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ORIGINAL ARTICLE

Robotic surgery for cT2 kidney cancer: analysis of the National Cancer Database

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Abstract

Robotic surgery for renal cell carcinoma (RCC) is increasingly adopted for cT1 disease, but its utilization for cT2 disease remains unexplored. We aimed to characterize the trend in robotic approach for cT2 RCC. The National Cancer Database was queried for patients who were diagnosed with cT2N0M0 RCC from 2010 to 2016 and underwent subsequent radical (RN) or partial (PN) nephrectomy. Analysis of treatment trends was performed and logistic regression (LR) undertaken for predictors of surgical approach. 21,258 patients met inclusion criteria for analysis; 1698 (8%) underwent a PN and 19,560 (92%) underwent RN. Use of robotics in PN increased 346% (12.3–42.6%) and 351% (6.2–21.8%) for RN during the studied time period. Robotic PN or RN was associated with shorter hospital stay compared to non-robotic approaches ($p < 0.001$). Academic institutions were more likely to perform a robotic procedure and the uninsured were less likely to receive robotic approach. There was no association between age, sex, race, or income and surgical approach. On LR, robotic approach was independently associated with academic institutions and a more recent year of diagnosis. There was no significant difference in the rate of positive margins, 30-day readmission, or 30/90-day mortality between approaches. Robotic PN and RN is becoming an increasingly popular approach in the treatment of cT2 RCC. Utilization of robotics is associated with academic institutions and results in a shorter hospital stay without significant differences rate of positive margins, readmission rates, or 30/90-day mortality.

Keywords Kidney cancer · Robotic · Minimally invasive · Clinical practice pattern

Introduction

Partial nephrectomy (PN) and radical nephrectomy (RN) are well established as the two definitive treatments of choice for renal cell carcinoma (RCC) [1]. Generally, PN is favored for small renal masses (cT1), whereas RN is favored for larger, more complex tumors (cT2–T4); however, the use of PN has been applied in select patients with larger cT2 tumors [2]. Additionally, the decision of treatment approach (open vs. laparoscopic vs. robotic) must account for the characteristics of the renal mass, along with the surgeon and patient preference. Robotic surgery was initially utilized for cT1 tumors that were minimally complex; however, with improvements in robotic technology and increased surgical training, a robotic approach has been shown to be a viable option to cT2 disease [3–5].

Institutional studies and systematic reviews have shown the expanding utilization of robotic surgery in the treatment of RCC; however, these studies failed to distinguish approach based on clinical T stage which often contributes to decision making when choosing approach. [6–9] To further elucidate the advantages to robotic surgery, we analyzed the nation-wide trend in surgical approach for treating cT2 RCC focusing on surgical and oncologic outcomes. We hypothesized that the landscape of cT2 RCC treatment is shifting in favor of robotic surgery.

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Materials and methods

Data source

Data for this analysis were derived from the Commission on Cancer's National Cancer Data Base (NCDB) Participant User File for RCC from 2010 to 2016. The NCDB is a national cancer outcomes dataset that includes input from over 1500 Commission on Cancer-accredited centers in the United States. These data include all cancer patients treated at participating Commission on Cancer-accredited institutions and are estimated to capture over 70% of new cancer cases in the United States [10]. Standardized coding definitions are utilized, and the data are freely available to participating institutions after application for projects are accepted by the NCDB. The data used in the study are derived from a de-identified NCDB file. The American College of Surgeons and the Commission on Cancer have not verified and are not responsible for the analytic or statistical methodology employed, or the conclusions drawn from these data by the investigator.

Study population

The National Cancer Database (NCDB) was queried for patients who were diagnosed with cT2 RCC from 2010 to 2016, including site-specific histology codes for clear cell, papillary, sarcomatoid, chromophobe and renal cell carcinoma not otherwise specified, and underwent subsequent RN or PN. PN was defined as partial or subtotal nephrectomy using site-specific surgery code 30. RN was defined as complete/total/simple nephrectomy for kidney parenchyma and radical nephrectomy using site-specific surgery codes 40 and 50. This study period was chosen, as the NCDB participant user file began noting information regarding surgical approach (robotic, laparoscopic, open, open conversion) in 2010. Patients were excluded if they had clinically nodal positive disease or clinically metastatic positive disease. 21,258 patients age ≥ 18 were identified and met inclusion criteria.

