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Surgeon preference of surgical approach for partial nephrectomy in patients with baseline chronic kidney disease: a nationwide population-based analysis in the USA

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Abstract
Purpose To examine trends in utilization of open, laparoscopic and robot-assisted surgical approaches for treatment of patients with chronic kidney disease (CKD) undergoing partial nephrectomy (PN) within the USA.
Methods We analyzed a weighted sample of 112,117 patients from the Premier administrative dataset who underwent PN for renal mass between 2003 and 2015. Proportions of surgical approach utilization were evaluated by CKD status and further stratified by surgery year and surgeon volume. A multivariate logistic regression model was created to predict receipt of minimally invasive PN.
Results Seven thousand five hundred and sixty-five (6.7%) patients with CKD were identified. The proportion of CKD patients receiving open PN decreased from 72.4% in 2003–2007 to 36.1% in 2012–2015 ($p < 0.001$). Although the robot-assisted PN was the dominant surgical approach for both patients with and without CKD in 2012–2015, the proportion receiving open PN was higher in patients with CKD compared to those without CKD ($p = 0.018$). Multivariate analysis showed that the presence of CKD was independently associated with lower odds of receiving a minimally invasive approach (OR 0.47 for the entire study cohort, OR 0.27 for high volume robot-assisted PN surgeons, and OR 0.51 for recent years, all $p < 0.001$). These trends remained when CKD stages were evaluated individually.
Conclusion Patients with CKD undergoing PN were preferentially treated with open surgery despite an overall increase in robot-assisted PN use over the past 13 years. Further studies evaluating surgical outcomes in this population are warranted for determination of optimal approach and construction of evidence-based guidelines.

Keywords Nephrectomy · Renal insufficiency · Chronic · Robotic surgical procedures · Laparoscopy

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Introduction

Nephron-sparing surgery (NSS) provides unique advantages for patients with pre-existing chronic kidney disease (CKD) by facilitating preservation of renal function through the conservation of nephron mass [1]. Though, despite its theoretical benefits, NSS introduces the additional risk of intra-operative ischemia which can result in irreversible renal damage if prolonged [1, 2]. The surgical approach (open vs. laparoscopic vs. robot-assisted) selected by the surgeon may influence the amount of time that the renal artery is clamped [3–5]. Unfortunately, current guidelines lack recommendations for the selection of NSS approach in patients with CKD [1, 6].

The utilization of robot-assistance has increased rapidly over the last decade and has actually overtaken the laparoscopic approach in some areas [7, 8]. The robotic technique results in shorter overall ischemia time compared to conventional laparoscopic PN, potentially making robot-assisted PN (RAPN) ideal for patients with CKD [5, 9]. Furthermore, some high volume centers have reported only nominal decreases in renal function after RAPN in patients with CKD [10, 11].

Still, there is a lack of high level evidence supporting the use of RAPN in this setting. Thus, there appears to be a significant need to assess current practice patterns across the country especially in light of recent technological advances in the field. Using a nationally representative sample within the USA, we examined trends in surgical approach for patients with CKD undergoing PN and the influence of the adoption of the robotic platform for this procedure.

Materials and methods

Using the Premier Hospital Database (Premier Inc, Charlotte, NC), an all-payer nationally representative dataset which includes 20% of all annual inpatient discharges in the USA, we identified patients who underwent PN between January 2003 and December 2015. International Classification of Diseases, Ninth Revision (ICD-9) codes were used to select for individuals meeting the inclusion criteria. Only patients presenting for partial removal of kidney (55.4) for suspicion of kidney cancer were included in our analysis. Patients with baseline CKD (585, 585.1–585.9) were identified by stage (1–5)—a classification system recommended by the National Kidney Foundation Kidney Disease Outcomes Quality Initiative based on Glomerular Filtration Rate (GFR) [12]. In accordance with prior literature, we defined renal insufficiency or "clinically significant CKD" as CKD stage III or worse (corresponding to GFR of less than 60 mL/min per 1.73 m^2), but we limited our population to only patients with CKD stages 3 and 4 as individuals with end stage renal disease often have unique considerations. Though, patients coded for an unspecified stage of CKD were included in the analysis to ensure capture of all of the target population despite an expected loss of specificity. Fortunately, the "unspecified" group has repeatedly been found to have comparable rates of cardiovascular and all-cause mortality as CKD stages 3 and 4 [11, 13, 14]. Still, we compared trends in management approach between these three groups to corroborate the assumption that patients with uncoded CKD staging are similar to patients with CKD stages 3 and 4.

