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Association of Robotic-Assisted vs Laparoscopic Radical Nephrectomy With Perioperative Outcomes and Health Care Costs, 2003 to 2015

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IMPORTANCE Use of robotic surgery has increased in urological practice over the last decade. However, the use, outcomes, and costs of robotic nephrectomy are unknown.

OBJECTIVES To examine the trend in use of robotic-assisted operations for radical nephrectomy in the United States and to compare the perioperative outcomes and costs with laparoscopic radical nephrectomy.

DESIGN, SETTING, AND PARTICIPANTS This retrospective cohort study used the Premier Healthcare database to evaluate outcomes of patients who had undergone robotic-assisted or laparoscopic radical nephrectomy for renal mass at 416 US hospitals between January 2003 and September 2015. Multivariable regression modeling was used to assess outcomes.

EXPOSURES Robotic-assisted vs laparoscopic radical nephrectomy.

MAIN OUTCOMES AND MEASURES The primary outcome of the study was the trend in use of robotic-assisted radical nephrectomy. The secondary outcomes were perioperative complications, based on the Clavien classification system, and defined as any complication (Clavien grades 1-5) or major complications (Clavien grades 3-5, for which grade 5 results in death); resource use (operating time, blood transfusion, length of hospital stay); and direct hospital cost.

RESULTS Among 23 753 patients included in the study (mean age, 61.4 years; men, 13 792 [58.1%]), 18 573 underwent laparoscopic radical nephrectomy and 5180 underwent robotic-assisted radical nephrectomy. Use of robotic-assisted surgery increased from 1.5% (39 of 2676 radical nephrectomy procedures in 2003) to 27.0% (862 of 3194 radical nephrectomy procedures) in 2015 (*P* for trend <.001). In the weighted-adjusted analysis, there were no significant differences between robotic-assisted and laparoscopic radical nephrectomy in the incidence of any (Clavien grades 1-5) postoperative complications (adjusted rates, 22.2% vs 23.4%, difference, −1.2%; 95% CI, −5.4 to 3.0%) or major (Clavien grades 3-5) complications (adjusted rates, 3.5% vs 3.8%, difference, −0.3%; 95% CI, −1.0% to 0.5%). The rate of prolonged operating time (>4 hours) for patients undergoing the robotic-assisted procedure was higher than for patients receiving the laparoscopic procedure in the adjusted analysis (46.3% vs 25.8%; risk difference, 20.5%; 95% CI, 14.2% to 26.8%). Robotic-assisted radical nephrectomy was associated with higher mean 90-day direct hospital costs ($19 530 vs $16 851; difference, $2678; 95% CI, $838 to $4519), mainly accounted for operating room ($7217 vs $5378; difference, $1839; 95% CI, $1050 to $2628) and supply costs ($4876 vs $3891; difference, $985; 95% CI, $473 to $1498).

CONCLUSIONS AND RELEVANCE Among patients undergoing radical nephrectomy for renal mass between 2003 and 2015, the use of robotic-assisted surgery increased substantially. The use of robotic-assistance was not associated with increased risk of any or major complications but was associated with prolonged operating time and higher hospital costs compared with laparoscopic surgery.

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Radical nephrectomy for renal cancer remains the standard of care for large tumors with curative intent and has become the preferred treatment option for T1 and T2 tumors not amenable to nephron-sparing surgery.[1] Evidence suggests that there are no significant differences in oncological outcomes between laparoscopic and open radical nephrectomy, although laparoscopic procedures confer certain advantages over the open approach in terms of morbidity, blood loss, hospital length of stay, and postoperative analgesic requirements.[2,3]

Robotic surgery, in particular, has been rapidly adopted for a wide range of procedures over the last decade in the United States. While increasingly preferred for procedures that required open surgery, such as prostatectomy, it has also gradually replaced conventional laparoscopic surgery. This has largely been driven by extensive marketing and competition among hospitals to offer the most advanced technology.[4-7] However, the introduction and rapid adoption of the robotic platform has resulted in increased costs without significantly improving outcomes compared with nonrobotic minimally invasive approaches.[7-10]

Since the first use of robotic-assisted radical nephrectomy for renal cancer was reported in 2005, several small, single institutional observational studies have reported limited evidence on oncological and perioperative outcomes, which may not have true clinical relevance.[11] Some studies have shown equivalent perioperative outcomes despite increased costs of robotic-assisted compared with laparoscopic radical nephrectomy, yet most of these studies were limited by small sample sizes, lack of randomization, and antiquated data.[12-14] The objective of this study was to examine the utilization of robotic-assisted radical nephrectomy in the United States from 2003 to 2015 and to compare the in-hospital outcomes and costs between the 2 procedures.