Patient demographic variables included age, sex, race, Charlson comorbidity index, income status, facility type, and insurance status. Disease and operative outcomes included surgical approach, length of hospital stay, clinical tumor stage, pathological tumor stage, margin status, length of follow-up, 30-day readmission, and 30-day mortality. Tumor size was not included in our analysis as the NCDB only records up to 9.9 cm. Therefore, measurements of all cT2b renal masses (> 10 cm) would not have been specified in the analysis.

Statistical analysis and outcome measures

Our primary aim was the trend in treatment approach (robotic vs. non-robotic) used for cT2 RCC resection. Non-robotic approach was defined as open, laparoscopic or converted open surgical approach. Secondary outcomes include trend of treatment type (RN vs PN), rates of positive margins and 30-day readmission between robotic and non-robotic approaches. Student's *T* test was performed for continuous variables. Fischer's exact or Pearson Chi-square test was used for categorical variables. Using factors that were deemed clinically significant, we performed multivariable logistic regression to identify risk factors associated with outcomes. We utilized SPSS v26 (New York, United States) for all analyses, with p value of < 0.05 denoting statistical significance.

Results

Patient demographics and tumor characteristics

In total, 21,258 subjects underwent surgical treatment for clinical grade T2 renal masses. Tables 1 and 2 represent patients undergoing PN and RN, respectively, who are then further divided based on surgical approach. There were 1698 PN patients with 526 robotic and 1172 non-robotic approach. In Table 2, there were 19,560 in the RN cohort with 2808 undergoing a robotic and 16,752 a non-robotic approach. There were no significant differences in the demographics between the two groups in the PN population. Meanwhile, in the RN population, patients undergoing robotic approach were less likely to be uninsured and more likely to receive their care in an academic facility ($p < 0.001$). Clinical stage of cT2a portended a robotic approach instead of an open/laparoscopic approach in both the PN (65.8% vs 59.9%) and RN (58.3% vs 50.5%) cohort.

Perioperative complications and survival outcomes

Tables 3 and 4 compare perioperative and survival outcomes of robotic surgery to non-robotic surgery for both PN and RN. In Table 3, patients who underwent a robotic PN had shorter hospital stays compared to non-robotic approaches (3.3 days versus 5.2 days, $p < 0.001$). When comparing the rates of pathologic upstaging, rates of positive margins, 30-day readmission rates, and 30-day mortality, no difference between the two groups was observed. Similar trends were shown in Table 4, when comparing a robotic approach to non-robotic approaches for RN. The robotic RN cohort had shorter hospital stays (3 days vs 4.2 days, $p < 0.001$)

Table 1 Patient demographics and clinical tumor characteristics—partial nephrectomy

