Original Investigation

Effect of Regional Hospital Competition and Hospital Financial Status on the Use of Robotic-Assisted Surgery

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IMPORTANCE Despite the lack of efficacy data, robotic-assisted surgery has diffused rapidly into practice. Marketing to physicians, hospitals, and patients has been widespread, but how this marketing has contributed to the diffusion of the technology remains unknown.

OBJECTIVE To examine the effect of regional hospital competition and hospital financial status on the use of robotic-assisted surgery for 5 commonly performed procedures.

DESIGN, SETTING, AND PARTICIPANTS A cohort study of 221 637 patients who underwent radical prostatectomy, total nephrectomy, partial nephrectomy, hysterectomy, or oophorectomy at 1370 hospitals in the United States from January 1, 2010, to December 31, 2011, was conducted. The association between hospital competition, hospital financial status, and performance of robotic-assisted surgery was examined.

MAIN OUTCOMES AND MEASURES The association between hospital competition was measured with the Herfindahl-Hirschman Index (HHI), hospital financial status was estimated as operating margin, and performance of robotic-assisted surgery was examined using multivariate mixed-effects regression models.

RESULTS We identified 221 637 patients who underwent one of the procedures of interest. The cohort included 30 345 patients who underwent radical prostatectomy; 20 802, total nephrectomy; 8060, partial nephrectomy; 134 985, hysterectomy; and 27 445, oophorectomy. Robotic-assisted operations were performed for 20 500 (67.6%) radical prostatectomies, 1405 (6.8%) total nephrectomies, 2759 (34.2%) partial nephrectomies, 14 047 (10.4%) hysterectomies, and 1782 (6.5%) oophorectomies. Use of robotic-assisted surgery increased for each procedure from January 2010 through December 2011. For all 5 operations, increased market competition (as measured by the HHI) was associated with increased use of robotic-assisted surgery. For prostatectomy, the risk ratios (95% CIs) for undergoing a robotic-assisted procedure were 2.20 (1.50-3.24) at hospitals in moderately competitive markets and 2.64 (1.84-3.78) for highly competitive markets compared with noncompetitive markets. For hysterectomy, patients at hospitals in moderately (3.75 [2.26-6.25]) and highly (5.30; [3.27-8.57]) competitive markets were more likely to undergo a robotic-assisted surgery. Increased hospital profitability was associated with use of robotic-assisted surgery only for partial nephrectomy in facilities with medium-high (1.67 [1.13-2.48]) and high (1.50 [0.98-2.29]) operating margins. With analysis limited to patients treated at a hospital that had performed robotic-assisted surgery, there was no longer an association between competition and use of robotic-assisted surgery.

CONCLUSIONS AND RELEVANCE Patients undergoing surgery in a hospital in a competitive regional market were more likely to undergo a robotic-assisted procedure. These data imply that regional competition may influence a hospital's decision to acquire a surgical robot.

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Robotic-assisted surgery allows for the performance of a minimally invasive surgical procedure by a surgeon seated at a remote console. This technology was initially used for prostatectomy but has diffused to a number of other procedures.[1,2] Despite the rapid uptake of robotic-assisted surgery, the usefulness of the technology has been questioned.[1-3] For many procedures, particularly those in which other minimally invasive alternatives are already available, robotic-assisted surgery has not been shown to reduce complications or improve outcomes, but it is substantially more costly than other alternatives.[1,2,4]

The adoption of new procedures and technologies is often influenced by nonmedical factors. For robotic-assisted surgery, marketing to physicians, hospitals, and directly to patients is widespread and has contributed to the diffusion of the technology.[5] Likewise, hospital-level market factors, including regional competition and hospital financial status, have been demonstrated to influence the adoption of new technologies.[6,7] For robotic-assisted surgery, there is a strong rationale as to why both market competition and hospital financial status would influence use. Technologic innovations, such as the robotic platform, can be advertised by hospitals and may help to attract patients.[6-8] Because the cost of these technologies is substantial, financially distressed hospitals are unlikely to have the resources to allocate to large capital investments. Centers that invest in expensive technologies have a strong incentive to use the innovations.

To date, evidence describing how hospital contextual factors influence the use of robotic-assisted surgery is limited. We hypothesized that regional market factors, including competition and hospital financial status, were associated with use of robotic-assisted surgery. We examined the use of robotic-assisted surgery across 5 procedures and explored the importance of hospital contextual factors along with clinical and demographic characteristics in the utilization of robotic-assisted surgery.

