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ORIGINAL ARTICLE

Open versus robot-assisted radical cystectomy: 30-day perioperative comparison and predictors for cost-to-patient, complication, and readmission

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Abstract

The objectives of this study are to evaluate if robotic cystectomy demonstrates reduced complications, readmissions, and cost-to-patient compared to open approach 30-day post-operatively, and to identify predictors of complication, readmission, and cost-to-patient. This retrospective cohort study analyzed 249 patients who underwent open ($n = 149$) or robotic ($n = 100$) cystectomy from 2009 to 2015 at our institution. Outcomes included 30-day post-operative complication, readmission, and cost-to-patient charges. We used modified Clavien–Dindo/MSKCC classifications. Multivariable logistic and linear regression models were used to evaluate associations to outcomes and to build predictive models. Patient, clinical, and surgical characteristics differed by open and robotic groups, respectively, only for estimated blood loss (median: 600 versus 150 cc, $p < 0.01$), operative time (mean: 6.19 versus 6.85 h, $p < 0.01$), and length of stay (median: 7 versus 5 days, $p < 0.01$). Complication: frequency of patients with at least one 30-day complication was 85% compared to 66% ($p < 0.01$). Minor gastrointestinal and bleeding complications were increased in the open group (50% versus 41%, $p = 0.01$; 52% versus 11%, $p < 0.01$, respectively). Fifty percent of patients required blood transfusion in open compared to 11% ($p < 0.01$). Patients in the open group experienced more major complications (19% versus 10%, $p = 0.04$). Robotic approach was a predictor for fewer complications (OR 0.44, 95% CI 0.20–0.99, $p = 0.049$). Readmission: no significant difference in number of patients readmitted was found. Cost-to-patient: Robotic approach predicted an 18% reduction in total cost-to-patient compared to open approach ($p < 0.01$). Robotic cystectomy demonstrated reduced total cost-to-patient when taking into account all 30-day post-operative services with fewer complications compared to open cystectomy.

Keywords Bladder cancer · Robotic cystectomy · Open cystectomy · Cost · Complications · Readmissions

Introduction

Bladder cancer is the tenth most common incident cancer in the U.S. and the fourth most common in men [1]. Approximately 74,000 new cases are diagnosed in the U.S. each year. For those over the age of 79 years, it is one of the top five causes of cancer deaths [1]. The cost of managing this disease remains one of the more expensive cancers for patients and health systems [2, 3]. One factor contributing to high cost is complications that may lead to readmission after cystectomy [4, 5].

Open radical cystectomy (ORC) is the current standard of care for surgical treatment of bladder cancer, but the prevalence of robotic-assisted radical cystectomy (RARC) has grown in the past decade with its utilization still being clarified [6]. Amidst an evolving health system with limited

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resources and an aging population, further investigation is necessary into which surgical approach, risk factors, and other modifiable targets could reduce costs, improve population health, and enhance patient experience.

Our study aims to inform financial and clinical comparisons between the current standard of care and the newest adopted technology. The combined analysis of both detailed clinical and cost-to-patient data makes this study unique. Given the high number of incident cases annually, cost savings from implementing a long-term financially favorable surgical approach in the appropriate regional setting could provide substantive savings over time.

Patients and methods

Study design

This retrospective cohort study compares complication and readmission frequencies in addition to cost-to-patient charges of robotic-assisted radical cystectomy (RARC) versus open radical cystectomy (ORC). In addition, it identifies predictors of these three outcomes.

Patients and data source

We used an institutional database compiled from electronic medical records of all patients who underwent either RARC ($n=100$) or ORC ($n=149$) for muscle-invasive bladder cancer from January 2009 to December 2015 at Oregon Health and Science University (OHSU). We combined this clinical database with cost-to-patient charge data from OHSU Billing (Supplemental Figure 1). Patients chose their surgical approach based upon personal preference as indications for either are identical [7]. Patient's then sought care from either of two available urologic oncologists. One of three surgeons performed 98% of all robotic cystectomies, while two of six surgeons performed 94% of all open cystectomies. Patients excluded from analyses had partial cystectomies or other procedures concomitant with radical cystectomy. Data abstractors were blinded to surgical approach and outcomes. This study obtained OHSU Institutional Review Board approval (#10437).

Measurements

Primary exposure: open radical cystectomy or robotic-assisted radical cystectomy

Outcomes within 30-day post-surgery:

1. Development of at least one cystectomy-related complication
2. Total and service-specific cost-to-patient charges
3. Development of at least one cystectomy-related hospital readmission

Surgery, comorbidity scoring, and complication grading

Patients underwent radical cystectomy with bilateral pelvic lymphadenectomy to the level of common iliac arteries whenever possible, followed by extracorporeal urinary diversion [ileal conduit (IC), neobladder (NB), or continent cutaneous diversion (CCD)].

