the last 204 patients, but found no difference in the percentage of patients with LOS > 3 days ($p = 0.651$). It is our belief that surgeon learning curve does not play a significant role in LOS after RAPN.

The primary purpose of our study was to create a simple and easy to calculate scoring system that consistently predicts which patients will require prolonged hospitalization following RAPN. We found only two variables, EBL and operative time, are needed to accurately predict prolonged LOS for our BLOT score system. Postoperatively, this tool can be used to set expectations and strive for discharge goals. However, because of the absence of preoperative variables in our model, there is limited ability to predict prolonged LOS prior to surgery. Even with its use, risk-stratifying patients preoperatively cannot be achieved and therefore pre-operative patient counseling or payer precertification could not be tailored based on the BLOT score.

Our study was not without limitations. Though we started with a sizeable patient cohort, only a small portion of patients met criteria for prolonged LOS (> 3 days) and thus our predictive scoring system was based off a small subset. In addition, our data comes from the experience of a single surgeon at a high volume institution, which may not be reflective of surgeons at other institutions. Larger cohorts from multiple surgeons will be needed to validate our findings and determine the generalizability of our scoring system across institutions. Additionally, we included patient

and operative factors which could theoretically affect our outcome of LOS; however, there may be other preoperative or perioperative factors not accounted for which could have skewed our results. One patient factor we did not include in our analysis which may play some role in LOS is the distance from a patient's home to our hospital. Since our institution is a tertiary referral center, many of our patients travel from a distance. Patients who live farther away may be less likely to be discharged in the evening due to concerns of travel safety, and may remain hospitalized an additional night after meeting discharge criteria. It would be interesting to examine this factor in future studies.

The BLOT score adequately predicted prolonged LOS in our patient cohort, but the validity of this scoring system will need to be determined in larger cohorts of patients undergoing RAPN at other surgical centers.

Conclusion

In conclusion, operative time and EBL are associated with prolonged LOS following RAPN. The BLOT score is simple to calculate and accurately predicts prolonged LOS in these patients. Prospective studies are needed to validate the BLOT scoring system. □

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