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ORIGINAL RESEARCH

The impact of robotic surgery access on the management of patients with clinical stage I kidney tumors

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ABSTRACT

INTRODUCTION: Robotic surgery is used in the treatment of kidney tumors. We aimed to determine if robotic access was associated with initial choice of management for patients with a clinical stage I kidney mass.

METHODS: Patients with a clinical stage I kidney mass were identified from the Canadian Kidney Cancer information system (CKCis) cohort. Sites were classified by year and access to robotic surgery. Associations between robotic access and initial management were determined using logistic regression. Univariable and multivariable analyses were performed, adjusting for tumor size and stage, and presented as relative risks (RR) or adjusted RR (aRR) and 95% confidence intervals (CI).

RESULTS: Overall, 4160 patients were included. Among patients treated with surgery, the proportion of partial nephrectomy compared to radical nephrectomy was significantly higher in robotic sites (77.3% for robotic sites vs. 65.9% for non-robotic sites; RR 1.17, 95% CI 1.12–1.23, $p<0.0001$; aRR 1.12, 95% CI 1.08–1.17, $p<0.0001$). Patients receiving partial nephrectomy at sites with robotic access were more likely to receive a minimally invasive approach compared to patients at non-robotic sites (61.4% vs. 50.9%, RR 1.21, 95% CI 1.12–1.30; aRR 1.16, 95% CI 1.08–1.25, $p<0.0001$). The proportion of patients managed by active surveillance was not significantly different between robotic (405, 16.9%) and non-robotic (258, 14.7%) sites (RR 1.15, 95% CI 0.99–1.32; aRR 0.97, 95% CI 0.84–1.12).

CONCLUSIONS: Access to robotic kidney surgery was associated with increased use of partial nephrectomy and minimally invasive partial nephrectomy. Use of active surveillance was similar at robotic and non-robotic institutions. Limitations of this study include lack of data on perioperative complications and cancer recurrence.

INTRODUCTION

The diagnosis of kidney cancer has been increasing worldwide.[1-3] Reasons for the increase may be a higher prevalence of kidney cancer risk factors (e.g., obesity, hypertension) and increased use of radiographic imaging.[3,4] Historically, kidney tumors were managed with radical nephrectomy; however, the use of partial nephrectomy has become the preferred surgical treatment when technically feasible to preserve overall kidney function.[5,6] For certain patients with kidney masses, active surveillance may be the preferred management approach to avoid treatment-related complications.[7]

Coinciding with the increased use of partial nephrectomy, there has been a rapid adoption of minimally invasive surgical (MIS) approaches. For kidney surgery, MIS results in less pain, decreased hospital stay, and faster postoperative recovery compared to open approaches.[8] The most common MIS approaches are standard laparoscopy or robotic-assisted laparoscopy. Standard laparoscopic radical nephrectomy has been quickly adopted by urologists;[9] however, the added complexity associated with laparoscopic partial nephrectomy has limited its widespread adoption.[10,11] Patients and clinicians are often challenged with weighing the benefits and harms of open partial nephrectomy vs. laparoscopic nephrectomy. In fact, the introduction of laparoscopic radical nephrectomy in Ontario in 1995 was unfortunately associated with a decrease in use of partial nephrectomy.[12]

Since the introduction of robotic surgical systems, robotic-assisted laparoscopic partial nephrectomy has gained significant popularity for the treatment of kidney masses, likely due to the technical dexterity provided by robotic instruments compared to standard laparoscopic instruments.[13] Furthermore, it is reasonable to surmise that in an individual patient, some surgeons may believe a robotic-assisted partial nephrectomy may be feasible, while a standard laparoscopic partial nephrectomy is not.

Given the benefits of both a partial nephrectomy and an MIS approach, we hypothesized access to a robotic surgical platform may increase the proportion of patients receiving partial nephrectomy and MIS kidney surgery. It is also possible that access to robotic surgery may influence patients and surgeons toward surgical treatment rather than active surveillance. Using a large, prospective cohort of Canadian patients with clinical stage I kidney tumors, we aimed to determine if access to a surgical robot was associated with use of partial nephrectomy, MIS surgical approach, and active surveillance.