Methods

Data Sources

We used the Nationwide Inpatient Sample (NIS) to identify patients who underwent robotic surgery from January 1, 2010, to December 31, 2011. The NIS is maintained by the Agency for Healthcare Research and Quality and includes a random sample of 20% of hospital discharges in the United States. The NIS collected data on approximately 8 million hospital stays from 45 states in calendar year 2010.[9] Study exemption was obtained from the Columbia University institutional review board.

Hospital Market Structure (HMS) file was linked to the NIS and used to ascertain data on regional market competition.[10] The HMS file contains variables describing competition and can be linked to the NIS using encrypted hospital identifiers. Data from the HMS are updated approximately every 3 years, and we therefore used those data from 2009.

Estimation of market competition relies on 2 factors: the definition of the market and the intensity of competition.[8,10] We used a variable radius market definition as our primary indicator of a market. A variable radius is an area around a hospital from which a given percentage of a hospital's patients are drawn. For each institution, the HMS calculates the distance between a hospital and the zip codes of patients who are served. The zip codes are then ranked and aggregated until 75% of a hospital's discharges are captured. The distance between the hospital and the last zip code is defined as the variable radius. We performed sensitivity analyses using a 90% variable radius (radius captures 90% of discharges) and fixed radius (15-mile radius) definitions.[10]

Our primary metric for competition was the Herfindahl-Hirschman Index (HHI). The HHI is used to evaluate mergers and acquisitions but has also been applied to other industries, including health care.[11-13] The HHI is calculated as the sum of the squared market share of each hospital in a given area multiplied by 10 000. A lower HHI indicates a more competitive marketplace. We used standard definitions of HHI: greater than 2500 was considered highly concentrated (noncompetitive); 1500 to 2500, moderately concentrated; 100 to 1500, unconcentrated and/or competitive; and less than 100, highly competitive.[13] Because there were very few hospitals with an HHI of less than 100, we considered an HHI of less than 1500 as a competitive market. The HMS file also contains the number of hospitals within a given market. We performed sensitivity analyses using the number of hospitals within a market as a definition of competition. This definition of a market relies on an aggregate area that captures 75% of a hospital's discharges.[10]

Hospital financial performance was analyzed using Medicare Cost Reports submitted annually to the Healthcare Cost Report Information System.[14,15] Our primary measure of profitability was operating margin, estimated as net revenue from patient care and operations less total operating expenses divided by net revenues derived from patient care and other operations. As a sensitivity analysis, we also explored total margin, net income divided by net patient revenue, and other income.[16,17] These measures were winsorized, setting values less than the 5th percentile at the 5th percentile and those above the 95th percentile at the 95th percentile.[16,17] Hospital fiscal data from the year prior to the index admission for surgery were used. The American Hospital Association database was used to determine safety-net hospital status.[18] We defined *safety-net hospitals* as centers with a disproportionate share index of greater than 25%.[19]

Patients and Procedures

We analyzed patients who underwent 1 of 5 surgical procedures: radical prostatectomy, total nephrectomy, partial nephrectomy, hysterectomy, and oophorectomy. These procedures were chosen because they represent the operations that are most commonly performed using robotic assistance. Performance of each procedure was captured using *International Classification of Diseases, Ninth Revision* (*ICD-9*) procedure codes (eTable 1 in the Supplement). Performance of a robotic-assisted procedure was defined as the occurrence of a billing code for the index procedure along with a code for robotic-assisted surgery (*ICD-9* code 17.4x). A hierarchy was created so that patients were included only once (ie, a patient who

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underwent a hysterectomy along with oophorectomy was included only in the hysterectomy cohort).

Patients were classified based on age, sex, and race/ethnicity. Insurance status was categorized as commercial, Medicare, Medicaid, self-pay, and other or unknown. Comorbid medical conditions were measured using the Elixhauser Comorbidity Index.[20] Hospitals were classified based on percentage of black patients who underwent each procedure, teaching status, region (Northeast, Midwest, South, or West) and size (small, medium, large, or unknown).

Statistical Analysis

Frequency distributions between categorical variables for patient and hospital characteristics were compared with χ^2 tests based on the use of robotic-assisted surgery for each index procedure. Descriptive data are presented at the patient level as well as at the hospital level. Separate hospital-level analyses were performed for calendar years 2010 and 2011, and a hospital was considered a robotic-utilizing facility if at least one of the procedures was performed using robotic assistance during the given calendar year.

For the hospital-level analysis, we developed multivariable logistic regression models to examine the association between hospital characteristics and performance of robotic-assisted surgery. For the patient-level analysis, we developed multivariate, mixed-effects, log-linear Poisson regression models to examine the association between clinical, demographic, and hospital characteristics and use of robotic-assisted surgery. These models included a random intercept for each hospital to account for hospital-level clustering. Because of strong multicollinearity, patients from hospitals with unknown bed size and teaching status were excluded from these models.