Key Points

Questions Has the use of robotic-assisted vs laparoscopic radical nephrectomy changed from 2003 to 2015?

Findings The proportion of radical nephrectomies using robotic-assisted operations increased from 1.5% in 2003 to 27.0% in 2015. Although there was no significant difference between robotic-assisted vs laparoscopic radical nephrectomy in major postoperative complications, robotic-assisted procedures were associated with longer operating time and higher direct hospital costs.

Meaning The use of robotic-assisted radical nephrectomy increased substantially from 2003 to 2015 and was associated with prolonged operating time and increased costs.

Methods

Data Source

A retrospective cohort study was performed using the Premier Healthcare database (Premier), an all-payer, fee-supported database developed to measure resource use and quality, to assess the usage of the robotic platform for radical nephrectomy. This database captures approximately 20% of all hospitalizations from more than 700 acute care hospitals in the United States (>530 million hospital visits and 6 million inpatient discharges per year since 2011). This database also contains information on demographic and clinical characteristics, such as pharmaceuticals administered, laboratory and other diagnostic tests performed, and therapeutic services provided during admission. The Premier Healthcare database uses a reconciliation process that allows for verification and validation of hospital reporting for the use of resources and cost. Data audits are performed, and if reported costs submitted do not match the hospital's financial statement, Premier works with the hospital to correct the discrepancy.[15] Procedure and comorbidity data are provided by *International Classification of Diseases, Ninth Revision (ICD-9)* codes. This method has been used in other studies.[6,8,16,17] This investigation was deemed exempt from informed consent requirements by the Stanford University Medical Center institutional review board.

Patients

Patients receiving radical nephrectomy between January 2003 and September 2015 were identified by *ICD-9* code (55.51) and included in the analysis. Affiliated codes were identified and reviewed to ensure that radical nephrectomy was the primary procedure performed based on the diagnosis or concern for kidney cancer (eTable 1 in the Supplement). For example, cases of upper tract urothelial carcinoma (*ICD-9* codes 189.1 or 189.2), which have unique postoperative complication profiles stemming from the need for concurrent ureterectomy and cystotomy were excluded. Only patients receiving either robotic-assisted or laparoscopic radical nephrectomy were included. Patients undergoing open radical nephrectomy or nonelective surgeries were excluded. The inclusion and exclusion methodology is further depicted in the eFigure in the Supplement.

Main Exposures

Patients receiving robotic-assisted or laparoscopic radical nephrectomy were identified using the Charge Description Master, a catalog of all billable items eventually charged to the patient, to avoid possible inaccuracies stemming from the use of the *ICD-9* coding system in identifying robotic-assisted surgery.[17] The utilization of supplies unique to robotic procedures, as specified by the EndoWrist Instrument & Accessory Catalog from Intuitive Surgical, was used as an indicator for the use of robotic-assistance.[18] Nonrobotic cases were identified in a similar manner.

Demographic and Clinical Characteristics

Hospital-level data collected directly by Premier included size (<300, 300-500, and >500 beds), location (urban, rural), and teaching status (teaching, nonteaching). Patient-related data included year of surgery, age, race (white, black, and other), sex, and insurance status (private, Medicare, Medicaid, and other). Race determination was based on self-reporting by the patient and included in the demographics analysis to further characterize the patient population.[6,17,19] Patients were also categorized based on the Charlson comorbidity index (0, 1, ≥2).