METHODS

This study was performed using data from the Canadian Kidney Cancer information system (CKCis). CKCis is a multicenter, prospective cohort of kidney tumor patients from 14 Canadian academic centers. This study included data from inception (January 1, 2011) until December 31, 2020. Patients were included if they were diagnosed for a clinical stage I tumor (≤7 cm diameter and localized to the kidney parenchyma on imaging) and initially managed with surgery, thermal ablation (cryoablation or radiofrequency), or active surveillance. Patients with bilateral tumors or multiple tumors, non-cortical kidney tumors (e.g., urothelial carcinoma), and those treated with radiation were excluded. Patients treated with radiation were excluded because this was not a common treatment modality during the study period and these patients were not included in CKCis. Patients with previously treated tumors in the ipsilateral kidney were also excluded.

Patient characteristics

Baseline demographic and clinical information were obtained from the medical record and patient surveys. Perioperative information was obtained from medical records. All data was entered into the CKCis central repository by trained abstractors at each CKCis site. Data verification was performed on approximately 5% of patients by the central data coordinator. The initial management of patients was classified as active surveillance, thermal ablation, or surgery. Surgical patients were classified as receiving radical or partial nephrectomy by laparoscopic (robotic or pure laparoscopic) or open approach. For patients designated as active surveillance, the plan for active surveillance was explicitly documented in the medical record, with a plan to treat with surgery or ablation if there was a change in tumor characteristics.

Robotic and non-robotic centers

Sites were classified as robotic or non-robotic. If a site began performing robotic kidney surgery during the study period, the time interval prior to robotic access was included in the non-robotic cohort and the time interval after access to robotic surgery was included in the robotic cohort.

Outcomes

The primary outcome was type of nephrectomy received (partial vs. radical). The secondary outcomes were the surgical approach, minimal invasive (laparoscopic or robotic) vs. open, and proportion of patients treated with active surveillance.

Analysis

Characteristics of patients treated at non-robotic centers and robotic centers were summarized using means and standard deviation (SD) or proportions and interquartile ranges (IQR). Comparisons in baseline characteristics were performed using t-tests or Chi-squared tests. The associations between robotic-access and surgical treatment were determined using logistic regression. The proportion of partial nephrectomies and MIS surgeries was calculated both in the context of the entire cohort, as well as in the subcohort treated with surgery. In the centers where robotic access occurred during the study period, the association of robotic access to patient management could be confounded by year of diagnosis. To assess this potential confounding, we stratified patient management by year of diagnosis at robotic centers and non-robotic centers. Univariable and multivariable (adjusting for imaging tumor diameter and clinical tumor stage) analyses were performed and presented as relative risk (RR) and adjusted RR (aRR) with 95% confidence intervals (CI). To further assess for effect modification between year of diagnosis and robotic access, an interaction term was included in models for the primary outcome. No adjustment was made for multiple testing and p-values ≤0.05 were considered statistically significant. All analysis was performed using SAS.

RESULTS

Between January 1, 2011, and December 31, 2020, 4160 patients met inclusion criteria. Demographic and clinical data are presented in Table 1. Overall, 3208 (77.1%) patients with cT1 kidney masses were treated surgically. Of those 2317 (72.2%) underwent a partial nephrectomy and 891 (27.8%) a radical nephrectomy. Of the radical nephrectomy patients, 185 (20.8%) were treated via an open approach and 706 (79.2%) received an MIS approach. Of all patients receiving a partial nephrectomy, 993 (42.9%) were performed open and 1324 (57.1%) underwent a MIS approach. In the entire cohort, 166 (4.0%) were treated with cryoablation (30 [1.7%] and 136 [5.7%] of non-robotic and robotic sites, respectively) and 123 (3.0%) with radiofrequency (41 [2.3%] and 82 [3.4%] of non-robotic and robotic sites, respectively). Overall, 663 (15.9%) patients underwent active surveillance (Figure 1). Year of diagnosis was not associated with treatment and an interaction term of year of diagnosis and robotic access for partial nephrectomy was not significant, therefore, all further analyses did not adjust for year of diagnosis (Figure 1).