Both margin and HHI (competition) were initially modeled as continuous variables. However, neither variable was normally distributed, and inclusion of the terms as linear functions in the regression model suggested nonlinear associations. Logarithmic transformations did not resolve the issue. Both variables were therefore included as restricted cubic splines to allow for the nonlinear association of margin and HHI while adjusting for other categorical variables.[21,22] These models are presented graphically with 95% CIs. To facilitate the reporting of results with risk ratios (RRs), we also classified margin and HHI as categorical variables. The HHI was classified based on accepted definitions described above, and margin was stratified into quartiles.

We also performed a subset analysis of hospitals that performed robotic-assisted surgery. For this analysis, the cohort was limited to patients treated at a hospital that had performed a robotic-assisted procedure. Patients who underwent surgery at a hospital before the first robotic-assisted procedures at that center or at a hospital that did not use robots were excluded.[1] Separate estimates were derived for each procedure.

We estimated the contribution of each variable in predicting the use of robotic-assisted surgery. For each procedure, we estimated the change in the Akaike information criterion observed with the removal of each covariate from the final model. The variables were then ranked in order of importance.[23] All analyses were performed with SAS, version 9.4 (SAS Institute Inc). All statistical tests were 2-sided.

Results

Characteristics of Hospitals and Patients

A total of 221 637 patients treated at 1370 hospitals were identified. The cohort included 30 345 patients who underwent radical prostatectomy; 20 802, total nephrectomy; 8060, partial nephrectomy; 134 985, hysterectomy; and 27 445, oophorectomy. Across these procedures, robotic-assisted operations were performed for 20 500 (67.6%), 1405 (6.8%), 2759 (34.2%), 14 047 (10.4%), and 1782 (6.5%) of the cases, respectively (**Table 1**).

Characteristics of the hospitals are reported in **Table 2**. The number of centers performing robotic-assisted surgeries increased from 2010 to 2011 for each procedure: prostatectomy (from 42.5% of hospitals in 2010 to 49.5% in 2011), total nephrectomy (from 21.7% to 26.6%), partial nephrectomy (from 37.4% to 41.2%), hysterectomy (from 23.0% to 28.6%), and oophorectomy (from 18.4% to 22.3%). Hospitals that performed robotic-assisted surgery, compared with those that did not, were more often large centers, teaching hospitals, had higher positive operating margins, operated in more competitive markets, and were less often safety-net hospitals (eTable 2 in the Supplement).

Patient-Level Analysis

In a multivariate, mixed-effects model of patient-level use of robotic assistance for radical prostatectomy, year of surgery, hospital teaching status, hospital bed size, and market competition were statistically significantly associated with performance of a robotic-assisted procedure (**Table 3** and **Table 4**). Compared with patients treated in hospitals in noncompetitive markets, the risk ratios (RRs) for undergoing a robotic-assisted procedure were 2.20 (95% CI, 1.50-3.24) at hospitals in moderately competitive markets and 2.64 (95% CI, 1.84-3.78) in highly competitive markets. There was no association between operating margin and use of robotic-assisted surgery. The **Figure** and eFigure in the Supplement display the association between use of robotic-assisted surgery and operating margin and market competition for each procedure.

Similar findings were noted for total nephrectomy; patients treated at hospitals in moderately competitive (RR, 1.90; 95% CI, 1.22-2.98) and highly competitive (RR, 2.01; 95% CI, 1.32-3.06) markets were more likely to undergo robotic-assisted surgery. For partial nephrectomy, both competition and operating margin were associated with robotic-assisted surgery; the RRs for use of a robotic-assisted procedure at hospitals with a medium high operating margin were 1.67 (95% CI, 1.13-2.48) and 1.50 (95% CI, 0.98-2.29) for a high operating margin compared with hospitals with a low operating margin.