Variable	All PN (n = 1698)	Open/Lap PN (n = 1172)	Robotic PN (n = 526)	Sig
Mean age	60.5 ± 12.1	60.6 ± 12.1	60.1 ± 12.2	0.417
Sex				0.862
Male	1209 (71.2%)	836 (71.3%)	373 (70.9%)	
Female	489 (28.8%)	336 (28.7%)	153 (29.1%)	
Race				0.274
White	1359 (80.0%)	928 (79.2%)	431 (81.9%)	
Black	263 (15.5%)	186 (15.9%)	77 (14.6%)	
Other	76 (4.5%)	58 (4.9%)	18 (3.4%)	
Charlson				0.425
0	1125 (66.3%)	788 (67.2%)	337 (64.1%)	
1	388 (22.9%)	255 (21.8%)	133 (25.3%)	
2	117 (6.9%)	83 (7.1%)	34 (6.5%)	
3 +	68 (4.0%)	46 (3.9%)	22 (4.2%)	
Income status				0.154
< $38,000	288 (17.0%)	205 (17.5%)	83 (15.8%)	
$38,000–47,999	411 (24.2%)	284 (24.3%)	127 (24.2%)	
$48,000–62,999	411 (24.2%)	266 (22.7%)	145 (27.6%)	
$63,000 +	586 (34.6%)	416 (35.5%)	170 (32.4%)	
Facility type				0.186
Comm cancer	66 (4.1%)	49 (4.4%)	17 (3.4%)	
Comp comm cancer	417 (25.9%)	280 (25.1%)	137 (27.7%)	
Academic	928 (57.6%)	658 (58.9%)	270 (54.5%)	
Integrated network	201 (12.5%)	130 (11.6%)	71 (14.3%)	
Uninsured	42 (2.5%)	30 (2.6%)	12 (2.3%)	0.863
cT stage				0.013
cT2a	1048 (61.7%)	702 (59.9%)	346 (65.8%)	
cT2b	251 (14.8%)	192 (16.4%)	59 (11.2%)	
cT2x	399 (23.5%)	278 (23.7%)	121 (23.0%)	
Approach				N/A
Open	891 (52.5%)	891 (76.0%)	N/A	
Laparoscopic	238 (14.0%)	238 (20.3%)	N/A	
Converted open	43 (2.5%)	43 (3.7%)	N/A	
Robotic	526 (31.0%)	N/A	526 (100%)	

without significant differences in pathologic upstaging, rates of positive margins, 30-day readmission rates, or 30-day mortality.

Surgical approach over time

Figure 1 outlines the nation-wide trend of robotic approach in cT2 RCC. Over the study period of 2010–2016, the overall rate of robotic surgery increased from about 6% to nearly 24% in the treatment of cT2 RCC. Utilization of robotic surgery increased by 346% (from 12.3 to 42.6%) for PN and 351% (from 6.2 to 21.8%) for RN.

Multivariable analysis: robotic approach

Table 5 is a logistic regression for robotic approach. For RN, surgery at an academic hospital or a more recent year of diagnosis were positively predictive of robotic approach ($p < 0.001$). Black race, being uninsured and cT2b disease were negatively predictive of robotic surgery ($p < 0.05$). As for PN, a more recent year of diagnosis was also positively predictive of robotic utilization, while cT2b disease was negatively predictive of a robotic approach ($p < 0.05$).

Discussion

In this population-based retrospective review of various surgical approaches to cT2 RCC, we found a drastic increase in the use of robotics from 2010 to 2016. A robotic approach was undertaken in 42.6% of PN in 2016, up from 12.3% in 2010. RN saw a similarly large increase in utilization of robotics from 6.2 to 21.8%. Robotic approach was not associated with adverse clinical and oncologic outcomes, such as 30-day readmission rates, 30-day mortality, positive margins or rates of pathological upstaging when compared to non-robotic approaches. Instead, patients undergoing robotic surgery experienced a shorter hospital stay. On multivariate analysis, an academic hospital positively predicts the use robotics whereas uninsured and cT2b disease are negatively predictive. Taken together, this data suggests that robotic surgery in the treatment of cT2 disease is becoming an increasingly popular surgical option that provides similar outcomes to other surgical approaches in well-selected patients.

Our findings support current literature with respect to the rising rates of robotic surgery used for RCC. In an NCDB analysis by Alameddine et al., rates of robotic-assisted PN (RAPN) for cT1 disease increased to 63% in 2013 from 41% in 2010 [11]. Jabaji et al. found a similar increase in RAPN at their institution from 2011 to 2014 [12]. For RN, Jeong et al. reported that a robotic approach comprised 27% of RN in 2015 up from just 1.5% in 2003 [13]. However, to our knowledge, our study is the first to establish the uptrend in robotic surgery specific to larger and surgically complex cT2 disease. The driving force behind this finding is not clear and likely multifactorial. One potential explanation is increased training on the robotic platform during training, leading to its application with many urologic procedures. Robot-assisted radical prostatectomy quickly took over open prostatectomy during the early 2000s, comprising 85% of cases in 2013, likely even a higher percentage now [14].