Baseline demographics evaluated included age, sex, race, insurance status, hospital size, location, and surgical approach (open, laparoscopic or robotic). Robotic and laparoscopic surgeries were determined using the Charge Description Master, a list of chargeable items utilized during a patient's hospitalization. Cases using supplies specific to the robot were designated as robot-assisted while the same approach was applied for minimally invasive (MIS) cases that did not utilize any robotic equipment.

All demographical data were described categorically with descriptive statistics comparing the two groups using Pearson's Chi-square test. Selection of surgical approach was then compared among tertiles of annual surgeon PN volume: low (1–2 cases), intermediate (3–6 cases), and high volume (7 or more cases). Annual volume was defined as number of PNs performed in one calendar year. This analysis was repeated to include only patients treated by surgeons performing at least one RAPN per year thus indicating that all surgeons had access to the robotic platform. Tertiles were similarly created for annual surgeon RAPN volume: low (1–3 cases), intermediate (4–7 cases), and high (8 or more cases). Indeed, the interpretation of the term "high volume" depends on practice setting; however, this dataset presents data that is nationally representative and includes rural and non-teaching institutions alike. Finally, a multivariate binary logistic regression model predicting receipt of minimally invasive PN (laparoscopic or RAPN) was developed. The odds ratio of receiving either laparoscopic or RAPN were presented along with the 95% confidence intervals. A separate analysis for patients treated between 2012 and 2015 was incorporated as this era naturally has the most applicability to current clinical practice.

Survey weights provided by the Premier database were applied to all analyses to achieve a nationally representative sample allowing for greater extrapolation of our conclusions. Further adjustments were made for hospital clustering to account for similarities in practice patterns and quality of care within each hospital. Statistical tests were two-sided utilizing a significance level of $p < 0.05$. All analyses were performed with StataCorp version 14 (College Station, TX).

Results

A weighted total of 112,117 patients underwent PN during our study period of which 7563 (6.7%) suffered from clinically significant CKD. Table 1 contains the patient and hospital characteristics. Overall, patients with clinically significant CKD were older with a mean age of 66.5 compared to 58.9 years for the control group ($p < 0.001$). CKD patients were also more often male and on Medicare and less likely to be white (all $p < 0.001$). Demographical data between patients with CKD stages 3, 4, and unspecified were

Table 1 Baseline patient and hospital characteristics by chronic kidney disease status

	All	Non-CKD	CKD	*p*
No. of pts (%)	112,117	104,554	7563	
No. age (%)				<0.001
<55	36,588 (32.6)	35,665 (34.1)	923 (12.2)	
55–64	32,805 (29.3)	30,893 (29.5)	1912 (25.3)	
65–74	29,647 (26.4)	26,716 (25.6)	2931 (38.7)	
>74	13,077 (11.7)	11,280 (10.8)	1797 (23.8)	
No. sex (%)				<0.001
Male	64,020 (57.1)	58,770 (56.2)	5250 (69.4)	
Female	48,097 (42.9)	45,784 (43.8)	2313 (30.6)	
No. race/ethnicity (%)				<0.001
White	81,441 (72.6)	76,125 (72.8)	5316 (70.3)	
Black	10,302 (9.2)	9203 (8.8)	1099 (14.5)	
Others	20,374 (18.2)	19,226 (18.4)	1148 (15.2)	
No. insurance status (%)				<0.001
Medicare	43,173 (38.5)	38,461 (36.8)	4712 (62.3)	
Medicaid	6019 (5.4)	5725 (5.5)	294 (3.9)	
Private	57,390 (51.2)	55,056 (52.6)	2334 (30.9)	
Others	5535 (4.9)	5312 (5.1)	223 (4.9)	
No. hospital type (%)				0.786
Non-teaching	67,516 (60.2)	62,893 (60.2)	4623 (61.1)	
Teaching	44,601 (39.8)	41,661 (39.8)	2940 (38.9)	
No. hospital bed size (%)				0.831
<300	26,797 (23.9)	24,889 (23.8)	1908 (25.2)	
300–500	45,487 (40.6)	42,508 (40.7)	2979 (39.4)	
>500	39,833 (35.5)	37,157 (35.5)	2676 (35.4)	
No. hospital location (%)				0.148
Rural	3283 (2.9)	3103 (3.0)	180 (2.4)	
Urban	108,834 (97.1)	101,451 (97.0)	7383 (97.6)	
No. annual surgeon volume (tertile) (%)				0.582
Low	42,952 (38.3)	39,969 (38.2)	2983 (39.5)	
Intermediate	34,528 (30.8)	32,354 (30.9)	2174 (28.7)	
High	34,637 (30.9)	32,231 (30.8)	2406 (31.8)	

CKD chronic kidney disease

similar with no significant differences noted between the three groups (Supplementary Table 1).