Outcomes

The primary outcome of the study was the trend in use of the robotic-assisted radical nephrectomy. The secondary outcomes of interest were perioperative complications, resource use, and direct hospital costs. Postoperative complications were classified based on the Clavien classification system.[20] These complications were defined as any (Clavien grades 1-5) or major (Clavien grades 3-5). Grade 1 complications include "Any deviation from the normal postoperative course without the need for pharmacological treatment or surgical, endoscopic, and radiological intervention." Grade 2 complications "[require] pharmacologic treatment with drugs other than such allowed for grade 1 complications." Grade 3 complications "[require] surgical, endoscopic or radiological intervention." Grade 4 describes "Life-threatening complications requiring intermediate care/intensive care unit." Grade 5 complications result in the "[d]eath of a patient." To identify events defined by the Clavien classification system, we used *ICD-9* codes as previously described.[6,21] Resource use variables analyzed included blood transfusion (packed red blood cells), operating time (hours), and length of stay (days). Operating time (≤4 hours vs >4 hours) and length of stay (≤4 days vs >4 days) were categorized as dichotomous variables.[19,22]

Two types of direct hospital costs were provided by the Premier Healthcare database. A total of 78.5% of all patients included in the study were treated by hospitals providing procedural costs (or "reported costs") and the remainder were treated by hospitals providing estimates based on Medicare cost-to-charge ratios (MCCR or "estimated costs").[17,23,24] If hospitals have their own cost-accounting system, they assign relative value units to procedures to estimate cost. These hospitals are then able to provide Premier with both charge and cost data. If hospitals do not have a cost-accounting system or do not use relative value units to estimate cost, they provide only charge data. Hospital departments are mapped to a specific line on the Medicare Cost Report to determine the appropriate MCCR, which is then used to determine cost at a given resource level. All costs were adjusted to 2015 US dollars using the consumer price index.

Statistical Analyses

Categorical variables were presented as numbers and percentages and were compared using the χ^2 test. Linear trends in the proportion of robotic-assisted radical nephrectomies over 13 years were assessed using a logistic regression model. To reduce potential confounding, we performed an adjustment for differences in baseline patient characteristics by using a weighted logistic regression model with inverse probability of treatment weighting (IPTW).[25] Using this technique, the weights used for patients undergoing laparoscopic radical nephrectomy were the inverse of 1 minus the propensity score, and weights used for patients receiving robotic-assisted radical nephrectomy were the inverse of the propensity score alone. The propensity scores were estimated by multiple logistic regression analysis without regard to outcomes. A full nonparsimonious model was developed including all variables shown in **Table 1**.

Log-binomial regression models were used to estimate risk ratios (RRs) for each exposure on perioperative outcomes. Since it was determined that the outcome variables related to direct hospital costs were not normally distributed, a generalized linear model with gamma distribution was generated, allowing for a link function to connect the predictor with the response variables.[26] All models were adjusted for clustering of patients within hospitals using robust standard errors to account for interhospital variability. An analysis was also conducted to determine if the costs related to each surgical approach (robotic-assisted and laparoscopic radical nephrectomy) were related to the source of cost obtained within the Premier Hospital database. For these analyses, the propensity score analyses were re-performed to obtain a new IPTW for each patient. These analyses were not prespecified but rather post hoc and thus interpreted as exploratory. Statistical analysis was performed using 2-sided tests, with a significance level of <.05 and Stata 14 statistical software (StataCorp).

Results

A cohort of 23 753 patients undergoing elective laparoscopic radical nephrectomy (n = 18 573) or robotic-assisted radical nephrectomy (n = 5180) for the management of renal masses at 416 US hospitals between 2003 and 2015 was evaluated. The **Figure** shows the trend in surgical approach for radical nephrectomy over time. Use of robotic-assisted surgery for radical nephrectomy increased from 1.5% to 27.0% in the entire radical nephrectomy cohort from 2003 to 2015 (*P* for trend <.001). Since 2009, the decrease in laparoscopic radical nephrectomies paralleled the increase in robotic-assisted radical nephrectomies, while the proportion of open radical nephrectomy cases plateaued. By 2015, robotic-assisted radical nephrectomy was performed more commonly than laparoscopic radical nephrectomy in the United States.

The characteristics before and after propensity weighting are summarized in Table 1. Before the propensity weighting process, the robotic-assisted and laparoscopic radical nephrectomy cohorts differed in several variables, particularly year of surgery, Charlson comorbidity index, and insurance status. After propensity score weighting, similar covariate distributions were achieved between robotic-assisted and laparoscopic radical nephrectomy in the weighted populations (the standardized difference score, <0.2).