Table 2 Patient demographics and clinical tumor characteristics—radical nephrectomy

Variable	All RN (n = 19,560)	Open/Lap RN (n = 16,752)	Robotic RN (n = 2808)	Sig
Mean age	60.9 ± 12.2	60.8 ± 12.2	61.1 ± 12.0	0.231
Sex				0.368
Male	12,815 (65.5%)	10,954 (65.4%)	1861 (66.3%)	
Female	6745 (34.5%)	5798 (34.6%)	947 (33.7%)	
Race				0.011
White	16,527 (84.5%)	14,131 (84.4%)	2396 (85.3%)	
Black	2154 (11.0%)	1885 (11.3%)	269 (9.6%)	
Other	879 (4.5%)	736 (4.4%)	143 (5.1%)	
Charlson				0.068
0	13,682 (69.9%)	11,735 (70.1%)	1947 (69.3%)	
1	4115 (21.0%)	3523 (21.0%)	592 (21.1%)	
2	1190 (6.1%)	1025 (6.1%)	165 (5.9%)	
3 +	573 (2.9%)	469 (2.8%)	104 (3.7%)	
Income status				0.117
< $38,000	3437 (17.6%)	2950 (17.6%)	487 (17.4%)	
$38,000–47,999	4643 (23.8%)	4001 (23.9%)	642 (22.9%)	
$48,000–62,999	5353 (27.4%)	4606 (27.6%)	747 (26.6%)	
$63,000 +	6088 (31.2%)	5159 (30.9%)	929 (33.1%)	
Facility type				< 0.001
Comm cancer	1386 (7.4%)	1256 (7.9%)	130 (4.8%)	
Comp comm cancer	7633 (40.9%)	6630 (41.5%)	1003 (37.1%)	
Academic	6997 (37.5%)	5902 (37.0%)	1095 (40.5%)	
Integrated network	2655 (14.2%)	2182 (13.7%)	473 (17.5%)	
Uninsured	804 (4.1%)	728 (4.3%)	76 (2.7%)	< 0.001
cT stage				< 0.001
cT2a	10,093 (51.6%)	8457 (50.5%)	1636 (58.3%)	
cT2b	5498 (28.1%)	4929 (29.4%)	569 (20.3%)	
cT2x	3969 (20.3%)	3366 (20.1%)	603 (21.5%)	
Approach				N/A
Open	8710 (44.5%)	8710 (52.0%)	N/A	
Laparoscopic	7410 (37.9%)	7410 (44.2%)	N/A	
Converted open	632 (3.2%)	632 (3.8%)	N/A	
Robotic	2808 (14.4%)	N/A	2808 (100%)	

Alternatively, although an oncological and survival benefit to robotic nephrectomy compared to non-robotic approaches has not been proven, there is increasing evidence suggesting superior perioperative outcomes, such as lower estimated blood loss, fewer postoperative complications, and shorter hospital stays [6, 8, 9]. These benefits are confirmed in our own analysis, suggesting a decreased length of stay for robotic surgery, even in the setting of larger renal masses. Thus, while long-term outcomes are not fully elucidated, the short-term perioperative benefits may sway surgeon preference towards a robotic approach for cT2 disease.

A shorter hospital stay experienced after robotic nephrectomy has been previously reported, but its significance requires further investigation [8, 15]. Cost analyses regarding surgical approach are not in unanimous agreement. In a nation-wide review by Jeong et al. and Yang et al. from 2003 to 2015 and 2009 to 2011 respectively, robotic-assisted RN (RARN) was associated with a significantly higher hospital and total cost compared to laparoscopic-assisted radical nephrectomy (LARN) [13, 16]. On an institutional level, Helmers et al. report a higher cost trend in RARN compared to LARN, but lacked statistical significance [17]. In contrast, Buse et al. report a cost benefit to RAPN relative to open PN at select high-volume centers, as the increased supply and maintenance of a robotic platform was offset by the shorter hospital stay and fewer perioperative complications [18]. Moreover, as reported by Bahler et al., the cost of RAPN is downtrending and demonstrated a cost benefit to open nephrectomy in 2012 despite being $1,464 more expensive three years prior [19]. Altogether, it appears there is no