Robotic vs. non-robotic site patients

Of the 14 CKCis institutions, five did not have robotic access during the entire study period. One site had robotic kidney surgery access for the entire study period and eight sites obtained robotic kidney surgery access during the study period. Overall, 2403 (57.8%) patients were treated in centers with robotic access and 1757 (42.2%) were treated in centers without robotic access. Patients treated in robotic centers had a statistically significant smaller mean tumor size than non-robotic centers on imaging (3.4 cm and 3.7 cm, respectively for the entire cohort, p<0.0001). For the subgroup treated with surgery, the mean radiologic tumor size was 3.7 cm and 3.9 cm for robotic and non-robotic centers, respectively, and the mean respective pathologic size was 3.5 cm and 3.8 cm (p<0.0001). Robotic centers had a higher proportion of clinical stage cT1a than non-robotic centers, 72.4% compared to 65.7% (p<0.0001). Patients treated in robotic centers also had a significantly higher proportion of pathologic stage T1a masses compared to non-robotic centers (72.1% and 67.9%, p=0.02). Detailed comparison of patient characteristics between robotic and non-robotic centers is presented in Table 1. Of all patients treated at centers with robotic access, 1780 (74.1%) were initially treated with surgery compared to 1428 (81.3%) for patients treated at centers without robotic access (p<0.0001).

Primary outcome: Partial nephrectomy

The proportion of patients treated with partial nephrectomy was higher at centers with robotic access com-

Table 1. Clinical and pathologic characteristics of the study cohort, stratified by robotic and non-robotic sites

	Non-robotic sites	Robotic sites	p
Demographic information			
Participants, n	1757	2403	
Mean age, years (SD)	61.8 (12.0)	61.6 (12.9)	0.63
Sex, n (%)			
Male	1088 (61.9)	1510 (62.8)	0.55
Female	669 (38.1)	893 (37.1)	
Ethnicity, n (%)			
Caucasian	926 (87.9)	1289 (81.1)	<0.0001
Non-Caucasian	128 (12.1)	301 (18.9)	
Clinical information			
Mean BMI, kg/m² (SD)	30.3 (9.6)	29.8 (13.4)	0.34
Mean Charlson comorbidity index (SD)	2.82 (1.98)	2.85 (2.03)	0.67
Smoking, n (%)	876 (56.1)	1104 (55.1)	0.52
Family history of kidney cancer, n (%)	70 (4.0)	76 (3.2)	0.16
Median creatinine, mmol/L (IQR)	79 (67, 95)	81 (69,97.5)	0.01
Median eGFR, ml/minute/1.73 m² (IQR)	97.3 (74.7,124.3)	93.2 (72,118.4)	0.03
Oncologic information			
Mean tumor size on imaging, cm (SD)	3.66 (1.67)	3.42 (1.68)	<0.0001
Mean tumor size on imaging, subgroup treated with surgery, cm (SD)	3.9 (1.6)	3.7 (1.6)	
Mean tumor size on pathology, cm (SD)	3.76 (1.65)	3.53 (1.67)	<0.0001
Clinical stage, n (%)			
cT1a	1155 (65.7)	1739 (72.4)	<0.0001
cT1b	602 (34.3)	664 (27.6)	
Pathologic T-stage, n (%)			
pT1	1172 (85.1)	1452 (87.9)	0.05
pT1a	796 (67.9)	1047 (72.1)	0.02
pT1b	376 (32.1)	405 (27.9)	0.02
pT2	20 (1.5)	25 (1.5)	0.05
pT3-pT4	186 (13.5)	172 (10.6)	0.05

BMI: body mass index; eGFR: estimated glomerular filtration rate; IQR: interquartile range; SD: standard deviation.

Table 1 (cont'd). Clinical and pathologic characteristics of the study cohort, stratified by robotic and non-robotic sites

	Non-robotic sites	Robotic sites	p
Oncologic information (cont'd)			
Pathologic N stage, n (%)			
N0	67 (4.7)	127 (7.5)	0.004
N1	7 (0.5)	5 (0.3)	
NX	1346 (94.8)	1564 (92.2)	
Margin positivity, n (%)			
Positive	94 (6.9)	106 (6.3)	0.50
Negative	1277 (93.1)	1590 (93.8)	
Grade, n (%)			
Low	752 (58.3)	1100 (66.5)	<0.0001
High	538 (41.7)	555 (33.5)	

BMI: body mass index; eGFR: estimated glomerular filtration rate; IQR: interquartile range; SD: standard deviation.

pared to sites that did not have robotic access (1376 [57.3%] vs. 941 [53.6%], RR 1.07, 95% CI, 1.01–1.13, p=0.02) (Figure 1, Table 2). When evaluating the subgroup of patients treated with surgery, the difference was greater, with 1376 (77.3%) receiving partial nephrectomy at robotic centers vs. 941 (65.9%) for non-robotic centers (RR 1.17, 95% CI 1.12–1.23, p<0.0001) (Table 2). Following adjustment for differences in clinical stage and tumor size, there remains an association between robotic access and partial nephrectomy (aRR 1.12, 95% CI 1.08–1.17, p<0.0001) (Table 2).

