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Abbreviations and Acronyms

PN: partial nephrectomy

RAPN: robot-assisted partial nephrectomy

ORT: operating room time

ICD: International Classification of Diseases, Ninth Revision

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The Impact of Surgeon Volume on Perioperative Outcomes and Cost for Patients Receiving Robotic Partial Nephrectomy

Running Head: Surgeon Volume in Robotic Partial Nephrectomy

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Key words: robotic surgical procedures, nephrectomy, postoperative complications, economics

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ABSTRACT

Introduction: Little is known about the impact of surgeon volume on the succcess of the robot-assisted partial nephrectomy (RAPN). The objective of this study was to compare the perioperative outcomes and cost related to RAPN by annual surgeon volumes.

Patients and Methods: Using the Premier Hospital Database, we retrospectively analyzed 39,773 patients who underwent RAPN between 2003 and 2015 in the USA. Surgeons for each index case were grouped into quintiles for each respective year. Outcomes were 90-day postoperative complications, operating room time, blood transfusion, length of stay, and direct hospital costs. Logistic regression and generalized linear models were used to identify factors predicting complications and cost.

Results: After accounting for patient and hospital demographics, high and very high volume surgeons had 40% and 42% decreased odds of having major complications ($p=0.045$ and $p=0.027$, respectively). Surgeons with higher volumes were associated with fewer odds of prolonged operating room time (0.68 for low, 0.72 for intermediate, 0.56 for high, 0.44 for very high volume, all $p<0.05$) and length of hospital stay (0.67 for intermediate, 0.51 for high, 0.45 for very high volume, all $p<0.01$) compared to very low volume surgeons. 90-day hospital cost was also significantly lower for the surgeons with higher volume, but the statistical significance diminished after consideration of hospital clustering.

Conclusion: Surgeons with very high RAPN volumes were found to have superior perioperative outcomes. Although cost of care appeared to correlate with surgeon volume, there may be other more influential factors predicting cost.

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INTRODUCTION

Nephron-sparing surgery has rapidly become the preferred treatment modality for small renal tumors. While this approach has minimized renal function loss and acquired chronic kidney disease compared to radical nephrectomy, it remains a technically challenging operation with substantial risk.[1,2] The advent of robot-assistance for partial nephrectomy (PN) in the early 2000s was initially believed to reduce the learning curve for inexperienced surgeons attempting PNs and also improve surgical outcomes. Recent large population-based studies have also suggested that morbidity, in-hospital complication rates and oncological outcomes of robot-assisted PN (RAPN) are similar or superior to laparoscopic and open PN. Even cost, after accounting for shorter operating room times (ORTs) and hospital stays in the RAPN population has been shown to be marginally different.[2-6] Thus, given the ease of use and improved outcomes compared to alternatives, the utilization of robot-assistance has increased rapidly since 2008 and in some areas overtaken laparoscopic PN, contributing to an increase of overall PNs in the United States over this period.[5,7]

While the increased usage of robotic assistance for small renal tumors has ostensibly benefited healthcare at a population-level, there remains significant debate on the impact of RAPN adoption by inexperienced surgeons at the patient-level. The advantages of the robotic approach for PN over laparoscopic PN may be specific only to surgeons intimately familiar with the minimally invasive technique exposing some patients to sub-optimal care.[6,8,9] Although the learning curve for RAPN has previously been reported to be insignificant, there is little evidence estimating the true number of cases required to reach the learning curve plateau.[10,11] Most of the literature touting the benefits of robot assistance for PN presents data from experienced surgeons practicing at high volume centers while little is known about the outcomes of the majority of surgeons in the United States.[4,12,13] Thus, we sought to compare perioperative complications and in-hospital cost between surgeons with very low, low, intermediate, high and very high robotic PN volumes to evaluate the impact of robot experience on RAPN outcomes using a nationally representative cohort.

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PATIENTS AND METHODS

Data Source and Study Cohort

We used the Premier Hospital Database (Premier Inc., Charlotte, NC, USA) from January 2003 through December 2015 to identify patients within the nationally representative sample undergoing RAPN for resection of renal mass. The Premier Database is an all-payer hospital clinical and economic archive that contains longitudinal billing data for each patient. It captures more than 50 million inpatient discharges (approximately 20% of total discharges in the U.S.) and has been validated and used in a previous landmark study.[14] The Premier Hospital Database has hospital-specific projection weights, which allowed us to obtain nationally representative estimates for discharge data. There were no missing data. Our university's Institutional Review Board granted exemption for this study as patient information was de-identified.

International Classification of Diseases, Ninth Revision (ICD-9) codes for PN (55.4) and the diagnosis of kidney cancer (189.0) or kidney tumor (223.0, 236.91, 593.2, 593.9) were used as inclusion criteria and the charge description master for each patient was used to generate relevant variables as well as exclude cases not utilizing robot-assistance.[15] A final cohort of 39,773 patients who underwent RAPN were included in our study.

Covariates

All patient and hospital characteristics associated with perioperative outcomes and cost were captured. Patient characteristics included age, sex, race, insurance status and Charlson comorbidity index. Hospital characteristics included teaching status, hospital size and location.