Figure 1a shows the trend of surgical approach for PN by surgery year. Between 2003 and 2007, surgeons appeared to prefer the open approach slightly more in patients with compared to without CKD (72.4 and 70.5%) ($p = 0.041$). Between 2008 and 2011, this difference was pronounced with 62% of CKD patients who underwent PN receiving open surgery compared to 48.5% of non-CKD patients ($p < 0.001$). Between 2012 and 2015, the percentage of open procedures for PN continued to drop, but CKD patients were still treated with the more invasive procedure more often than their counterparts (36.1 vs. 29.7%, respectively; $p = 0.040$). The use of robot-assistance increased steadily for both groups from 3.2 and 6.6% for non-CKD and CKD patients, respectively, between 2003 and 2007, to 62.9 and 55.2% between 2012 and 2015, respectively. Among patients with CKD, those with stage 4 disease received open surgery more frequently than patients with stage 3 disease between 2008 and 2015 (2008–2011: 81.5 vs. 61.4%, respectively, $p < 0.001$; 2012–2015: 57.6 vs. 32.3%, respectively; $p < 0.001$, Fig. 1b).

After stratifying by surgeon volume tertile, no difference was seen in surgical approach distribution regardless of CKD status. However, when the population was limited to only patients treated by surgeons performing at least one RAPN annually, the open approach appeared to be utilized at a higher rate in the CKD population than the non-CKD group for surgeons performing intermediate and high volumes of RAPN (19.3 vs. 10.8%, $p = 0.021$ and 18.5 vs.

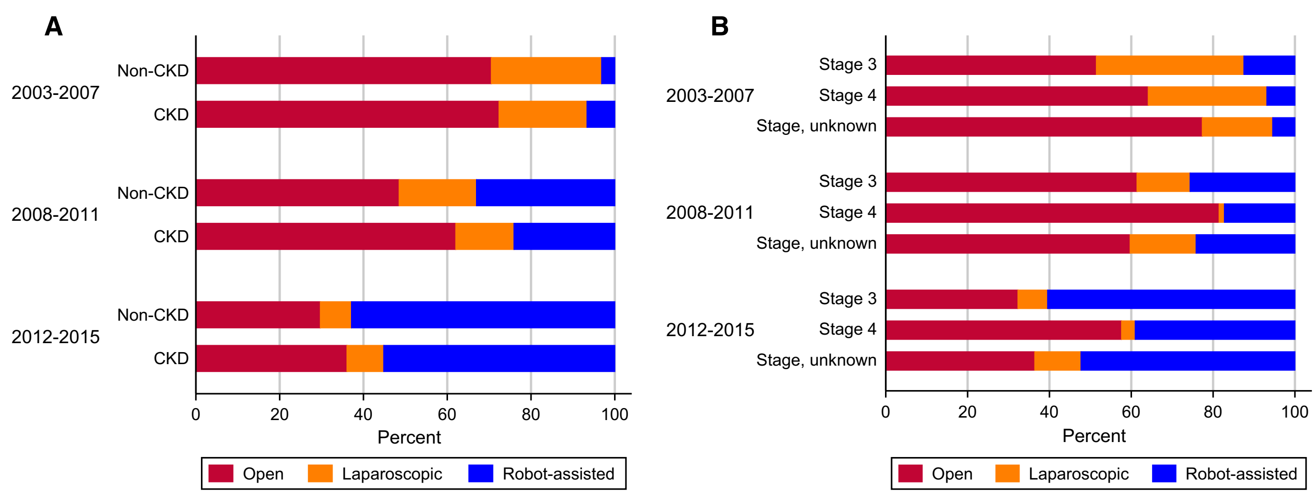

Fig. 1 Trend in surgical approach for partial nephrectomy *over time* by surgery year *alone* (**a**) and chronic kidney disease stage (**b**)

6.0%, $p < 0.001$, respectively, Table 2). The multivariate analyses for predicting receipt for minimally invasive (laparoscopic or robot-assisted) PN in all patients, high volume RAPN surgeons, and years 2012–2015 are presented in Table 3. Although RAPN is preferred over other approaches for both CKD and non-CKD patients by high volume surgeons performing RAPN, patients with CKD treated by these surgeons had 73% lower odds of receiving a minimally invasive approach compared to patients with normally functioning kidneys after adjustment for patient and hospital characteristics (OR 0.27, CI 0.18–0.41, $p < 0.001$). When only the most recent years of the study (2012–2015) were considered, patients with CKD had 49% lower odds (OR 0.51, CI 0.38–0.68, $p < 0.001$) although each successive year increased these odds by 15% (OR 1.15, CI 1.01–1.30, $p = 0.029$). These trends remained when CKD stages were evaluated individually (supplementary Table 2).