Pre-operative comorbidity was quantified using Charlson Comorbidity Score (CCS) [8]. Post-operative complication grading was measured using modified Clavien–Dindo classification [9]. Complications were further grouped into 11 subcategories using the Memorial Sloan-Kettering Cancer Center (MSKCC) system [10].

Cost-to-patient

Cost-to-patient was defined as dollar amount charged consistently for services rendered. We grouped cost-to-patient charges into four service categories (Operative, Diagnostic, Hospital, Other) and then into various subcategories.

Statistical analysis

Categorical variables are reported using absolute and relative frequencies. Chi-squared tests, including Cochran–Armitage test, evaluated the association between categorical variables. Continuous variables approximately normally distributed are reported using mean and standard deviation. Two-sample *t* tests compared those variables. Continuous variables not normally distributed are reported using median and interquartile range (IQR). Wilcoxon Rank Sum test compared differences in these distributions.

Univariate and multivariable logistic regression models determined predictive variables for both analyses of complication and readmission, separately. Univariate and multivariable linear regression models determined predictive variables for cost-to-patient.

We utilized Stata software for all analyses (StataCorp, v13.1, College Station, TX).

Results

One hundred and forty-nine patients received ORC and 100 patients received RARC. Tables 1 and 2 display patient, clinical, and surgical characteristics. Characteristics were similar between groups except for estimated blood loss (EBL) (median: 600 cc (open) versus 150 cc (robot), $p<0.01$),

Table 1 Patient and clinical characteristics of patients undergoing either open or robotic cystectomy

	Open $n=149$	Robot $n=100$	p value
Patient characteristics			
Age in years, no. (%)[a]			0.24
< 50	5 (3)	5 (5)	
50–59	21 (14)	12 (12)	
60–69	55 (36)	34 (12)	
70–79	55 (36)	31 (31)	
≥ 80	13 (9)	18 (18)	
Female, no. (%)[b]	42 (28)	16 (16)	0.03*
Caucasian, no. (%)[b]	144 (97)	100 (100)	0.06
Smoking history, no. (%)[b]	113 (76)	79 (79)	0.56
Living location, no. (%)[b]			0.71
Urban	65 (44)	46 (46)	–
Rural	84 (56)	54 (54)	–
Clinical characteristics			
Charlson Comorbidity Score (mean ± SD)[c]	3.9 (±1.9)	3.7 (±2)	0.62
Pre-operative BMI, kg/m^2 (mean ± SD)[c]	28.2 (±5.7)	27.8 (±5.2)	0.58
Prior pelvic radiation, no. (%)[b]	12 (8)	13 (13)	0.20
Neoadjuvant chemotherapy, no. (%)[b]	38 (26)	23 (23)	0.65
Prior abdominal surgery, no. (%)[b]	75 (50)	52 (52)	0.80
Clinical stage, no. (%)[a]			0.24
cT0/Ta/Tcis	5 (3)	8 (8)	
cT1	36 (24)	30 (30)	
cT2	98 (66)	56 (56)	
cT3	2 (1)	1 (1)	
cT4	3 (2)	4 (4)	
Unavailable	5 (3)	1 (1)	
Value of pre-operative labs (mean ± SD)[c]			
Creatinine, mg/dL	1.1 (±0.46)	1.12 (±0.43)	0.75
Hematocrit, %	38.29 (±6.3)	38.7 (±4.8)	0.61

IQR interquartile range

*Statistically significant $p < 0.05$

[a]Cochran–Armitage test

[b]Chi-square

[c]*t* test

operative time (mean: 6.19 versus 6.85, $p<0.01$), and length of stay (LOS) (median: 7 days versus 5 days, $p=0.01$). Mortality for the open group was 2% (3/149) compared to 1% (1/100) for the robotic group ($p=0.65$).

Complication

Crude complication estimates

Tables 3, 4, and 5 present the frequencies of recorded complications. The frequency of patients with at least one 30-day complication was 86% for open compared to 66% for robot ($p<0.01$). Significantly more patients in the open group had at least one 30-day minor complication (85% versus 66%, $p<0.01$) and at least one grade 2–5 complication (69 versus 42%, $p<0.01$). Minor gastrointestinal and bleeding complications were significantly increased in the open group (50 versus 41%, $p=0.01$; 52% versus 11%, $p<0.01$, respectively). Fifty percent of open patients required blood transfusion compared to only 11% in the robotic group ($p<0.01$).