Unadjusted and IPTW-adjusted perioperative outcomes are presented in **Table 2**. The unadjusted rate of any (28.2% vs 21.9%; risk difference, 6.3%; 95% CI, 4.9% to 7.6%) or major complications (4.3% vs 3.6%; risk difference, 0.7%; 95% CI, 0.1% to 1.3%), prolonged operating time (43.8% vs 26.2%; risk difference, 17.6%; 95% CI, 16.1% to 19.1%), and blood transfusion (19.5% vs 18.2%; risk difference, 1.4%; 95% CI, 1.4% to 2.6%) for patients receiving robotic-assisted radical nephrectomy were higher than for those who received laparoscopic

Table 1. Baseline Characteristics of Patients Receiving Laparoscopic and Robotic Radical Nephrectomy (2003-2015)

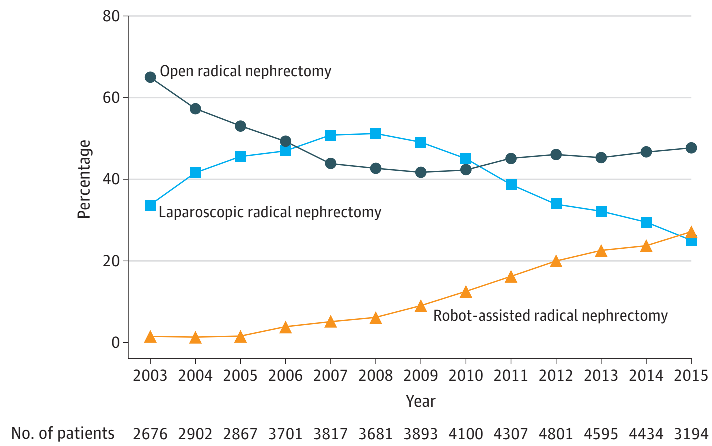
	Before Propensity Weighting				After Propensity Weighting			
	No. (%) of Patients				No. (%) of Patients			
	Laparoscopic (n = 18 573)	Robotic (n = 5180)	Standardized Difference	P Value	Laparoscopic (n = 18 573)	Robotic (n = 5180)	Standardized Difference	P Value
Age, y								
<55	5313 (28.6)	1472 (28.4)	−0.004	.03	5317 (28.6)	1491 (28.8)	0.003	.92
55-64	4917 (26.5)	1387 (26.8)	0.007		4936 (26.6)	1405 (27.1)	0.013	
65-74	4892 (26.3)	1441 (27.8)	0.033		4936 (26.6)	1345 (26.0)	−0.014	
>74	3451 (18.6)	880 (17.0)	−0.042		3384 (18.2)	1939 (18.1)	−0.002	
Sex								
Men	10 732 (57.8)	3060 (59.1)	0.026	.10	10 781 (58.1)	2998 (57.9)	−0.003	.88
Women	7841 (42.2)	2120 (40.9)			7792 (41.9)	2182 (42.1)		
Race/ethnicity								
White	13 754 (74.1)	3854 (74.4)	0.008	.64	13 756 (74.1)	3873 (74.8)	0.016	.64
Black	1904 (10.2)	540 (10.4)	0.006		1930 (10.4)	587 (11.3)	0.030	
Others[a]	2915 (15.7)	786 (15.2)	−0.014		2887 (15.5)	720 (13.9)	−0.047	
Charlson comorbidity score								
0	10 005 (53.9)	2530 (48.8)	−0.101	<.001	9817 (52.9)	2759 (53.2)	0.008	.93
1	4357 (23.4)	1218 (23.5)	0.001		4346 (23.4)	1195 (23.1)	−0.008	
≥2	4211 (22.7)	1432 (27.7)	0.115		4410 (23.7)	1226 (23.7)	−0.002	
Insurance status								
Medicare	8574 (46.1)	2470 (47.7)	0.030	<.001	8624 (46.4)	2373 (45.8)	−0.012	.73
Medicaid	888 (4.8)	338 (6.5)	0.076		973 (5.2)	303 (5.8)	0.027	
Private	7999 (43.1)	2106 (40.7)	−0.049		7904 (42.6)	2231 (43.1)	0.010	
Others	1112 (6.0)	266 (5.1)	−0.037		1072 (5.8)	273 (5.3)	−0.022	
Teaching hospital								
No	9582 (51.6)	2093 (40.4)	−0.226	<.001	9059 (48.8)	2228 (43.0)	−0.116	.40
Yes	8991 (48.4)	3087 (59.6)			9514 (51.2)	2952 (57.0)		
Hospital bed size								
<300	4668 (25.1)	1098 (21.2)	−0.093	<.001	4469 (24.0)	1044 (20.1)	−0.094	.74
300-500	6817 (36.7)	1707 (32.9)	−0.079		6699 (36.1)	2009 (38.8)	0.056	
>500	7088 (38.2)	2375 (45.9)	0.156		7405 (39.9)	2127 (41.1)	0.024	
Hospital location								
Rural	1517 (8.2)	246 (4.8)	−0.139	<.001	1365 (7.4)	275 (5.3)	−0.084	.25
Urban	17 056 (91.8)	4934 (95.2)			17 208 (92.6)	4905 (94.7)		
Surgery years								
2003-2007	6883 (37.0)	447 (8.6)	−0.720	<.001	5714 (30.7)	1482 (28.6)	−0.047	.83
2008-2011	7087 (38.2)	1681 (32.5)	−0.120		6826 (36.7)	1915 (37.0)	0.004	
2012-2015	4603 (24.8)	3052 (58.9)	0.738		6033 (32.6)	1783 (34.4)	0.041	