Table 2 Comparison of surgical approach selection by the presence of chronic kidney disease stratified by surgeon volume

	Low PN volume			Intermediate PN volume			High PN volume		
	Non-CKD ($N = 39,969$)	CKD ($N = 2983$)	p	Non-CKD ($N = 32,354$)	CKD ($N = 2174$)	p	Non-CKD ($N = 32,232$)	CKD ($N = 2406$)	p
All patients			0.123			0.694			0.084
No. open (%)	24,152 (60.4)	1881 (63.0)		16,061 (49.7)	1090 (50.1)		10,241 (31.8)	855 (35.5)	
No. laparoscopic (%)	8304 (20.8)	476 (16.0)		4608 (14.2)	259 (11.9)		4692 (14.5)	192 (8.0)	
No. robot-assisted (%)	7513 (18.8)	626 (21.0)		11,685 (36.1)	825 (38.0)		17,299 (53.7)	1359 (56.5)	
	Low RAPN volume			Intermediate RAPN volume			High RAPN volume		
	Non-CKD ($N = 18,965$)	CKD ($N = 1563$)	p	Non-CKD ($N = 11,552$)	CKD ($N = 929$)	p	Non-CKD ($N = 14,607$)	CKD ($N = 1412$)	p
Patients treated by surgeons performing RAPN[a]			0.068			0.021			<0.001
No. open (%)	4123 (21.7)	459 (29.3)		1245 (10.8)	179 (19.3)		873 (6.0)	261 (18.5)	
No. laparoscopic (%)	1661 (8.8)	128 (8.2)		530 (4.6)	48 (5.2)		195 (1.3)	20 (1.4)	
No. robot-assisted (%)	13,181 (69.5)	977 (62.5)		9777 (84.6)	702 (75.5)		13,539 (92.7)	1131 (80.1)	

PN partial nephrectomy, *CKD* chronic kidney disease, *RAPN* robot-assisted partial nephrectomy

[a]All surgeons included in this analysis performed at least 1 RAPN during the index year

Table 3 Multivariate binary logistic regression model for the prediction of receiving minimally invasive partial nephrectomy

	All patients		High volume RAPN surgeon		Surgery year 2012–2015	
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Age (continuous)	1.00 (0.99–1.01)	0.625	0.99 (0.98–1.01)	0.269	1.01 (1.00–1.02)	0.226
Sex (female vs. male)	1.07 (0.95–1.20)	0.245	0.99 (0.73–1.33)	0.946	1.10 (0.91–1.33)	0.315
Race						
Black versus white	1.00 (0.76–1.30)	0.990	0.98 (0.61–1.59)	0.948	0.88 (0.65–1.19)	0.413
Others versus white	0.71 (0.53–0.95)	0.021	0.58 (0.31–1.08)	0.084	0.85 (0.60–1.21)	0.376
Insurance status						
Medicaid versus medicare	1.05 (0.72–1.53)	0.786	0.68 (0.37–1.24)	0.207	1.00 (0.64–1.56)	0.989
Private versus medicare	1.05 (0.53–0.95)	0.589	074 (0.53–1.04)	0.085	1.01 (0.79–1.29)	0.954
Others versus medicare	1.12 (0.77–1.62)	0.566	1.37 (0.63–2.98)	0.418	1.16 (0.67–2.01)	0.604
Hospital type (teaching vs. non-teaching)	0.86 (0.56–1.34)	0.512	1.18 (.58–2.38)	0.650	0.68 (0.43–1.09)	0.108
Hospital bed size						
300–500 versus <300	0.93 (0.60–1.44)	0.732	2.32 (0.78–6.89)	0.127	0.81 (0.49–1.34)	0.403
>500 versus <300	0.65 (0.42–1.03)	.066	0.98 (0.50–1.93)	0.960	0.71 (0.41–1.23)	0.224
Hospital location (urban vs. rural)	0.66 (0.22–1.97)	0.452	0.21 (0.04–1.27)	0.009	0.93 (0.31–2.81)	0.902
Surgery year (continuous)	1.12 (1.06–1.18)	<0.001	1.18 (1.00–1.41)	0.056	1.15 (1.01–1.30)	0.029
Surgeon total PN volume (continuous)	0.97 (0.94–.99)	0.007	0.97 (0.95–0.99)	0.013	0.98 (0.97–0.99)	<0.001
Surgeon RAPN volume						
Intermediate versus low	2.44 (1.78–3.36)	<0.001			2.13 (1.47–3.08)	<0.001
High versus low	6.06 (3.36–10.94)	<0.001			5.24 (3.55–7.73)	<0.001
Presence of CKD						
CKD versus non-CKD	0.47 (0.37–0.59)	<0.001	0.27 (0.18–0.41)	<0.001	0.51 (0.38–0.68)	<0.001