Major complications were more common in the open group (19% versus 10%, $p=0.04$). No significant differences in frequency of individual major complication MSKCC categories existed between groups.

Table 2 Surgical characteristics of patients undergoing either open or robotic cystectomy

Surgical characteristics	Cystectomy approach		p value
	Open $n=149$	Robot $n=100$	
Estimated blood loss, cc (median (IQR))[a]	600 (350–1200)	150 (100–250)	< 0.01*
Operating time, h (mean ± SD)[b]	6.19 (± 1.7)	6.85 (± 1.16)	< 0.01*
Length of stay, days (median (IQR))[a]	7 (5–8)	5 (4–8)	< 0.01*
Diversion type no. (%)[c]			0.12
Ileal conduit	110 (74)	84 (84)	
Neobladder	37 (25)	16 (16)	
Continent cutaneous diversion	2 (1)	0 (0)	
Pathological tumor stage, no. (%)[c]			0.77
pT0/Ta/Tis	45 (30)	28 (28)	
pT1	11 (7)	9 (9)	
pT2	17 (11)	15 (15)	
pT3	62 (42)	33 (33)	
pT4	14 (9)	15 (15)	
Pathological nodal stage, no. (%)[c]			0.07
Nx	1 (1)	0 (0)	
N0	96 (64)	75 (75)	
N1	14 (9)	9 (9)	
N2	18 (12)	8 (8)	
N3	20 (13)	8 (8)	
Pathological metastatic stage, no. (%)[c]			0.31
Mx	85 (57)	65 (65)	
M0	60 (40)	35 (35)	
M1	3 (1)	0 (0)	

IQR interquartile range

*Statistically significant $p < 0.05$

[a]Wilcoxon rank sum

[b]*t* test

[c]Cochran-Armitage test

Table 3 Thirty-day post-operative complications by grade (modified Clavien–Dindo) and type (MSKCC) for open ($n=149$) and robotic ($n=100$) cystectomies

Complication category, %	Grade 1		Grade 2		Grade 3		Grade 4		Grade 5	
	Open	Robot	Open	Robot	Open	Robot	Open	Robot	Open	Robot
Gastrointestinal	27	15	23	26	4	5	0	0	0	0
Infectious	0	1	14	17	< 1	3	5	2	< 1	1
Wound	6	0	3	4	3	4	0	0	0	0
Genitourinary	12	11	1	0	3	2	1	1	0	0
Cardiac	2	3	5	1	< 1	1	2	0	0	0
Pulmonary	1	0	2	3	0	0	< 1	0	0	0
Bleeding	0	0	52	11	0	0	< 1	0	0	0
Thromboembolic	0	0	0	0	0	0	0	0	< 1	0
Neurological	2	3	< 1	1	0	0	< 1	1	< 1	0
Miscellaneous[a]	7	6	2	2	1	1	1	0	0	0
Surgical	0	0	0	0	2	1	0	0	0	0
Overall[b]	Robot 66%, Open 86%, $p<0.01$*									

*Statistically significant $p < 0.05$

[a]Miscellaneous includes dehydration, acidosis, or other rare complications not appropriate in other categories

[b]Chi-square

Table 4 Thirty-day post-operative complications for grades 2–5 for open ($n = 149$) and robotic ($n = 100$) cystectomies

Complication category, %	Grades 2–5		
	Open	Robot	p value[a]
Gastrointestinal	28%	31%	0.57
Infectious	32	30	0.89
Wound	5	8	0.44
Genitourinary	6	3	0.37
Cardiac	8	2	0.05
Pulmonary	3	3	1.00
Bleeding	52	11	< 0.01*
Thromboembolic	9	4	0.14
Neurological	2	2	1.00
Miscellaneous[b]	5	3	0.74
Surgical	2	1	0.65
Overall	69%	42%	< 0.01*

*Statistically significant $p < 0.05$

[a]Chi-square

[b]Miscellaneous includes dehydration, acidosis, or other rare complications not appropriate in other categories

Univariate analysis: complication

Robotic approach was significantly associated with decreased odds of having a complication within 30 day post-operatively ($p < 0.04$) (Supplemental Table 1A).

Adjusted complication estimates

Multivariable analysis: complication In the final multivariable model, robotic approach was a significant predictor for at least one complication within 30 day post-surgery (OR 0.44, $p = 0.049$) (Table 6). Other significant variables in the final multivariable model include clinical stage T2 (OR 5.66, $p = 0.02$) (overall clinical stage, $p = 0.11$) and length of stay (OR 1.41, $p = 0.01$). No clinically meaningful effect modifiers were identified. No specific confounders were explored given that during multivariable model building, potential confounders were already included in the model.