Table 3 Perioperative and survival outcomes—partial

Variable	All PN ($n=1698$)	Open/Lap PN ($n=1172$)	Robotic PN ($n=526$)	Sig
Hospital stay (days)	4.6 ± 6.3	5.2 ± 7.0	3.3 ± 4.2	< 0.001
pT stage				0.001
pT1	325 (19.1%)	196 (16.7%)	129 (24.5%)	
pT2	1131 (66.6%)	810 (69.1%)	321 (61.0%)	
pT3	240 (14.1%)	164 (14.0%)	76 (14.4%)	
pT4	2 (0.1%)	2 (0.2%)	0 (0%)	
Upstaging	242 (14.2%)	166 (14.2%)	76 (14.4%)	0.881
Margin status				0.588
Negative	1560 (91.9%)	1082 (92.3%)	478 (90.0%)	
Positive	119 (7.0%)	78 (6.7%)	41 (7.8%)	
Unknown or N/A	19 (1.1%)	12 (1.0%)	7 (1.3%)	
Complications				
30-Day readmission	49 (2.9%)	32 (2.7%)	17 (3.2%)	0.638
Death within 30 days	6 (0.4%)	4 (0.3%)	2 (0.4%)	0.901

Table 4 Perioperative and survival outcomes—radical

Variable	All RN ($n=19{,}560$)	Open/Lap RN ($n=16{,}752$)	Robotic RN ($n=2808$)	Sig
Hospital stay (days)	4.0 ± 3.7	4.2 ± 3.8	3.0 ± 2.8	< 0.001
pT stage				< 0.001
pT1	1902 (9.7%)	1534 (9.2%)	369 (13.1%)	
pT2	11,839 (60.5%)	10,201 (60.9%)	1638 (58.3%)	
pT3	5663 (29.0%)	4880 (29.1%)	783 (27.9%)	
pT4	155 (0.8%)	137 (0.8%)	18 (0.6%)	
Upstaging	5818 (29.8%)	5017 (29.9%)	801 (28.5%)	0.133
Margin status				0.315
Negative	18,973 (97.0%)	16,237 (96.9%)	2736 (97.4%)	
Positive	470 (2.4%)	411 (2.5%)	59 (2.1%)	
Unknown or N/A	117 (0.6%)	104 (0.6%)	13 (0.5%)	
Complications				
30-Day readmission	476 (2.4%)	414 (2.5%)	62 (2.2%)	0.426
Death within 30 days	125 (0.6%)	111 (0.7%)	14 (0.5%)	0.369

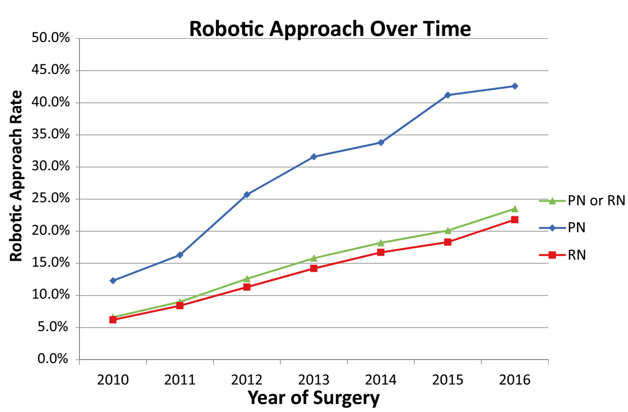

Fig. 1 Robotic utilization over time

unanimous cost benefit to favor a given approach. Rather, a cost-effective approach is one that takes into account the specific tumor characteristics, a surgeon's preference, the experience of the treatment center, and the always evolving paradigm of surgical technology.