Secondary outcomes

Of all nephrectomies performed (partial and radical), robotic sites used an MIS approach in 1152 (64.7%) surgeries compared to 878 (61.5%) for non-robotic sites (RR 1.05, 95% CI 1.00–1.23, p=0.06; aRR 1.05, 95% CI 0.99–1.11, p=0.09) (Table 2). Of the partial nephrectomies performed, it was found that robotic sites used a minimally invasive technique significantly more than non-robotic sites (845 [61.4%] vs. 479 [50.9%]; RR 1.21, 95% CI 1.12–1.30; aRR 1.16, 95% CI 1.08–1.25, p<0.0001) (Table 2). There was no significant difference in the proportion of patients treated with active surveillance between robotic (405, 16.9%) and non-robotic (258, 14.7%) sites (RR 1.15, 95% CI 0.99–1.32, p=0.06; aRR 0.97, 95% CI 0.84–1.12, p=0.68) (Table 2).

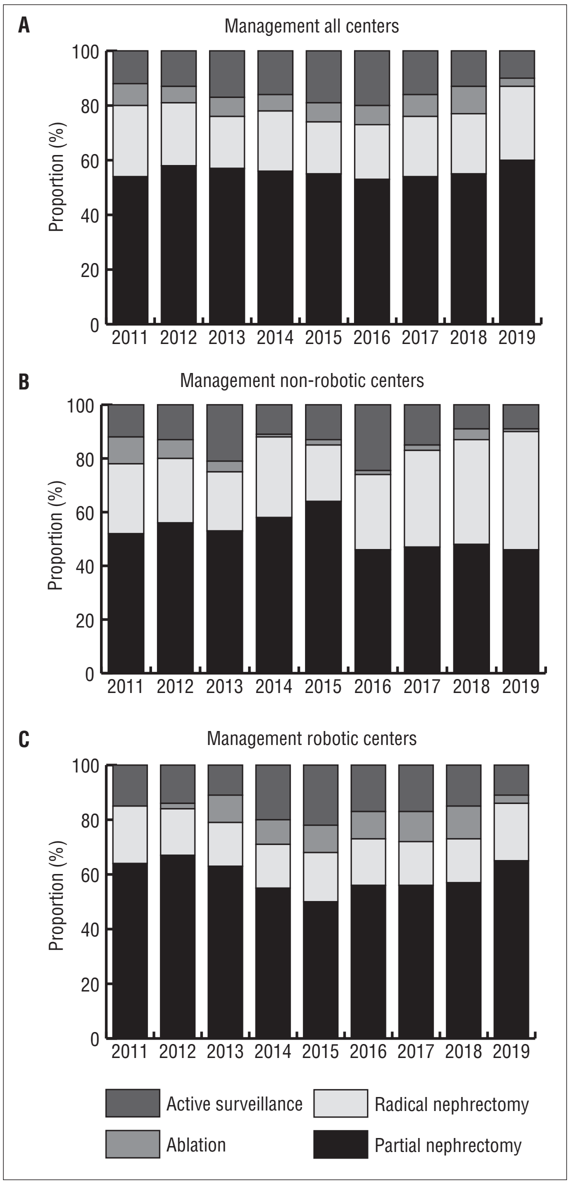

Figure 1. Management of clinical stage I kidney masses in (A) the entire cohort; (B) centers without robotic access; and (C) centers with robotic access.

Impact of robotic introduction

From the eight sites that acquired robotic platform during the study period, the proportion of partial nephrectomy was 71.7% before robotic access compared to 76.1% after robotic access (RR 1.06, 95% CI 1.002–1.12, p=0.044). The proportion of MIS was 57.5% before robotic access compared to 64.5% after robotic access (RR 1.12, 95% CI 1.04–1.21, p=0.042). Of the partial nephrectomies performed, the proportion MIS partial nephrectomy was 49.3% before robotic access compared to 60.6% after robotic access (RR 1.23, 95% CI 1.10–1.37, p=0.0002).