Physician experience in RAPN was determined using unique identifiers available within the Premier database. We analyzed the annual surgeon volume as a categorical variable by dividing surgeons into approximately equal quintiles based on annual volume for each respective year by surgeon (1) very low volume; (2) low volume; (3) intermediate volume; (4) high volume; and (5) very high volume.[16] In this study, these quintiles of annual RAPN volume were defined as: very-low, ≤2 cases/year; low, 3-4 cases/year; intermediate, 5-7 cases/year; high, 8-13 cases/year; and very-high, ≥14 cases/year.

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Endpoints

ICD-9 codes for identifying events defined by the Clavien classification system, including events occurring during the index hospital stay and/or on readmission to the hospital within 90 days of the surgery were used. A score of 3 to 5 was considered to be a major complication.[17] Blood transfusion, ORT, and hospital length of stay were directly captured and evaluated by the database. Prolonged length of stay (>3 days) and ORT (>240 min) were defined as a hospital stay and ORT longer than the median of the entire RAPN cohort. Cost was measured as a 90-day direct hospital cost inflation-adjusted to 2015 US dollars using the consumer price index. A further breakdown into operating room, supply, room and board, and pharmaceutical cost was also presented.

Statistical Analysis

Descriptive statistics of patient and hospital demographics were conducted along with inter-quintile comparisons using chi-square test for categorical variables. Adjusted rates for complications were presented as percentages while cost and ORT were presented using means with 95% confidence intervals. Multivariate logistic regression was utilized to determine factors predicting complications when RAPN was performed. Since it was determined that the outcome variables (ORT and cost) did not follow a normal distribution, a generalized linear model with gamma distribution was applied which allowed for a link function to connect the predictor with the response variables.[18] Factors accounted for within the model were patient demographics, hospital characteristics, annual surgeon and hospital case volume. Survey weighting using Premier specific weights allowed for the construction of a nationally representative sample. All models were adjusted for clustering of patients within hospitals to account for inter-hospital variability and compared to unadjusted outcomes.[19] Statistics were completed using two-sided tests, a significance level of <0.05 and Stata 14 Statistical Software (College Station, TX).

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RESULTS

Patients and hospital characteristics of 39,773 patients were shown in Table 1. The median age of all patients was 61 years (interquartile range: 52-68) and 56.0% were male. Although there were no significant differences in patient characteristics including age, sex, race, comorbidities and insurance status among surgeon volume quintiles, surgeons with higher annual RAPN volume were more likely to practice in teaching hospitals (p=0.015). Figure 1 shows the distribution of annual hospital and surgeon volume for RAPN in the US between 2003 and 2015.

For the entire study cohort, the 90-day risk-adjusted any, and major complications rates were 25.3% and 3.2%, respectively. 16.8% and 26.7% of patients required blood transfusions and prolonged hospitalization, respectively. Table 2 shows the adjusted perioperative outcomes by surgeon volume. After accounting for confounding variables, very high volume surgeons had lower any complication rates compared with very low volume surgeons (23.3% vs. 29.0%, p = 0.031). Surgeons with very high volume and high volume had lower major complication rates of 2.3% and 2.4%, respectively, compared to 3.9% for very low volume surgeon (p = 0.027 and p = 0.045, respectively). ORT and prolonged hospital time for patients treated by very high volume surgeons were also significantly shorter.

After accounting for patient and hospital demographics, surgeons performing more than 13 RAPNs per year (very high volume surgeons) had 42% fewer odds of having a major complication (p = 0.027), 56% fewer odds of having a prolonged ORT (p = 0.005) and 55% fewer odds of having prolonged length of hospital stay (p<0.001) compared to very low volume surgeons. The details of the results are listed in supplementary Tables 1-5 and depicted in Figure 2.

Risk-adjusted mean 90-day hospital costs were also lower for patients treated by the highest volume surgeons at $16,415 compared to $17,512 for very low volume surgeons (p=0.013) but the significance of this difference abated after inclusion of clustering (p=0.220). This trend persisted for both operating room cost and supply cost as well, although higher volume surgeons had higher supply costs. Room and board cost was significantly lower for very high volume surgeons, $2,606, compared with very low volume surgeons, $3,465, before (p<0.001) and after adjusting for hospital clustering (p=0.004). Patients treated by very low volume surgeons were more likely to encounter a prolonged length of stay, likely explaining the latter difference in cost. (Table 3).

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DISCUSSION

The large sample size and nationally representative population accessible through the Premier Database allow for an unbiased and generalizable impact analysis of surgeon experience on perioperative outcomes and financial cost. Surgeons in our study with a very high annual RAPN volume were found to have significantly decreased odds of any and major surgical complication. And while no association between surgeon volume and rates of blood transfusion were found, greater surgeon volume was correlated with shorter ORTs, shorter hospital stays, and lower room and board charges. Although our definitions of high and very high annual RAPN volume are not applicable to large tertiary referal centers, our estimates are representative of the nation as a whole and generalizable to the majority of urologic practices with relatively low numbers of procedures per year.[16,20]

Although the inclusion of hospital clustering did not alter the statistical significance of surgical outcomes, it was found to greatly attenuate the relationship between surgeon volume and cost related with RAPN. This likely reflects confounding by an unknown hospital-related factor outside of our current model that may be influencing cost. The degree of clustering itself is important to characterize for volume-outcome studies as it may facilitate the understanding of the extraneous effect on outcome variation [19]. For patients undergoing RAPN by very high volume surgeons, room and board costs, operating room costs, and total 90-day costs were significantly lower than for very low volume surgeons before clustering adjustment. Hospitals with high volume surgeons likely have infrastructure in place promoting operating room and discharge efficiency.[21] Thus, even for expenses related to supplies, which was initially found to be substantially more expensive for higher volume surgeons, significance subsided after accounting for clustering.