Market competition was also associated with performance of both robotic-assisted hysterectomy and oophorectomy. With results reported as RRs (95% CIs), for hysterectomy, patients at hospitals in moderately (3.75 [2.26-6.25]) and

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Table 1. Patient Characteristics[a]

Characteristic	Radical Prostatectomy No. (%)	Radical Prostatectomy *P* Value	Total Nephrectomy No. (%)	Total Nephrectomy *P* Value	Partial Nephrectomy No. (%)	Partial Nephrectomy *P* Value	Hysterectomy No. (%)	Hysterectomy *P* Value	Oophorectomy No. (%)	Oophorectomy *P* Value
Patients	20 500 (67.6)		1405 (6.8)		2759 (34.2)		14 047 (10.4)		1782 (6.5)	
Age, y										
<40	16 (55.2)	.15	133 (4.0)	<.001	232 (29.7)	.045	2593 (8.5)	<.001	225 (2.5)	<.001
40-49	1060 (68.0)		147 (5.3)		432 (35.6)		5157 (9.4)		419 (6.3)	
50-59	6756 (67.4)		319 (7.0)		729 (35.2)		3034 (11.5)		381 (8.8)	
60-69	10 012 (67.2)		384 (7.8)		836 (35.1)		1995 (14.3)		424 (11.3)	
70-79	2605 (69.2)		279 (7.8)		448 (33.2)		945 (13.5)		250 (9.9)	
≥80	51 (63.8)		143 (8.7)		82 (31.3)		323 (14.1)		83 (6.4)	
Sex										
Male	NA		839 (7.2)	.002	1616 (34.5)	.52	NA		NA	
Female	NA		566 (6.2)		1143 (33.8)		NA		NA	
Year of diagnosis										
2010	8925 (65.0)	<.001	660 (6.4)	.08	1115 (29.6)	<.001	5142 (7.4)	<.001	695 (4.9)	<.001
2011	11 575 (69.7)		745 (7.1)		1644 (38.3)		8905 (13.6)		1087 (8.2)	
Race/ethnicity										
White	14 253 (67.8)	<.001	970 (7.0)	<.001	1896 (34.3)	<.001	8755 (11.7)	<.001	1157 (7.2)	<.001
Black	2121 (63.8)		104 (4.8)		220 (29.0)		1280 (6.9)		145 (3.9)	
Hispanic	1083 (66.4)		75 (3.9)		148 (24.0)		1385 (8.8)		159 (5.1)	
Other/unknown	3043 (69.7)		256 (9.1)		495 (42.6)		2627 (10.1)		321 (7.1)	
Insurance										
Commercial	12 806 (68.1)	<.001	591 (7.3)	<.001	1558 (36.1)	<.001	9739 (11.0)	<.001	973 (6.8)	<.001
Medicare	6547 (68.4)		639 (7.4)		923 (34.1)		2501 (13.5)		567 (9.3)	
Medicaid	402 (59.4)		90 (5.3)		148 (27.3)		975 (6.5)		149 (3.6)	
Self-pay	233 (56.3)		33 (4.1)		45 (23.0)		214 (4.5)		34 (2.2)	
Other/unknown	512 (57.7)		52 (3.4)		85 (28.5)		618 (7.8)		59 (4.4)	
Comorbidities[b]										
0	7434 (69.1)	<.001	317 (6.2)	.05	645 (34.9)	.04	5340 (10.0)	<.001	590 (5.5)	<.001
1	7709 (68.4)		397 (7.4)		853 (35.9)		4119 (10.1)		470 (6.6)	
≥2	5357 (64.5)		691 (6.7)		1261 (32.9)		4588 (11.3)		722 (7.5)	
Gynecologic cancer										
No	NA		NA		NA		11 147 (9.2)	<.001	NA	
Yes	NA		NA		NA		2900 (20.7)		NA	

Abbreviation: NA, not applicable.

[a] Percentages are based on the number of patients with a given characteristic who underwent robotic-assisted surgery.

[b] Elixhauser Comorbidity Index.[20]

highly (5.30 [3.27-8.57]) competitive markets were more likely to undergo a robotic-assisted surgery. Robotic-assisted oophorectomy was more likely to be performed in moderately (2.29 [1.57-3.33]) and highly (2.59 [1.81-3.71]) competitive markets.

eTable 3 in the Supplement displays the importance of each variable in predicting the use of a robotic-assisted procedure. For radical prostatectomy, market competition was the strongest factor associated with the use of robotic-assisted surgery followed by hospital teaching status, bed size, and operating margin. For total nephrectomy, market competition was the third most important factor associated with the use of robotic assistance and operating margin was fourth. In contrast, for partial nephrectomy, operating margin was the most important factor associated with the use of robotic assistance followed by competition. Among women who underwent hysterectomy, the presence of gynecologic cancer, insurance status, race/ethnicity, and year of diagnosis were the most important factors associated with the performance of a robotic-assisted procedure. For oophorectomy, age was the most important factor associated with the performance of robotic-assisted surgery followed by market competition.

Subset Analysis Among Hospitals

To further analyze whether competition and financial status influenced the choice of surgical modality after a robot was acquired, we limited the analysis to patients treated only at hospitals that had performed the given operation robotically. Across all 5 procedures, there was no longer a statistically significant association between market competition and use of robotic-assisted surgery (eTable 4 in the Supplement). Within these models, year of surgery was the only consistent factor associated with the use of robotic-assisted surgery.