Readmission

Crude readmission estimates

There was no significant difference in the number of patients readmitted at least one time within 30 days following cystectomy in the open group (31%) compared to robotic group (27%) ($p = 0.51$).

Univariate analysis: readmission

Surgical approach was not significantly associated with having at least one readmission within 30 days following cystectomy (OR 0.83, $p = 0.51$) (Supplemental Table 1B).

Table 5 Thirty-day post-operative minor (grades 1–2) and major (grades 3–5) complications for open ($n = 149$) and robotic ($n = 100$) cystectomies

Complication category, %	Grades 1–2 Minor complications			Grades 3–5 Major complications		
	Open	Robot	p value[a]	Open	Robot	p value[a]
Gastrointestinal	50%	41%	0.01*	4%	5%	0.76
Infectious	14	18	0.48	6	6	1.00
Wound	9	4	0.20	3	4	0.72
Genitourinary	13	11	0.70	4	3	0.74
Cardiac	7	4	0.42	3	1	0.65
Pulmonary	3	3	1.00	< 1	0	1.00
Bleeding	52	11	< 0.01*	< 1	0	1.00
Thromboembolic	0	0	–	< 1	0	1.00
Neurological	3	4	0.72	1	1	1.00
Miscellaneous[b]	9	8	1.00	3	1	0.65
Surgical	0	0	–	2	1	0.65
Overall	85%	66%	< 0.01*	19%	10%	0.04*

*Statistically significant $p < 0.05$

[a]Chi-square

[b]Miscellaneous includes dehydration, acidosis, or other rare complications not appropriate in other categories

Table 6 Multivariable logistic regression model for predictors of 30-day post-cystectomy complication following either open or robotic cystectomy ($n = 236$), $p < 0.01$*

	Odds ratio	*p* value	95% CI lower limit	95% CI upper limit
Dichotomous variables				
Surgical group				
Open cystectomy	Reference	–	–	–
Robotic cystectomy	0.44	0.049*	0.20	0.99
Prior chemotherapy	1.17	0.76	0.42	3.29
Polychotomous variables				
Clinical stage		0.11		
Ta/Tcis	Reference	–	–	–
T1	2.87	0.14	0.71	11.55
T2	5.66	0.02*	1.39	23.03
T3	2.36	0.65	0.06	99.3
T4	14.84	0.12	0.51	435.67
Pathological T stage		0.65		
Ta/Tcis/T0	Reference	–	–	–
T1	0.58	0.39	0.16	2.03
T2	0.48	0.19	0.16	1.43
T3	0.83	0.69	0.33	2.09
T4	1.04	0.96	0.26	4.12
Urinary diversion type		0.31		
Ileal conduit	Reference	–	–	–
Neobladder	2.40	0.13	0.78	7.35
Continent cutaneous	1.70	0.32	0.07	42.70
Continuous variables				
Length of stay	1.03	0.01*	1.06	1.61
Pre-operative creatinine	2.25	0.15	0.75	6.72
Charlson Comorbidity Score	1.12	0.28	0.91	1.38
Pre-operative hematocrit	0.97	0.49	0.90	1.05
Operative time	1.08	0.68	0.76	1.52

*Statistically significant $p < 0.05$

Thirteen patients with missing values (six Clinical stage and seven Pre-operative creatinine)

Adjusted readmission estimates

Multivariable analysis: readmission In the final multivariable model, robotic approach was not a significant predictor for at least one readmission within 30 days following cystectomy (OR 0.70, $p = 0.29$) (Table 7). Significant covariates predictive of readmission include urinary diversion type ($p < 0.01$) (neobladder, OR 4.05, $p < 0.01$), Charlson Comorbidity Score (OR 1.22, $p = 0.02$), pre-operative BMI (OR 1.07, $p = 0.02$), operating time (OR 1.37, $p = 0.01$), and length of stay (OR = 0.87, $p = 0.01$). No clinically meaningful effect modifiers were identified. No specific confounders were explored given that, during multivariable model building, potential confounders were already included in the model.