Prior literature has acknowledged the possible impact that provider inexperience may have on surgical outcomes of patients undergoing RAPN, but there remains significant debate on the severity of the learning-curve period and its consequentiality on patient care.[22,23] Mottrie et al. evaluated warm ischemia time, console time, blood loss and overall complications of a single experienced surgeon performing his first 62 RAPNs. The authors of this small, single surgeon study concluded that the learning curve for RAPN was about 30 cases to achieve optimal warm ischemic time of <30 min and console time of <100 min [24].

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While the number of cases required to become adequately proficient at performing RAPN seems reasonably low, there is sufficient evidence that increased experience through repetition continues to improve outcomes past the initial learning curve.[10,16,25,26] Monn et al found that hospitals conducting high volumes of RAPN have fewer blood transfusions and lower odds of post-operative, in-hospital complications. Although this study utilized much larger sample sizes providing the study sufficient power, the outcomes were not evaluated using the Clavien system and only captured during the hospitalization, not accounting for any delayed complications or cost.[27] Still, hospital volume alone may not have been the ideal predictive variable to evaluate operative outcomes as technically demanding surgeries are more heavily dependent on surgical skill than hospital-based services for success.[16] Our finding that surgeons with the highest volume have significantly fewer major complications than their peers suggests that while the learning curve of RAPN may be inconsequential, annual surgeon volume continues to play a substantial role in predicting surgical outcomes past the initial period—a consideration that must be made by hospitals or physicians contemplating the adoption of RAPN.

Understanding the influence of surgical experience on complication rates is undoubtedly important for the patient but its impact on systemic costs may also benefit centers of care and insurance providers. It is well known that robot use for surgery is expensive with initial investments between $1.3 million and $2.25 million dollars along with $170,000 annually for general upkeep and disposable equipment.[28] However, the decreased length of stay and reduction of complications achieved when utilizing the RAPN approach has been found to offset much of this difference in cost when compared to open or laparoscopic PN—except in low-volume hospitals. While a thorough cost-analysis of RAPN surgeon volume has to our knowledge never been completed, there is also concern that RAPN may not be as cost-effective when performed by an inexperienced or low-volume surgeon.[6] Indeed, we found that physicians performing the most annual RAPN generally had lower costs than their counterparts. While experience and annual volume may be incomparable, surgeons who perform operations frequently have better outcomes than their peers when volume is calculated both cumulatively and annually and cost likely follows a similar trend.[16,25]

The intention of our study is not to comment on the validity of RAPN use compared to other surgical approaches but rather to provide greater clarity on important considerations surrounding the adoption of robot technology for PNs. Undoubtedly, a much deeper exploration of the utility of RAPN should be undertaken by individual hospitals or surgeons considering implementation of this technology into their practice, however, we feel that annual surgeon volume should be considered

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an important variable and included in the decision process. Furthermore, the balance of quality of care and cost has never been more pressing; the regionalization of specialized care has been touted by economists and public health specialists and may have some merit for urologic care of small renal tumors requiring RAPN.[29,30]

There are several limitations to our retrospective, population-based study. First, the use of claims data and ICD-9 classification limits the detail of our investigation. For example, the identification of warm ischemic time, trifecta rates or other specific measures of intra-operative success of PN is not possible. In addition, despite the longitudinal design of our database, we were unable to capture data on successive surgical cases for each participating surgeon. The only prior studies commenting on cumulative surgeon experience have fewer than 300 data points and are primarily from a single surgeon as this is a difficult analysis to scale. Instead, we used quintiles based on annual volume to classify surgeon volume. Although imperfect, it is unlikely that a surgeon’s case load will vary drastically on an annual basis except during the adoption phase. For the latter scenario, the rapid acceleration in case load is aptly captured by our methodology as quintiles are ascribed based on the annual number of RAPNs by the participating surgeon during the index year of the surgery.

CONCLUSION

Our study represents the first large, nationally representative, population based analysis of the impact of surgeon volume on perioperative outcomes and cost for RAPN. We found that surgeons with a very high annual volume tend to have lower odds of reporting major surgical complications, have shorter ORTs, and fewer prolonged hospital stays. Although differences in cost may be attenuated by hospital clustering, higher volume surgeons generally have lower cost of care. There remains a need to interpret these results in the context of individual hospitals and surgeons considering adoption and further analysis is required to fully characterize the influence of experience on surgical outcomes for RAPN.