[a] Included Hispanic, other, and unknown.

radical nephrectomy. Prolonged length of stay was less frequent in the robotic-assisted vs the laparoscopic radical nephrectomy group (21.2% vs 25.1%; risk difference, −3.9%; 95% CI, −5.2% to −2.7%). However, the IPTW-adjusted rates of any or major complications, blood transfusion, and prolonged length of stay were similar between the robotic-assisted and laparoscopic radical nephrectomy groups. The IPTW-adjusted rate of prolonged operating time for patients undergoing robotic-assisted radical nephrectomy was higher than for patients receiving laparoscopic radical nephrectomy (46.3% vs 25.8%; risk difference, 20.5%; 95% CI, 14.2% to 26.8%).

An unadjusted cost comparison by surgical approach is presented in the eTable 2 in the Supplement. The IPTW-adjusted analysis suggests that robotic-assisted radical nephrectomy was associated with higher mean 90-day direct hospital costs ($19530 vs $16851; difference, $2678; 95% CI, $838 to $4519), likely accounted for by higher operating room ($7217 vs $5378; difference, $1839; 95% CI, $1050 to $2628) and supply costs ($4876 vs $3891; difference, $985, 95% CI, $473 to $1498; **Table 3**). Further analyses were performed to identify the association of the source of cost obtained by the Premier data set (reported vs estimated) and the difference in direct hospital costs between robotic-assisted and

Figure. Trends of Open, Laparoscopic, and Robotic-Assisted Radical Nephrectomy in the United States, 2003 to 2015



Numbers below each year represent the total number of patients receiving radical nephrectomy.

Table 2. Unadjusted and Adjusted Risk Ratios and Absolute Risk Differences for Perioperative Outcomes in Patients Undergoing Laparoscopic and Robotic Radical Nephrectomy, 2003-2015