Cost-to-patient

Crude cost-to-patient estimates

Thirty-day cost-to-patient was significantly reduced in the robotic group versus open (median: $57,336 versus $69,976, $p < 0.01$) (Table 8). The Operative service category was not significantly different between surgical groups ($p = 0.10$), while the remaining three service categories (Diagnostic, Hospital, and Other) were significantly less in the robotic group compared to open (all $p < 0.01$). There were more Diagnostic service charges in the open group compared to the robotic group, but even when excluding this service category from comparison, the overall cost-to-patient remained significantly reduced for the robotic group (median: $52,368 versus $59,479, $p < 0.01$). Specifically, the open group had significantly more patients who had any imaging within 30-day

Table 7 Multivariable logistic regression model for predictors of 30-day post-cystectomy readmission following either open or robotic cystectomy ($n = 248$), $p < 0.01$*

	Odds ratio	*p* value	95% CI lower limit	95% CI upper limit
Dichotomous variables				
Surgical group				
Open cystectomy	Reference	–	–	–
Robotic cystectomy	0.70	0.29	0.36	1.37
Smoking history	0.56	0.12	0.27	1.15
Race, non-Caucasian	2.56	0.36	0.35	18.89
Prior abdominal surgery	1.38	0.30	0.75	2.55
Prior pelvic radiation	1.52	0.39	0.58	4.04
Polychotomous variables				
Urinary diversion type		< 0.01*		
Ileal conduit	Reference	–	–	–
Neobladder	4.05	< 0.01*	1.87	8.78
Continent cutaneous	0.22	0.38	0.01	6.26
Continuous variables				
Charlson Comorbidity Score	1.22	0.02*	1.04	1.45
Pre-operative BMI	1.07	0.02*	1.01	1.13
Operative time	1.37	0.01*	1.08	1.74
Length of stay	0.87	0.01*	0.79	0.97

*Statistically significant $p < 0.05$

One patient with missing values (one pre-operative BMI)

post-surgery (85%) compared to the robotic group (62%) ($p < 0.01$). Within the Hospital service category, Room & Board, Inpatient Medications, and Pharmacy subcategories all significantly contributed to increased cost-to-patient in the open group (all $p < 0.01$).

In Table 9, the frequencies and median total cost-to-patient are displayed for each surgical group. The frequency of open cystectomy is higher in later years, whereas the robotic group is more frequent in the early years. The cost-to-patient for the robotic group was significantly reduced in 4 out of the 7 years (2010–2013). Only, in 2015, did the open approach demonstrate a reduced median cost-to-patient compared to the robotic group ($p = 0.07$). Using a regression analysis and likelihood ratio test with surgical group and year of surgery included, year of surgery did not significantly affect cost-to-patient ($p = 0.73$).

Univariate analysis: cost-to-patient

Robotic approach was a significantly associated with a reduced cost-to-patient compared to open approach ($p < 0.01$) (Supplemental Table 1C).

Adjusted cost-to-patient estimates

Multivariable analysis: cost-to-patient Robotic approach was associated with approximately 18% reduction in cost-to-patient within 30-day post-cystectomy compared to open approach ($p < 0.01$) (Table 10). Age greater than 50 years was predictive of reduced cost-to-patient ($p = 0.03$). Pathological tumor stage ($p < 0.01$) (pT4, $p = 0.02$), Charlson Comorbidity Score ($p < 0.01$), pre-operative BMI ($p = 0.03$), operating time ($p < 0.01$), and length of stay ($p = 0.01$) were all predictive of increased total cost-to-patient. Other non-predictive covariates included in the model were prior chemotherapy, clinical stage, and urinary diversion type. No clinically meaningful effect modifiers were identified. No specific confounders were explored given that, during multivariable model building, potential confounders were already included in the model.

Discussion

In our analysis, robotic cystectomy demonstrates reduced gastrointestinal and bleeding complications, similar readmission frequency, and reduced cost-to-patient when assessing the 30-day post-cystectomy perioperative period compared to open cystectomy. Couple this with prior studies suggesting fewer complications and lower blood loss, robotic cystectomy is a strong alternative to the standard open cystectomy. This is particularly true in a high-volume setting when robotic costs are dispersed throughout institutional departments, especially after robot acquisition costs have been completed and maintenance contracts have leveled. In the long term, this may translate into overall savings.

Bladder cancer management is costly with frequent complications and readmissions

Bladder cancer is a common malignancy in the U.S. that is one of the most costly cancers to manage [3]. It has high post-operative morbidity ranging from 11 to 68% and readmission frequency up to 40% [3–5, 11, 12]. Currently, studies suggest that RARC may offer operative cost disadvantages compared to ORC due to the robot's high amortization, maintenance costs, and longer operating time [13–17]. This is of course only considering the time period when amortization is actively being paid and due. In contrast, some recent studies suggest the robot could have post-operative cost advantages over ORC due to fewer complications [18], lower blood loss [13, 19], lower transfusion rates [15], earlier return to bowel function [20], and shorter lengths of stay [14, 17–19, 21]. Importantly, similar oncologic outcomes comparing RARC and ORC have been shown [13, 20, 22].