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None

Conflicts of interest

None

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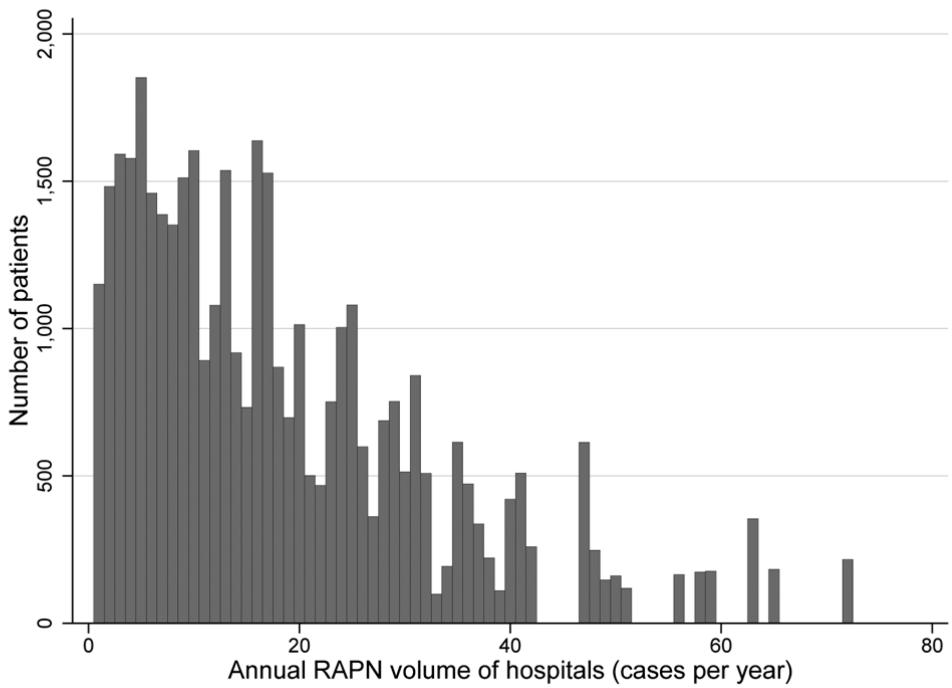
FIGURE LEGENDS



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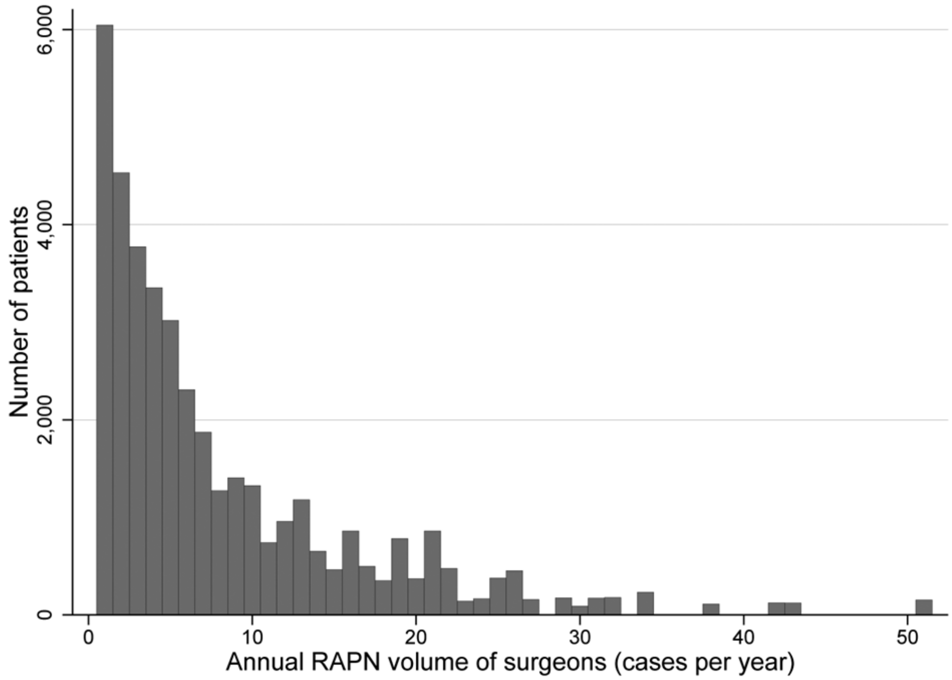

Figure 1. ***Annual RAPN volume of hospitals (A) and annual RAPN volume of surgeons (B) in the United States between 2003 and 2015***