	No. of Events (%)			
	Laparoscopic (n = 18 573)	Robotic (n = 5180)	Absolute Risk Difference (95% CI), %	Risk Ratio (95% CI)
Unadjusted				
Any postoperative complication[a]	4074 (21.9)	1461 (28.2)	6.3 (4.9 to 7.6)	1.29 (1.22 to 1.35)
Major postoperative complications[a]	674 (3.6)	223 (4.3)	0.7 (0.1 to 1.3)	1.19 (1.02 to 1.38)
Operating time (>4 h)	4868 (26.2)	2270 (43.8)	17.6 (16.1 to 19.1)	1.67 (1.61 to 1.74)
Blood transfusion (packed red blood cells)	3373 (18.2)	1011 (19.5)	1.4 (1.4 to 2.6)	1.08 (1.01 to 1.44)
Length of hospital stay (>4 d)	4663 (25.1)	1097 (21.2)	−3.9 (−5.2 to −2.7)	0.84 (0.80 to 0.89)
Adjusted by Inverse Probability of Treatment Weighting[b]				
Any postoperative complication[a]	4347 (23.4)	1149 (22.2)	−1.2 (−5.4 to 3.0)	0.95 (0.78 to 1.15)
Major postoperative complications[a]	709 (3.8)	183 (3.5)	−0.3 (−1.0 to 0.5)	0.93 (0.75 to 1.16)
Operating time (>4 h)	4794 (25.8)	2398 (46.3)	20.5 (14.2 to 26.8)	1.79 (1.52 to 2.11)
Blood transfusion (packed red blood cells)	3310 (17.8)	1098 (21.2)	3.4 (−0.6 to 7.3)	1.19 (0.98 to 1.44)
Length of hospital stay (>4 d)	4593 (24.7)	1253 (24.2)	−0.5 (−3.6 to 2.5)	0.98 (0.86 to 1.11)

[a] Postoperative complications were defined as any (Clavien grades 1-5) or major (Clavien grades 3-5).

[b] Adjusted for age, sex, race, Charlson comorbidity index, insurance status, teaching status, number of beds, hospital location, surgery year, and hospital clustering.

laparoscopic radical nephrectomy (**Table 4**). The 90-day direct hospital ($19 471 vs $16 779; difference, $2692; 95% CI, $787 to $4597), supply ($4905 vs $3999; difference, $906; 95% CI, $289 to $1524), and operating room costs ($7022 vs $5265; difference, $1758; 95% CI, $869 to $2647) were higher for robotic-assisted radical nephrectomy among patients treated at hospitals providing reported costs. Among patients receiving care from hospitals providing estimated costs using MCCR, robotic-assisted radical nephrectomy was associated with higher supply costs ($4728 vs $3474; difference, $1254; 95% CI, $136 to $2373) and operating room costs ($7589 vs $5810; difference, $1779; 95% CI, $227 to $3331) but similar 90-day direct hospital cost compared with laparoscopic radical nephrectomy ($19 187 vs $17 112; difference, $2075; 95% CI, −$1288 to $5439).

Discussion

In this retrospective cohort study evaluating patients undergoing robotic-assisted or laparoscopic radical nephrectomy for renal mass in the United States between 2003 and 2015, use of robotic-assisted surgery increased from 1.5% to 27.0% for the entire radical nephrectomy cohort. Compared with laparoscopic radical nephrectomy, robotic-assisted radical nephrectomy was not associated with an increased risk of any or major postoperative complications but was associated with prolonged operating time and higher hospital costs.

The use of the robotic platform has increased rapidly for curative renal surgery, especially for partial nephrecto-

Table 3. Adjusted Cost Comparison by Surgical Approach, 2003-2015

Services[a]	Costs, Mean (95% CI), US $ Laparoscopic (n = 18 573)	Robotic (n = 5180)	Difference (95% CI)	P Value
Supply	3891 (3632 to 4150)	4876 (4377 to 5376)	985 (473 to 1498)	<.001
Room and board	4432 (4174 to 4691)	4262 (3691 to 4833)	−170 (−743 to 401)	.56
Pharmacy	1132 (994 to 1270)	1103 (934 to 1272)	−29 (−207 to 150)	.75
Operating room	5378 (5081 to 5676)	7217 (6379 to 8055)	1839 (1050 to 2628)	<.001
90-d Direct hospital	16 851 (16 209 to 17 494)	19 530 (17 617 to 21 443)	2678 (838 to 4519)	.004

[a] Adjusted for age, sex, race, Charlson comorbidity index, insurance status, teaching status, number of beds, hospital location, surgery year, and hospital clustering.