Table 8 Thirty-day post-operative median cost-to-patient comparison between open and robotic cystectomies by overall and category-specific services rendered, excluding direct robot purchase, amortization, and maintenance cost

Service category	Service subcategory	Surgical group				*p* value
		Open ($n=149$)		Robot ($n=100$)		
		Median $ (IQR)	%	Median $ (IQR)	%	
Operative	OR services and supplies[a]	$32,502 (29,955–37,404)	100	$32,460 (28,328–36,255)	100	0.18
	Anesthesia[b]	6049 (5388–6875)	100	5641 (4921–6414)	100	< 0.01*
	Category total	$38,818 (35,415–44,169)		$38,247 (33,192–42,168)		0.10
Diagnostic	Laboratory	$4120 (2729–6043)	100	$1935 (1141–3121)	100	< 0.01*
	Pathology	4477 (3475–5428)	100	2630 (2146–3715)	100	< 0.01*
	Imaging	1024 (657–2102)	76	484 (270–1217)	51	< 0.01*
	Category total	$9718 (6588–12,623)		$5260 (4348–6804)		< 0.01*
Hospital	Room and board	$10,575 (8460–14,805)	98	$9093 (7268–12,360)	100	< 0.01*
	Inpatient medications	2701 (1947–4200)	100	1239 (859–2058)	100	< 0.01*
	Pharmacy fees	1958 (1263–2892)	100	1274 (721–2110)	100	< 0.01*
	PACU	1217 (838–1570)	86	1173 (770–1617)	99	0.94
	ICU	8900 (4741–14,675)	7	3838 (3365–30,649)	4	0.19
	GI services	1080 (–)	< 1	1337 (–)	1	0.32
	PT/OT	743 (0–1397)	70	550 (0–1001)	69	0.10
	Speech	725 (683–3575)	5	951 (504–2505)	3	0.91
	Respiratory	1914 (40–4263)	50	243 (0–2660)	31	0.04*
	Clinic	140 (117–280)	13	170 (117–280)	9	0.98
	Professional fees	263 (255–449)	30	255 (252–271)	16	0.16
	Emergency room	0	0	1381	1	–
	Category total	$18,980 (15,027–24,331)		$13,666 (11,035–19,456)		< 0.01*
Other	Blood products	$1755 (1142–2728)	52	$1109 (814–1610)	11	0.10
	Doppler/duplex	885 (831–1296)	28	831 (755–1030)	13	0.69
	Category total	$885 (0–2330)		$0 (0–0)		< 0.01*
Overall cost-to-patient		$69,976 (62,410–78,785)	–	$57,336 (50,757–66,664)	–	< 0.01*

Purchase, amortization, and maintenance contract costs of robot are dispersed across hospital-wide services and departments using the robot, and are not linked to any particular procedure

Excludes cardiology, EEG, dialysis services due to excess occurrences in open cases

*Statistically significant $p < 0.05$

[a]Staff, time, operating room space

[b]Staff, time, intraoperative medications, and fluids

Table 9 Median total cost-to-patient by surgical approach and year of cystectomy

Year	Open ($n=149$)			Robot ($n=100$)			*p* value
	Median $	IQR	*n* (%)	Median $	IQR	*n* (%)	
2009	72,116	–	1 (< 1)	71,290	60,832, 72,516	4 (4)	0.48
2010	72,139	61,372, 131,299	10 (7)[a]	56,614	48,563, 63,844	25 (25)[a]	< 0.01*
2011	74,035	67,676, 83,830	16 (11)	49,340	43,740, 58,905	15 (15)	< 0.01*
2012	73,561	62,116, 83,811	23 (15)	54,760	48,685, 59,521	18 (18)	< 0.01*
2013	66,502	58,809, 75,377	30 (20)	58,549	52,687, 64,970	20 (20)	0.01*
2014	71,939	64,717, 81,567	44 (30)[a]	61,896	55,261, 82,014	9 (9)[a]	0.08
2015	62,995	55,715, 72,395	25 (17)	76,536	61,241, 107,755	9 (9)	0.07

*Statistically significant difference between open and robotic cost-to-patient for given year

[a]Statistically significant difference in proportion of surgeries for given year ($p<0.01$ for 2010, 2014)

Table 10 Multivariable linear regression model for 30-day post-cystectomy log total cost-to-patient ($n=242$), $p<0.01$*, Adjusted $R^2=0.83$