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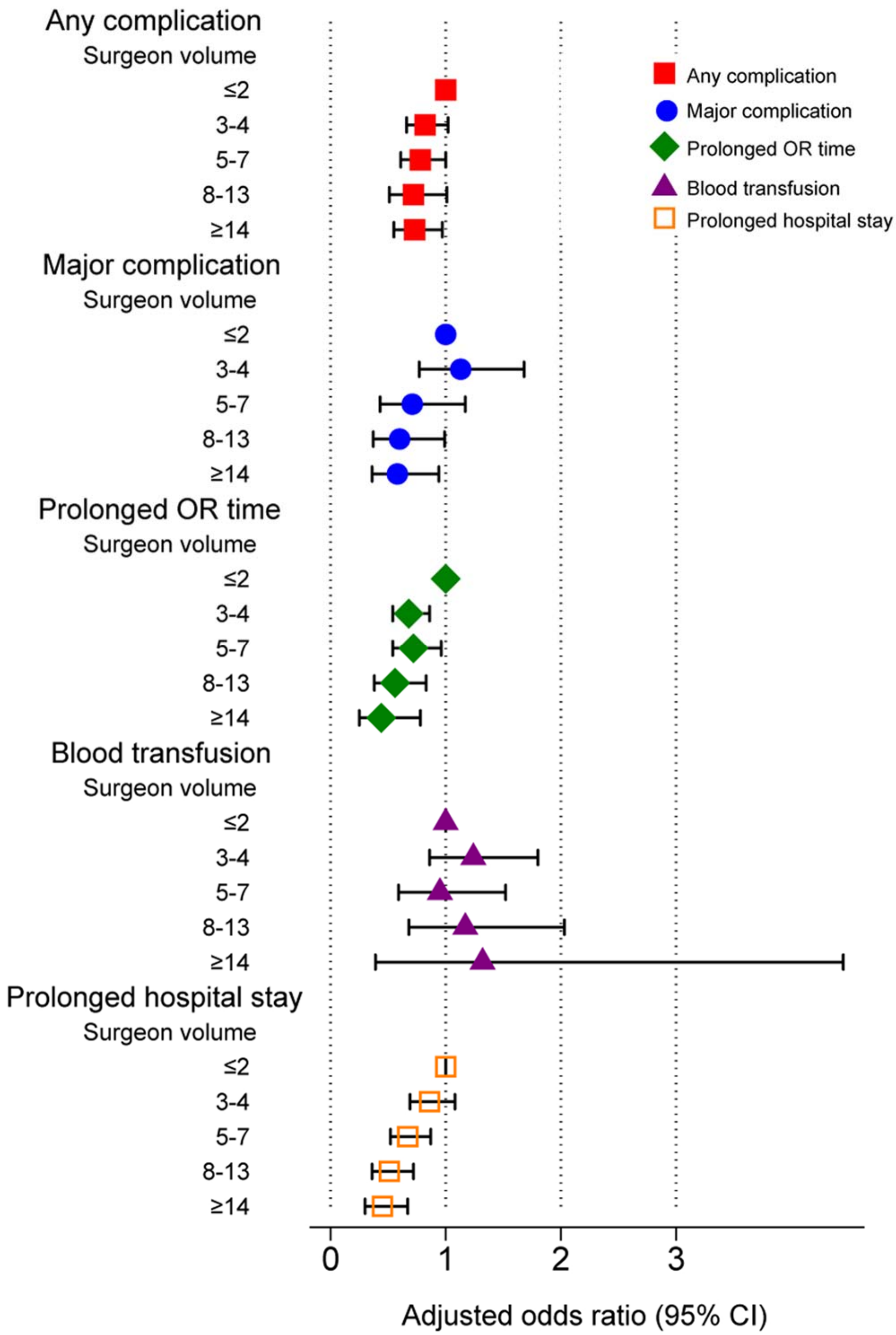

Figure 2. Forest plot for different perioperative outcomes. OR, operating room

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Table 1. Baseline characteristics of robotic partial nephrectomies by surgeon volume

		Surgeon volume					
	Total	**Very low**	**Low**	**Intermediate**	**High**	**Very high**	**P**
No. of pts	39,773	10,611	7,162	7,199	6,875	7,926	
Age, No. (%)							0.535
<55	12,653 (31.8)	3,332 (31.4)	2,361 (33.0)	2,289 (31.8)	2,234 (32.5)	2,438 (30.8)	
55-64	12,195 (30.7)	3,454 (32.6)	2,216 (30.9)	2,054 (28.5)	2,067 (30.0)	2,403 (30.3)	
65-74	10,573 (26.6)	2,790 (26.3)	1,908 (26.6)	1,970 (27.4)	1,785 (26.0)	2,119 (26.7)	
>74	4,353 (10.9)	1,035 (9.7)	677 (9.5)	885 (12.3)	789 (11.5)	966 (12.2)	
Sex							0.449
Male	22,256 (56.0)	5,989 (56.4)	3,819 (53.3)	4,098 (56.9)	3,806 (55.4)	4,545 (57.3)	
Female	17,517 (44.0)	4,623 (43.6)	3,343 (46.7)	3,101 (43.1)	3,069 (44.6)	3,381 (42.7)	
Race, No. (%)							0.149
White	29,860 (75.1)	7,616 (71.8)	5,369 (75.0)	5,395 (74.9)	5,138 (74.7)	6,342 (80.0)	
Black	3,798 (9.5)	943 (8.9)	708 (9.9)	648 (9.0)	710 (10.3)	789 (10.0)	

Others	6,116 (15.4)	2,053 (19.3)	1,085 (15.1)	1,157 (16.1)	1,027 (15.0)	795 (10.0)	
Charson comorbidity index, No. (%)							0.421
0	22,729 (57.1)	6,067 (57.2)	4,258 (59.5)	4,171 (57.9)	3,965 (57.7)	4,267 (53.8)	
1	9,945 (25.0)	2,593 (24.4)	1,770 (24.7)	1,739 (24.2)	1,738 (25.3)	2,105 (26.6)	
≥2	7,100 (17.9)	1,951 (18.4)	1,134 (15.8)	1,289 (17.9)	1,172 (17.0)	1,554 (19.6)	
Insurance status, No. (%)							0.144
Medicare	15,481 (38.9)	3,934 (37.1)	2,623 (36.6)	2,931 (40.7)	2,614 (38.0)	3,379 (42.6)	
Medicaid	2,182 (5.5)	555 (5.2)	480 (6.7)	320 (4.4)	416 (6.1)	412 (5.2)	
Private	20,040 (50.4)	5,490 (51.7)	3,791 (52.9)	3,590 (49.9)	3,440 (50.0)	3,728 (47.0)	
Others	2,072 (5.2)	633 (6.0)	268 (3.8)	358 (5.0)	405 (5.9)	408 (5.2)	
Hospital type, No. (%)							0.015
Non-teaching	23,824 (59.9)	7,528 (70.9)	4,783 (66.8)	4,161 (57.8)	4,122 (60.0)	3,230 (40.8)	
Teaching	15,949 (40.1)	3,083 (29.1)	2,379 (33.2)	3,038 (42.2)	2,753 (40.0)	4.696 (59.2)	
Hospital bed size, No. (%)							0.052
<300	9,711 (24.4)	3,012 (28.4)	1,555 (21.7)	1,406 (19.5)	2,188 (31.8)	1,550 (19.6)	
300-500	14,670 (36.9)	4,744 (44.7)	3,204 (44.7)	2,865 (39.8)	1,786 (26.0)	2,071 (26.1)	
>500	15,392 (38.7)	2,855 (26.9)	2,403 (33.6)	2,928 (40.7)	2,901 (42.2)	4,305 (54.3)	
Hospital location , No. (%)							0.235
Rural	787 (2.0)	149 (1.4)	171 (2.4)	113 (1.6)	297 (4.3)	56 (0.7)	