Table 4. Cost Comparison Analysis by the Source of Cost Data, 2003-2015

Services	Costs, Mean (95% CI), US $[a] Laparoscopic (n = 14 679)	Robotic (n = 3958)	Difference (95% CI)	P Value
Reported Costs (Procedural)				
Supply	3999 (3694 to 4303)	4905 (4320 to 5491)	906 (289 to 1524)	.004
Room and board	4346 (4053 to 4640)	4290 (3623 to 4957)	−57 (−702 to 589)	.86
Pharmacy	1154 (982 to 1325)	1138 (1016 to 1259)	−16 (−175 to 143)	.85
Operating room	5265 (4921 to 5608)	7022 (6083 to 7961)	1758 (869 to 2647)	<.001
90-d Direct hospital	16 779 (16 042 to 17 516)	19 471 (17 488 to 21 454)	2692 (787 to 4597)	.006
Estimated Costs (MCCR)				
Supply	3474 (3051 to 3896)	4728 (3557 to 5898)	1254 (136 to 2373)	.03
Room and board	4767 (4256 to 5278)	4095 (3491 to 4699)	−672 (−1457 to 113)	.09
Pharmacy	1043 (897 to 1189)	968 (586 to 1351)	−74 (−436 to 287)	.69
Operating room	5810 (5234 to 6387)	7589 (5797 to 9382)	1779 (227 to 3331)	.03
90-d Direct hospital	17 112 (15 891 to 18 333)	19 187 (15 620 to 22 754)	2075 (−1288 to 5439)	.23

Abbreviation: MCCR, Medicare cost-to-charge ratios.

[a] Adjusted for age, sex, race, Charlson comorbidity index, insurance status, teaching status, number of beds, hospital location, surgery year and hospital clustering.

mies. However, little is known about the nationwide use of robotic-assistance for radical nephrectomy in the United States. Some studies have suggested that the proportion of robotic-assisted cases was less than 10% of all radical nephrectomies during the late 2000s.[13,27] In contrast, this study found that the proportion of robotic-assisted radical nephrectomies increased to approximately 30% of all radical nephrectomies by 2015, which is higher than for the laparoscopic approach in the United States. A parallel decrease in the use of laparoscopic radical nephrectomy suggests a shift to robotic surgery from cases that would have been previously treated laparoscopically rather than by open surgery.

It remains unclear why the use of robotic-assistance has increased substantially and has been steadily replacing laparoscopic radical nephrectomies. One possibility is the financial viability of the robotic system in relatively small hospitals. The costs of purchasing and maintaining the robotic system range from $0.5 to $2.5 million and $80 000-$170 000 per year , respectively.[28] Surgeons have to perform at least 100 to 150 procedures annually to offset the upfront and ongoing costs of its acquisition.[29] Another possibility is that the increase in robotic-assisted radical nephrectomies might be associated with the known increase in robotic-assisted partial nephrectomies. The use of robotic-assistance has increased rapidly since 2008 and in some areas has overtaken laparoscopic partial nephrectomy.[27,30] This trend suggests an overall increase in the risk of intraoperative conversion to radical nephrectomy as surgeons attempt to treat larger and more complex tumors using the nephron-sparing approach.[31] Considering that the incidence of intraoperative robotic-assisted partial to radical nephrectomy conversion remains prevalent especially for low-volume hospitals and surgeons in the United States, the increase in unsuccessful robotic-assisted partial nephrectomies may have contributed to the increase in robotic-assisted radical nephrectomy use.[32] As urological training has been focused on robotic surgery driven predominantly by the widespread use of robotic-assisted radical prostatectomy (more than 80% of the total prostatectomies in the United States in 2013), urologists completing their residency or fellowship training may also prefer the robotic platform over laparoscopic surgery due to its ergonomic console and 3-dimensional screen.[6]

Although the use of the robotic platform has been well-received by surgeons performing laparoscopic partial nephrectomy due to ease of tumor resection and renorrhaphy, the evidence supporting the use of robotic-assistance for radical nephrectomy remains somewhat biased. Radical nephrectomy does not require the routine use of intracorporeal suturing, which is a primary advantage of robotic assistance in partial nephrectomy and radical prostatectomy. Furthermore, there are several disadvantages of robotic technology scarcely acknowledged by prior literature. For example, robot arms return minimal tactile feedback to the surgeon. Moreover, the field of view during robotic-assisted radical nephrectomy is relatively narrow. Therefore, special attention is required to prevent unintentional trauma to peripheral organs not felt or visualized by the surgeon.[10]