Our multivariate analysis is in agreement with prior work revealing the discrepancies in the distribution of robotic surgery application; namely black race and being uninsured negatively predicts a robotic approach to cT1 and cT2 RCC nephrectomy [11, 20]. It is widely known that minorities and patients with a low socioeconomic status have unequal access to health care and are more likely to have their surgery at low-volume centers [21, 22]. Considering we found academic hospitals to be predicative

Table 5 Logistic regression for robotic approach

Variable	Radical				Partial			
	OR	95% CI low	95%CI high	Sig	OR	95% CI low	95% CI high	Sig
Age	.999	.996	1.003	.694	.995	.986	1.003	.228
Male sex	1.033	.948	1.125	.463	1.012	.799	1.282	.921
Race (white ref)								
Black	**.855**	**.743**	**.984**	**.029**	.967	.709	1.319	.832
Other	1.096	.908	1.322	.340	.695	.397	1.216	.203
Charlson (0 ref)								
1	1.054	.952	1.167	.310	1.290	.999	1.665	.051
2	.952	.799	1.135	.584	.960	.621	1.483	.853
3+	1.129	.902	1.411	.289	.879	.505	1.530	.647
Income (< $38,000 ref)								
$38,000–47,999	.943	.827	1.074	.377	1.158	.818	1.639	.408
$48,000–62,999	.950	.836	1.079	.428	1.337	.948	1.887	.098
$63,000+	1.036	.915	1.172	.578	1.077	.772	1.503	.661
Academic	**1.175**	**1.080**	**1.278**	**.000**	.842	.679	1.045	.118
Uninsured	**.641**	**.502**	**.820**	**.000**	.984	.486	1.991	.963
Year of diagnosis	**1.248**	**1.221**	**1.276**	**.000**	**1.297**	**1.222**	**1.377**	**.000**
cT2 stage (cT2x ref)								
cT2a	.943	.850	1.046	.270	1.054	.812	1.367	.693
cT2b	**.563**	**.497**	**.638**	**.000**	**.662**	**.456**	**.961**	**.030**

Bold data indicates $p < 0.05$

OR odds ratio, *CI* confidence interval, *sig* significance, *ref* reference

of a robotic approach, there is a risk of a treatment gap for at-risk patient group and a lack of access to this novel approach for cT2 disease. Given the comparable outcomes between surgical approaches, expanding robotic utilization to low-volume centers and improving access to health care for minority and uninsured patients may increase access for appropriate, cost-effective surgical decision making for these populations.

When subclassifying cT2 RCC into cT2a and cT2b, we report cT2b disease to be negatively predictive of both RAPN and RARN. While this suggests tumor size may be an important barrier to robotic surgery, the tumor staging used in this study is likely a surrogate of the relative tumor complexity. In general, larger tumors tend to be considered more complex, but size alone does not adequately characterize the mass. Ideally, imaging review with calculation of a RENAL nephrometry score (RNS) would be performed, but this is not available within the NCDB database [23]. The RNS considers not only the tumor size, but also its nearness to the collecting system, vessels and overall location within the kidney, giving a much better approximation of tumor complexity. RNS is widely used and prior work has found RNS to be predictive of tumor grade and various perioperative and overall outcome measures [24–26]. Therefore, future cohorts exploring detailed radiographic morphometrics, such as RNS, in the context of surgical approach, may provide a more comprehensive understanding of the variables driving the widespread increased usage of robotics.

An important limitation to our retrospective study design is we cannot readily determine the reason for the trends observed. We drew from other literature and clinical experience, but without the aforementioned decisional variables, namely patient's surgical preference, the surgeon preference, or the specific tumor characteristics, it is merely hypothesis generation. Although the NCDB data collection is a standardized process, certain data are unable to be obtained due to insufficient documentation. For example, nearly 21% of the study population did not have tumor staging documented, and thus had to be excluded in the multivariate analysis. Lastly, incorrect coding and data entry errors in the NCDB are a possible confounding factor, but we do not believe this played a large role in our study. Overall, we believe our analysis sheds light on and validates the recent shift toward robotic surgery for cT2 RCC while emphasizing the inequality and limitations to its application, laying the framework for future investigations.

Conclusion

Over our study period of 2010–2016, robotic PN and RN was an increasingly popular approach in the treatment of cT2 RCC. Utilization of robotics is associated with academic institutions and results in a shorter hospital stay without significant differences in the rate of positive margins, readmission rates, or 30/90 day mortality.

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Code availability Not applicable.

Declarations

Conflict of interest Not applicable.

Ethical approval Not required due to nature of data collection.

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