Urban	38,987 (98.0)	10,462 (98.6)	6,991 (97.6)	7,086 (98.4)	6,578 (95.7)	7,870 (99.3)

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Table 2. Adjusted outcomes of patients undergoing robotic partial nephrectomy by surgeon volume

	Surgeon volume				
	Very low	Low	Intermediate	High	Very high
Any complications (%, 95% CI)	29.0 (25.2-32.9)	25.3 (21.4-29.2)	24.4 (20.7-28.1)	22.9 (18.5-27.3)	23.3 (19.8-26.8)*
Major complications (%, 95% CI)	3.9 (3.0-4.8)	4.4 (3.1-5.6)	2.8 (1.7-3.9)	2.4 (1.5-3.3)*	2.3 (1.5-3.1)*
Operating room time (min, mean, 95% CI)	316 (277-355)	272 (244-300)**	264 (240-289)*	255 (227-282)**	248 (227-282)**
Blood transfusion (%, 95% CI)	15.5 (11.5-19.4)	18.3 (10.5-26.2)	14.8 (7.2-22.4)	17.5 (8.5-26.5)	19.2 (1.9-36.4)
Prolonged length of stay (%, 95% CI)	33.9 (29.2-38.6)	30.8 (25.3-36.3)	25.9 (20.9-30.9)**	21.2 (16.6-25.9)***	19.2 (15.2-23.3)***

Adjusted for age, gender, race, Charlson comorbidity index, insurance status, teaching status, number of beds, hospital location, hospital volume and hospital clustering

* Statistically significant compared with the reference group (very low volume surgeon) with p value <0.05 ** p value <0.01 *** p value <0.001

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Table 3. Adjusted cost comparison by surgeon volume and the effect of hospital clustering

	Very low	Low	Intermediate	High	Very high
Supply costs					
Adjusted mean	3,953	3,750	3,806	4,039	4,559
P*	Reference	0.117	0.312	0.525	<0.001
P**	Reference	0.359	0.603	0.802	0.084
Room and board costs					
Adjusted mean	3,465	3,324	3,228	2,960	2,606
P*	Reference	0.261	0.053	<0.001	<0.001
P**	Reference	0.317	0.174	0.036	0.004
Pharmacy costs					
Adjusted mean	1,015	1,145	1,020	928	952
P*	Reference	0.570	0.883	0.031	0.299
P**	Reference	0.626	0.925	0.318	0.624
Operating room costs					
Adjusted mean	7,437	7,007	7,065	6,636	6,816
P*	Reference	0.053	0.098	<0.001	0.007
P**	Reference	0.251	0.333	0.124	0.307
90-day direct hospital costs					
Adjusted mean	17,512	16,555	16,588	15,887	16,415
P*	Reference	0.017	0.022	<0.001	0.013
P**	Reference	0.098	0.147	0.034	0.220

* Adjusted for patient (age, gender, payor, Charlson comorbidity index) and hospital characteristics (teaching status, bed size and location)

** Adjusted for patient (age, gender, payor, Charlson comorbidity index), hospital charcteristics (teaching status, bed size and location) and hospital clustering

Table S1. Details of the logistic model for any complication after robotic partial nephrectomy in Figure 1

Table S2. Details of the logistic model for major complication after robotic partial nephrectomy in Figure 1

Table S3. Details of the logistic model for prolonged operating room time after robotic partial nephrectomy in Figure 1

Table S4. Details of the logistic model for blood transfusion after robotic partial nephrectomy in Figure 1

Table S5. Details of the logistic model for prolonged hospital stay after robotic partial nephrectomy in Figure 1

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Table S1. Details of the logistic model for any complication after robotic partial nephrectomy in Figure 1

	Crude OR	P	Adjusted OR	P
Age (continuous)	1.02 (1.01-1.02)	<0.001	1.01 (1.00-1.01)	0.029
Sex (female vs. male)	0.88 (0.76-1.02)	0.082	0.89 (0.77-1.04)	0.132
Race				
White	reference		reference	
Black	0.92 (0.75-1.13)	0.428	0.88 (0.72-1.08)	0.217
Others	1.13 (0.93-1.36)	0.210	1.10 (0.92-1.31)	0.277
Charlson comorbidity index				
0	reference		reference	
1	1.43 (1.25-1.64)	<0.001	1.38 (1.21-1.58)	<0.001
≥2	2.60 (2.19-3.09)	<0.001	2.38 (2.02-2.80)	<0.001
Insurance status				
Medicare	reference		reference	
Medicaid	0.98 (0.71-1.36)	0.900	1.20 (0.08-1.64)	0.253
Private	0.66 (0.57-0.75)	<0.001	0.83 (0.72-0.97)	0.018
Others	0.75 (0.56-1.00)	0.049	0.92 (0.68-1.25)	0.594
Hospital type				
Non-teaching	reference		reference	
Teaching	0.93 (0.71-1.22)	0.604	1.00 (0.76-1.33)	0.977
Hospital bed size				
<300	reference		reference	
300-500	1.05 (0.77-1.43)	0.769	1.03 (0.77-1.38)	0.827
>500	0.89 (0.62-1.29)	0.537	0.92 (0.63-1.35)	0.676