There is also a significant cost burden attributed to the use of the robotic system. This study shows that the use of the robotic platform for radical nephrectomy increased the total direct hospital cost by nearly $2700, which is more than 15% of the total cost of the laparoscopic approach. This increased expense for robotic-assisted radical nephrectomy was mostly accounted for by increased operating room cost, which is directly correlated with operating time. These findings are consistent with the observations of a study from Maryland that reported a $5111 increase in hospital charges per robotic-assisted radical nephrectomy compared with laparoscopic radical nephrectomy.[33] Hospitals are likely to increase charges for robotic surgery to recoup costs related to the acquisition and maintenance of the robotic system despite not receiving reimbursement for these fixed costs from Medicare and private insurers.[34] Increased hospital charges for robotic surgery influence future reimbursement because the Centers for Medicare & Medicaid Services (CMS) use hospital charges to calculate the relative weight for each diagnosis related group (DRG) annually, which in turn help determine the payment made for inpatient services. The DRG weight is determined by the average resources required to treat cases within the DRG and is multiplied by the average payment rate for a typical case to yield the total reimbursement rate.[35] Thus, hospitals are incentivized to charge payers for the true cost of robot use. A prior study estimates an additional cost to the health care system of $2.5 billion if conventional surgeries were to be fully replaced by robotic surgery.[7]

As for the acquisition, maintenance, and replacement of the robot, the attainment of these costs remains challenging. The true cost of the robot varies based on factors such as the number of robotic cases being performed by each hospital, nonurological use of the robot technology, the type of robotic system being used, specific price negotiations between the hospital and robot company, and likely other variables as well. Thus, the fixed costs of the robot cannot be accurately determined by this database.

Robotic surgery was associated with higher 90-day direct hospital costs (>$2692) for hospitals providing reported costs, though not for hospitals providing MCCR-estimated costs. Although CMS uses hospital charges to estimate the relative cost of treating patients, charges tend to vary among hospitals according to size, location, payer mix, and for-profit status.[36,37] Given the potential for variability using the latter process, hospitals have been encouraged to adopt an internal cost-measurement system.[38] Therefore, the higher costs for robotic surgery observed for patients from hospitals providing reported costs may have greater clinical relevance and accuracy.

Robotic partial nephrectomy does have some advantages over traditional laparoscopic partial nephrectomy, including reduced ischemic time and total operating time. However, this study suggests that the traditional advantages of robotic surgery are not applicable to radical nephrectomy when compared with conventional laparoscopy. Some high-volume surgeons also argue that robotic-assisted radical nephrectomy may be beneficial for treating advanced kidney cancer with vena cava tumor thrombus in a minimally invasive manner.[39] However, that does not adequately explain the rapid increase in robotic-assisted radical nephrectomy within the United States because these advanced kidney cancers have been largely treated by the open approach. Although the initial results of safety and short-term oncological outcomes are promising, further investigation is required to determine the role of robotic surgery for vena cava tumor thrombectomy.

Limitations

This study has several limitations. First, it is subject to potential misclassification bias as billing codes and *ICD-9* procedural codes were used to capture robotic-assisted surgeries. However, previous studies using the same method showed that *ICD-9* coding for robotic-assisted surgery was sufficiently specific.[6,8,17] Second, the Premier Healthcare database does not publish information regarding tumor characteristics. Large or complex renal tumors, such as hilar and endophytic tumors, increase the risk for perioperative complications during laparoscopic surgery, although more notably for partial nephrectomy.[40] The influence of tumor characteristics is likely negligible for both robotic-assisted and laparoscopic radical nephrectomy because they are both minimally invasive and have similar clinical indications. Third, because the rate of conversion to open radical nephrectomy is difficult to evaluate retrospectively, the rates of conversion could not be compared between the 2 approaches using the Premier Healthcare database. Fourth, long-term data are necessary to further compare oncological outcomes and quality of life between robotic-assisted and laparoscopic radical nephrectomy.

Conclusions

Among patients undergoing radical nephrectomy for renal mass between 2003 and 2015, the use of robotic-assisted surgery increased substantially. The use of robotic-assistance was not associated with increased risk of any or major complications but was associated with prolonged operating time and higher hospital costs compared with laparoscopic surgery.

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