RAPN robot-assisted partial nephrectomy, *OR* odds ratio, *CI* confidence interval, *PN* partial nephrectomy, *CKD* chronic kidney disease

Discussion

In this study, we found that surgeons were more likely overall to utilize an open approach when performing PN on clinically significant CKD patients compared to controls in both the unadjusted and risk-adjusted analyses. Patients with stage 4 renal disease had the lowest odds of receiving minimally invasive PN implying that surgeons were more likely to use the open approach as disease severity worsened. As MIS became more commonplace, the percentage of open procedures for PN subsequently began to decline. Nevertheless, surgeons continued to perform open surgery more frequently on patients with CKD compared to patients with normal renal function likely due to concerns over maintaining maximal renal perfusion and minimizing warm ischemia time [15, 16]. High volume RAPN surgeons, purported to have improved warm ischemia time and surgical outcomes compared to peers, were also found to prefer the open approach over MIS when treating CKD patients despite having the lowest rate of open utilization overall [17, 18]. These trends persist despite evidence suggesting that the rate of preservation of global renal function and parenchymal volume are similar between the robotic and open approaches [19].

Despite the obvious need to optimize post-operative renal function and outcomes after PN in this population, there remains limited available evidence guiding the selection of surgical approach. Guillotreau et al. [11] published findings utilizing a small prospective cohort suggesting that RAPN in CKD patients minimizes post-operative renal function decline despite an increase in minor complications. A similar, albeit larger and multi-institute study by Kumar et al. further concluded that the decrease in GFR of patients with CKD was lower (−5.1%) than patients without baseline CKD (−10.9%) after RAPN [10]. And importantly, split renal function of both kidneys after RAPN for renal tumors larger than 4 cm have been found to be similar to that of smaller tumors [20]. Recent comparisons between RAPN and open PN in patients with CKD also described similar functional outcomes [21]. However, these studies lack direct comparisons between open, laparoscopic and robot-assisted approaches using prospective, randomized controlled trials.

Importantly, there are many considerations to make when selecting the appropriate surgical approach for PN including tumor size, complexity, and overall clinical context, and our study is unable to account for many of these variables resulting in possible selection bias. Also, due to the retrospective nature of this study, vital information for evaluating patients with

CKD such as serum creatinine, GFR, and kidney volume were not plausibly retrieved. We thus relied on diagnostic codes to determine CKD staging from which we inferred baseline GFR. Finally, we included a faction of patients with unknown CKD severity in our study to maximize the sensitivity of our inclusion criteria while minimizing potential for selection bias. While it is possible that some of these patients had less severe renal dysfunction, we found that both demographical data and management trends of this group were comparable to patients with stage 3 or 4 disease.

Nevertheless, the identification of surgeon preference for the open approach and the growing use of robot-assistance for treating CKD patients with PN have significant clinical implications. It is becoming increasingly evident that robotic surgical techniques may have unique advantages for this population, but as this remains largely unfounded, surgeons may be operating with sub-optimal information. Large-scale surveys may facilitate a more comprehensive understanding of surgeon decision-making and prospective, multi-center studies will likely elucidate advantages of the various surgical approaches for PN treatment in patients with CKD further guiding management.

Conclusions

Our nationwide population-based study showed that patients with CKD undergoing PN were preferentially treated with open surgery despite an overall increase in RAPN use over the past 13 years. Further studies evaluating surgical outcomes in this population are warranted for determination of optimal approach and construction of evidence-based guidelines.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards This study has been approved by the institutional review board and has been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. IRB waived the mandate for obtaining legally effective informed consent from subjects. No information with the potential to disclose patient identities was included.

Human and animal rights This article does not contain any studies with human participants or animals performed by any of the authors.

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