Hospital location				
Rural	reference		reference	
Urban	0.92 (0.59-1.44)	0.715	0.87 (0.59-1.29)	0.489
Hospital volume (continuous)	1.00 (0.98-1.01)	0.435	1.00 (0.99-1.01)	0.935
Surgeon volume				
Very low	reference		reference	
Low	0.80 (0.65-1.00)	0.045	0.82 (0.66-1.02)	0.073
Intermediate	0.79 (0.63-0.98)	0.029	0.78 (0.61-1.00)	0.053
High	0.71 (0.53-0.95)	0.020	0.72 (0.51-1.01)	0.059
Very high	0.75 (0.58-0.97)	0.027	0.73 (0.55-0.97)	0.031

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Table S2. Details of the logistic model for major complication after robotic partial nephrectomy in Figure 1

	Crude OR	P	Adjusted OR	P
Age (continuous)	1.05 (1.04-1.06)	<0.001	1.03 (1.01-1.05)	0016
Sex (female vs. male)	0.71 (0.52-0.97)	0.032	0.72 (0.52-0.98)	0.038
Race				
White	reference		reference	
Black	1.06 (0.68-1.65)	0.802	1.09 (0.69-1.71)	0.706
Others	1.17 (0.83-1.64)	0.372	1.19 (0.85-1.68)	0.317
Charlson comorbidity index				
0	reference		reference	
1	2.29 (1.59-3.29)	<0.001	2.09 (1.47-2.98)	<0.001
≥2	5.01 (3.58-7.03)	<0.001	3.88 (2.82-5.33)	<0.001
Insurance status				
Medicare	reference		reference	
Medicaid	0.42 (0.23-0.77)	0.005	0.68 (0.32-1.44)	0.308
Private	0.35 (0.26-0.47)	<0.001	0.61 (0.39-0.96)	0.034
Others	0.29 (0.10-0.84)	0.023	0.48 (0.16-1.46)	0.195
Hospital type				
Non-teaching	reference		reference	
Teaching	1.02 (0.79-1.33)	0.872	1.32 (1.02-1.71)	0.034
Hospital bed size				
<300	reference		Reference	
300-500	1.11 (0.75-1.64)	0.607	1.02 (0.72-1.45)	0.899
>500	0.82 (0.56-1.21)	0.316	0.80 (0.53-1.19)	0.269

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Hospital location				
Rural	reference		reference	
Urban	1.50 (0.52-4.38)	0.453	1.42 (0.59-3.46)	0.436
Hospital volume (continuous)	0.99 (0.98-1.00)	0.066	1.00 (0.98-1.01)	0.530
Surgeon volume				
Very low	reference		reference	
Low	1.05 (0.72-1.52)	0.819	1.13 (0.77-1.68)	0.526
Intermediate	0.71 (0.45-1.14)	0.157	0.71 (0.43-1.17)	0.175
High	0.57 (0.35-0.91)	0.020	0.60 (0.37-0.99)	0.045
Very high	0.59 (0.38-0.89)	0.013	0.58 (0.36-0.94)	0.027

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Table S3. Details of the logistic model for prolonged operating room time after robotic partial nephrectomy in Figure 1

	Crude OR	P	Adjusted OR	P
Age (continuous)	1.00 (0.99-1.01)	0.813	0.99 (0.99-1.00)	0.039
Sex (female vs. male)	0.65 (0.59-0.71)	<0.001	0.64 (0.58-0.71)	<0.001
Race				
White	reference		Reference	
Black	0.87 (0.64-1.18)	0.358	0.89 (0.66-1.18)	0.411
Others	1.19 (0.93-1.53)	0.163	1.15 (0.91-1.46)	0.245
Charlson comorbidity index				
0	reference		reference	
1	1.18 (1.07-1.31)	0.002	1.23 (1.10-1.37)	<0.001
≥2	1.42 (1.16-1.74)	0.001	1.45 (1.19-1.76)	<0.001
Insurance status				
Medicare	reference		reference	
Medicaid	1.12 (0.83-1.50)	0.464	0.98 (0.72-1.32)	0.869
Private	0.97 (0.84-1.13)	0.711	0.90 (0.78-1.05)	0.183
Others	0.71 (0.54-0.95)	0.020	0.63 (0.47-0.86)	0.003
Hospital type				
Non-teaching	reference		reference	
Teaching	1.24 (0.82-1.88)	0.308	1.52 (0.99-2.34)	0.057
Hospital bed size				
<300	reference		reference	
300-500	0.98 (0.57-1.66)	0.927	0.95 (0.58-1.56)	0.852
>500	0.89 (0.51-1.56)	0.690	0.81 (0.47-1.40)	0.453