	Coefficient	SE	*p* value	95% CI lower limit	95% CI upper limit
Dichotomous variables					
Surgical group					
Open cystectomy	Reference	–	–	–	–
Robotic cystectomy	− 0.18	0.02	< 0.01*	− 0.22	− 0.14
Prior chemotherapy	0.04	0.02	0.08	0	0.09
Polychotomous variables					
Age category			0.03*		
< 50	Reference	–	–	–	–
50–59	− 0.11	0.05	0.03*	− 0.22	− 0.01
60–69	− 0.10	0.05	0.04*	− 0.20	− 0.003
70–79	− 0.13	0.05	0.01*	− 0.23	− 0.03
≥ 80	− 0.18	0.06	< 0.01*	− 0.30	− 0.06
Clinical stage			0.88		
Ta/Tcis	Reference	–	–	–	–
T1	0.03	0.04	0.52	− 0.06	0.11
T2	0.02	0.04	0.57	− 0.60	0.11
T3	0.04	0.09	0.66	− 0.14	0.23
T4	− 0.02	0.07	0.73	− 0.16	0.11
Urinary diversion type			0.15		
Ileal conduit	Reference	–	–	–	–
Neobladder	0.01	0.03	0.76	− 0.04	0.06
Continent cutaneous	0.20	0.10	0.05*	0	0.40
Pathological T Stage			< 0.01*		
Ta/Tcis/T0	Reference	–	–	–	–
T1	− 0.06	0.04	0.13	− 0.13	0.02
T2	− 0.06	0.03	0.07	− 0.12	< 0.01
T3	− 0.01	0.02	0.55	− 0.06	0.03
T4	0.08	0.03	0.02*	0.02	0.14
Continuous variables					
Charlson Comorbidity Score	0.02	0.01	< 0.01*	0.01	0.04
Pre-operative BMI	0.004	< 0.01	0.03*	< 0.01	0.01
Log (operating time)[a]	0.31	0.05	< 0.01*	0.21	0.40
Length of stay	0.04	< 0.01	< 0.01*	0.04	0.05

Seven patients excluded for missing values (six clinical stage and one Pre-operative BMI)

[a]Log here is natural log

A recent systematic review suggested that RARC may provide overall cost reduction compared to ORC when reduced RARC post-operative complications were factored in [23], but more data are needed to assess this clouded relationship [2, 18, 23]. As such, our findings are consistent with other reports, and our study adds a unique perspective by excluding the amortization (only 5 years to finish payment at our institution) and maintenance costs of the robot, since they are, in our institution, hospital-wide costs and dispersed amongst all departments, and, therefore, would not be valid to include in the cost-to-patient charge comparison.

ORC complication estimates

While large variability exists in complication estimates due to non-uniform complication classifications used, an estimate of minor complications for patients undergoing ORC was reported to be approximately 30% by Chang et al. [24–27]. The risk for a major complication with this procedure is about 5% with mortality rate estimated to be 1–3% [24–27]. These findings likely underreport the true complication frequency due to the grading system used, whereas our study used both the modified Clavien–Dindo and MSKCC systems.

Studies report that some of the most common minor complications include anemia (~45%) [27] and ileus (~18–23%)

[24, 25]. Approximately 30% of patients require blood transfusions [24, 27]. Chang et al. demonstrated that increased perioperative blood loss and transfusion requirement correlate with delayed discharge and thus higher room and board cost [24]. These are consistent with our data, and it suggests strongly that the reduced complications with RARC seem to strongly influence a reduced cost-to-patient and minimize the number of interventions required in response to a complication.

RARC complication estimates

A study by Johar et al. specifically assessed complications after RARC and reported that 41% of patients experienced a complication within 30 days of surgery [28]. Over 80% of these patients only had low-grade complications (grade ≤ 2 using the modified Clavien–Dindo and MSKCC classification) [28]. Most common complications were gastrointestinal and 30-day mortality was 1.3% [28]. While variability does still exist among estimates from various studies, notice that these complication estimates are overall higher compared to earlier ORC estimates. This is largely attributed to the difference in classification systems used in the Chang et al. studies from the early 2000s [10]. Newer post-operative complication classification systems provide more accurate collection and, therefore, report higher numbers [10]. For the present study, the overall 30-day complication estimate was 66% of patients in the robotic group compared to 86% in the open group. This is clearly higher than other reports and again likely reflects our use of both the modified Clavien–Dindo and MSKCC systems.

Predictors of complications

Chang et al. found that requiring a blood transfusion was a risk factor for other minor complications ($p = 0.03$); however, an EBL of greater than 600 ml was not [25]. In the current study, blood transfusion was a grade 2 complication and EBL was directly correlated with the surgical approach. Therefore, neither blood transfusion nor EBL was included in the multivariable modeling, since surgical approach was the preceding event prior to either. This also minimized collinearity of the two covariates, thus allowing surgical approach to be clearly evaluated as a predictor. Length of stay was a significant predictor of having a complication, which, therefore, favors the surgical approach (i.e., robotic) with lower length of hospital stay, thus reducing the odds of a complication.