Table 2. Management according to robotic access

	Non-robotic	Robotic	Relative risk (95% CI)	p	Adjusted relative risk* (95% CI)	p
Primary outcome, partial nephrectomy						
Entire cohort (N=4160)	1757	2403				
Partial nephrectomy, n (%)	941 (53.6)	1376 (57.3)	1.07 (1.01–1.13)	0.02	1.03 (0.97–1.09)	0.35
Radical nephrectomy, ablation or active surveillance, n (%)	816 (46.4)	1027 (42.7)				
Surgically managed patients (N=3208)	1428	1780				
Partial nephrectomy, n (%)	941 (65.9)	1376 (77.3)	1.17 (1.12–1.23)	<0.0001	1.12 (1.08–1.17)	<0.0001
Radical nephrectomy, n (%)	487 (34.1)	404 (22.7)				
Secondary outcome, minimal invasive surgery						
Entire cohort (N=4160)	1757	2403				
Minimally invasive surgery, n (%)	878 (50.0)	1152 (47.9)	0.96 (0.90–1.02)	0.19	0.97 (0.91–1.03)	0.36
Open surgery, ablation, or active surveillance, n (%)	879 (50.0)	1251 (52.1)				
Surgically managed patients (N=3208)	1428	1780				
Minimally invasive surgery, n (%)	878 (61.5)	1152 (64.7)	1.05 (1.00–1.11)	0.06	1.05 (0.99–1.11)	0.09
Open surgery, n (%)	550 (38.5)	628 (35.3)				
Minimally invasive partial nephrectomy n (%)	479(50.9)	845(61.4)	1.21 (1.12–1.30)	0.0001	1.16 (1.08–1.25)	0.0001
Secondary outcome, active surveillance						
Entire cohort (N=4160)	1757	2403				
Active surveillance, n (%)	258 (14.7)	405 (16.9)	1.15 (0.99–1.32)	0.06	0.97 (0.84–1.12)	0.68

*Adjusted for tumor stage and diameter. CI: confidence interval.

DISCUSSION

Patients with stage I kidney tumors treated at Canadian centers with access to robotic kidney surgery platform are more likely to be treated with partial nephrectomy and with a minimally invasive approach compared to centers without access to robotic kidney surgery. This association is likely due to the robotic platform allowing increasingly complex masses to be managed with an MIS partial nephrectomy. The learning curve for robotic partial nephrectomy is shorter than pure laparoscopic partial nephrectomy and we suspect this is the major contributing factor to our findings.[14]

While there are no randomized trials between open and MIS partial nephrectomy, there are clear advantages to patients for less invasive surgery. MIS decreases patient pain, analgesic requirements, length of stay in hospital, and postoperative recovery time compared to open surgery.[8] Partial nephrectomy also preserves kidney function compared to radical nephrectomy, so should be preferred over radical nephrectomy, if technically feasible.[15] Indeed, it seems that robotic access is associated with improved delivery of care. Similar associations have been demonstrated in both the gynecology and general surgery specialties, where introduction of robotic platforms has increased the use of MIS approaches to both hysterectomy and low anterior resection.[16,17]

It has been suggested that an increased proportion of patients receiving partial nephrectomy in robotic centers may be a consequence of fewer patients receiving active surveillance.[18] Reassuringly, in this study, the proportion of patients treated with active surveillance was not associated with robotic access. It seems that robotic surgery access in Canada does not appear to be associated with overtreatment of kidney masses.

While access to robotic surgical platforms is increasing, this technology is still not widely available in Canada outside of academic centers.[19] This is largely due to the increased cost of the robotic surgical system and its operation. At least one new robotic-assisted system has recently received a Health Canada license for urologic and gynecologic surgery.[20] If the cost of robotic surgical systems decrease, there may be more access in both academic and non-academic settings.[21]

Limitations

This study has some potential limitations that should be highlighted. This is a non-randomized study, so may be subject to unmeasured selection bias. We used partial nephrectomy and MIS surgery as outcomes based on the known benefits of these approaches but we did not evaluate outcomes such as perioperative complications, hospital stay, oncologic outcomes, or monetary cost. Other than tumor size, we did not have information on tumor complexity, which could have an impact on the choice of treatment. Furthermore, included data were solely from Canadian academic centers; therefore, the results may not be generalizable to non-academic hospitals or other healthcare systems.

CONCLUSIONS

Access to robotic kidney surgery was associated with increased use partial nephrectomy and MIS partial nephrectomy in the management of clinic stage I kidney tumors. This has important implications for patients, given the benefits of both a partial nephrectomy technique and an MIS approach to treatment of their disease. Robotic kidney surgery is still not widely available across Canada. Efforts to increase access and exposure, especially in training environments, may allow for widespread dissemination of MIS partial nephrectomy through altered learning curves compared to traditional laparoscopic partial nephrectomy.

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