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Hospital location				
Rural	reference		reference	
Urban	0.86 (0.40-1.84)	0.699	0.75 (0.36-1.53)	0.423
Hospital volume (continuous)	0.99 (0.97-1.01)	0.381	1.00 (0.98-1.02)	0.964
Surgeon volume				
Very low	reference		reference	
Low	0.68 (0.55-0.84)	<0.001	0.68 (0.54-0.86)	0.001
Intermediate	0.74 (0.58-0.95)	0.017	0.72 (0.54-0.96)	0.026
High	0.57 (0.40-0.83)	0.003	0.56 (0.38-0.83)	0.005
Very high	0.48 (0.29-0.82)	0.007	0.44 (0.25-0.78)	0.005

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Table S4. Details of the logistic model for blood transfusion after robotic partial nephrectomy in Figure 1

	Crude OR	**P**	**Adjusted OR**	**P**
Age (continuous)	1.02 (1.01-1.03)	<0.001	1.01 (1.00-1.02)	0.112
Sex (female vs. male)	1.25 (1.08-1.45)	0.003	1.28 (1.10-1.48)	0.001
Race				
White	reference		Reference	
Black	0.76 (0.54-1.08)	0.131	0.72 (0.52-1.01)	0.058
Others	0.71 (0.42-1.17)	0.178	0.71 (0.43-1.16)	0.166
Charlson comorbidity index				
0	reference		reference	
1	1.23 (1.07-1.41)	0.004	1.25 (1.06-1.42)	0.006
≥2	1.96 (1.32-2.91)	<0.001	1.95 (1.46-2.59)	<0.001
Insurance status				
Medicare	reference		Reference	
Medicaid	0.56 (0.31-0.99)	0.047	0.73 (0.43-1.23)	0.236
Private	0.71 (0.55-0.91)	0.008	0.88 (0.72-1.08)	0.211
Others	0.53 (0.39-0.73)	<0.001	0.67 (0.48-0.93)	0.018
Hospital type				
Non-teaching	reference		reference	
Teaching	0.62 (0.29-1.36)	0.234	0.60 (0.18-2.06)	0.416
Hospital bed size				
<300	reference		reference	
300-500	2.85 (1.25-6.50)	0.013	2.76 (1.21-6.29)	0.016
>500	2.00 (0.72-5.55)	0.183	3.02 (0.74-12.36)	0.124

Hospital location				
Rural	reference		reference	
Urban	2.31 (1.07-5.00)	0.034	1.77 (0.86-3.63)	0.121
Hospital volume (continuous)	0.99 (0.97-1.00)	0.046	0.98 (0.97-0.99)	0.004
Surgeon volume				
Very low	reference		Reference	
Low	1.18 (0.78-1.79)	0.426	1.24 (0.86-1.80)	0.254
Intermediate	0.85 (0.51-1.41)	0.529	0.95 (0.59-1.52)	0.824
High	0.87 (0.50-1.53)	0.630	1.17 (0.68-2.03)	0.568
Very high	0.82 (0.25-2.69)	0.745	1.32 (0.39-4.45)	0.656

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Table S5. Details of the logistic model for prolonged hospital stay after robotic partial nephrectomy in Figure 1

	Crude OR	P	Adjusted OR	P
Age (continuous)	1.02 (1.02-1.03)	<0.001	1.01 (1.01-1.02)	0.001
Sex (female vs. male)	0.99 (0.86-1.14)	0.923	1.01 (0.88-1.17)	0.859
Race				
White	reference		reference	
Black	1.02 (0.81-1.28)	0.898	0.97 (0.78-1.22)	0.816
Others	1.37 (1.08-1.74)	0.010	1.34 (1.07-1.68)	0.010
Charlson comorbidity index				
0	reference		reference	
1	1.46 (1.28-1.68)	<0.001	1.41 (1.22-1.63)	<0.001
≥2	2.80 (2.35-3.35)	<0.001	2.55 (2.13-3.05)	<0.001
Insurance status				
Medicare	reference		reference	
Medicaid	0.96 (0.74-1.25)	0.751	1.21 (0.91-1.61)	0.181
Private	0.63 (0.55-0.72)	<0.001	0.85 (0.73-1.00)	0.043
Others	0.70 (0.52-0.95)	0.022	0.93 (0.65-1.33)	0.672
Hospital type				
Non-teaching	reference		reference	
Teaching	1.05 (0.77-1.44)	0.752	1.19 (0.84-1.69)	0.335
Hospital bed size				
<300	reference		reference	
300-500	1.41 (0.90-2.22)	0.133	1.40 (0.96-2.04)	0.082
>500	1.16 (0.78-1.72)	0.476	1.17 (0.74-1.83)	0.505

Hospital location				
Rural	reference		reference	
Urban	0.92 (0.39-2.17)	0.843	0.67 (0.31-1.44)	0.301
Hospital volume (continuous)	0.99 (0.98-1.01)	0.271	1.00 (0.99-1.02)	0.686
Surgeon volume				
Very low	reference		reference	
Low	0.87 (0.69-1.09)	0.210	0.86 (0.69-1.08)	0.188
Intermediate	0.72 (0.56-0.92)	0.010	0.67 (0.52-0.87)	0.003
High	0.53 (0.38-0.74)	<0.001	0.51 (0.36-0.72)	<0.001
Very high	0.52 (0.37-0.75)	<0.001	0.45 (0.30-0.67)	<0.001

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