Predictors of readmission

Reported readmission rates are consistent between our study (~30%) and prior studies. Despite readmissions after cystectomy being common, risk factors have been challenging to identify [3–5, 11, 12, 29]. Compared to other urologic procedures with multiple risk factors identified, a few studies exist identifying risk factors after cystectomy [4, 29]. In studies that have identified risk factors reported age, being African American, receiving an orthotopic neobladder, discharging to a post-acute care facility, and patients with two or more comorbidities are more likely to be readmitted within 30 days following cystectomy [4, 30]. Our study confirms that receiving an orthotopic neobladder, having a higher CCS, and non-Caucasian race increases odds of readmission. In addition, we found higher pre-operative BMI and operative time and shorter length of stay to be significant predictors of readmission. Strategies to identify these risk factors for readmission are essential to optimize patient safety.

Cost-to-patient and robotic costs

Amortized and maintenance robot costs were not specifically included within the robotic operative charges for three reasons: (1) these data were specifically unavailable; (2) these costs are contracted and paid for by the entire hospital and dispersed amongst all departments that utilize the robot, not just Urology, and, as a result, (3) this study provides a direct charge-to-charge, service-to-service 30-day perioperative comparison of robotic and open surgical approaches.

While crude dollar comparison between studies and institutions is futile, the relative comparisons of open versus robotic costs (or costs-to-patient) are still valid and useful. Smith et al. compared fixed and variable costs of open versus robotic cystectomy while taking into account amortization of the robot during the perioperative period. Authors reported that the robotic approach costs $1640 higher than open (robot $16,248 versus open $14,608) [17]. This, however, does not take into account what the cost comparison would be after the period of amortization is complete, as our study simulates. In addition, the methods of that study do not explicitly state that hospital costs after surgery other than transfusion and length of stay were taken into account. Without doing so, a large portion of cost may have been unaccounted for during the perioperative period in the Smith study. In addition, in a systematic review by Lee et al., robotic cystectomy was shown to be less expensive than open cystectomy when complications were taken into account [23]. This is similar to our study where a large contributor of the cost increase for open cystectomy compared to robotic cystectomy appeared to be the length of stay. Leow et al. reported that robotic cystectomy added approximately $4236 per case largely due to supply cost, but this cost difference disappeared in high-volume centers

(≥ 19 cases per year) or for high-volume surgeons (≥ 7 cases per year), which satisfies the current study's criteria [21].

Predictors of cost-to-patient

We found robotic cystectomy to be predictive of reduced median total cost-to-patient compared to open approach. Despite similar operative service charges, the Diagnostic, Hospital, and Other service charges were significantly less expensive for robotic cystectomy. In addition, pT4 was predictive of an increased cost-to-patient compared to Ta/Tcis/T0. Lower pre-operative comorbidity, pre-operative BMI, operating time, and length of stay all predict lower median total cost-to-patient. Interestingly, age category was inversely related to cost-to-patient. As age increased above 50 years, the cost-to-patient decreased slightly, but significantly. The reason for this may be that the youngest patients with bladder cancer requiring cystectomy may intrinsically have more health service requirements given either genetically worse disease or long-term health needs that were unable to be detected with the CCS.

Limitations and considerations

Direct cost data may have been preferred but were not available. While cost-to-patient charge data do not allow direct inter-institutional comparisons, it still does allow valid intra-institutional analysis between the two surgical approaches. Therefore, cost-to-patient charge data are an appropriate surrogate of direct cost comparisons for this study.

Conclusion

Our study shows that robotic cystectomy can be a strong alternative to the current standard of care, open cystectomy, with reduced 30-day complication frequency, blood loss, need for transfusion, and length of hospital stay. The greater detail of complication grading and categorization utilized in our study provides more information to help anticipate expected complications for each surgical approach. In addition, robotic cystectomy was predictive of reduced odds of at least one 30-day complication occurring. In contrast, neither surgical approach was significantly associated with or predictive of 30-day post-operative readmission.

Ultimately, over the long-term as robotic amortization reaches maturity and maintenance contracts decrease with greater availability of robotic technology, robotic cystectomy may demonstrate a true overall cost-to-patient reduction compared to open cystectomy, particularly in a high-volume surgical center taking into account all 30-day post-operative service charges.

Compliance with ethical standards

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

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