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Table 2. Hospital Characteristics[a]

Characteristic	Radical Prostatectomy No. (%)	Radical Prostatectomy P Value	Total Nephrectomy No. (%)	Total Nephrectomy P Value	Partial Nephrectomy No. (%)	Partial Nephrectomy P Value	Hysterectomy No. (%)	Hysterectomy P Value	Oophorectomy No. (%)	Oophorectomy P Value
Region										
Northeast	4167 (66.3)	<.001	242 (6.5)	<.001	466 (25.2)	<.001	692 (8.5)	<.001	354 (7.7)	<.001
Midwest	4965 (68.6)		499 (10.0)		888 (43.7)		3968 (10.8)		378 (6.2)	
South	7164 (65.3)		385 (4.6)		890 (31.7)		5348 (10.0)		522 (4.9)	
West	4204 (71.8)		279 (7.7)		515 (37.5)		4039 (11.0)		528 (8.7)	
Hospital teaching status										
Teaching	14 236 (70.5)	<.001	957 (6.8)	<.001	1971 (33.6)	<.001	7358 (12.1)	<.001	1212 (8.2)	<.001
Nonteaching	5991 (61.6)		405 (6.4)		762 (36.8)		6509 (9.0)		551 (4.5)	
Unknown	273 (63.8)		43 (12.0)		26 (21.9)		180 (9.7)		19 (5.0)	
Bed size[b]										
Small	2758 (75.0)	<.001	180 (10.6)	<.001	360 (42.3)	<.001	890 (5.6)	<.001	147 (5.3)	<.001
Medium	3621 (64.7)		202 (5.6)		492 (37.5)		3470 (9.9)		278 (4.4)	
Large	13 848 (67.1)		980 (6.5)		1881 (32.6)		9507 (11.6)		1338 (7.4)	
Unknown	273 (63.8)		43 (12.0)		26 (21.9)		180 (9.7)		19 (5.0)	
Safety-net status										
Non-SNH	10 055 (66.9)	<.001	660 (7.8)	<.001	1343 (34.8)	<.001	6901 (11.2)	<.001	854 (6.4)	<.001
SNH	4498 (69.6)		240 (5.0)		449 (28.3)		2321 (11.0)		448 (8.6)	
Unknown	5947 (67.3)		505 (6.7)		967 (37.0)		4825 (9.3)		480 (5.4)	
Operating margin[c]										
Low	3029 (64.9)	<.001	196 (6.1)	<.001	374 (25.0)	<.001	1163 (8.6)	<.001	353 (8.9)	<.001
Medium	4272 (70.1)		184 (6.2)		504 (41.0)		2597 (13.2)		314 (7.5)	
Medium high	2828 (74.2)		250 (8.0)		414 (36.7)		2314 (11.2)		328 (7.0)	
High	3414 (61.7)		260 (8.0)		450 (34.6)		2882 (12.1)		288 (6.0)	
Unknown	6957 (67.9)		515 (6.3)		1017 (35.0)		5091 (8.9)		499 (5.1)	
Herfindahl-Hirschman Index[c]										
Noncompetitive	4071 (54.1)	<.001	294 (5.3)	<.001	539 (31.8)	<.001	5073 (7.8)	<.001	344 (3.7)	<.001
Moderately competitive	3065 (70.7)		233 (7.3)		316 (32.7)		3967 (13.2)		386 (7.9)	
Competitive	7777 (74.5)		516 (7.6)		1169 (38.7)		4684 (13.0)		674 (9.2)	
Unknown	5587 (69.5)		362 (7.0)		735 (30.9)		323 (9.0)		378 (6.5)	
Annualized hospital volume										
Low	65 (9.4)	<.001	2 (0.2)	<.001	9 (3.0)	<.001	23 (0.6)	<.001	9 (0.7)	<.001
Medium	1364 (34.0)		178 (5.3)		276 (22.8)		997 (4.2)		64 (1.5)	
High	19 071 (74.4)		1225 (7.4)		2474 (37.7)		13 027 (12.2)		1709 (7.9)	

Abbreviation: SNH, safety-net hospital.

[a] Percentages are based on the number of patients with a given characteristic who underwent robotic-assisted surgery.

[b] The data set used lists the categories of bed size but not the number of beds.

[c] Described in the Data Sources subsection of the Methods section.

Sensitivity Analyses

We explored the sensitivity of our findings to a number of assumptions. First, we modeled use of robotic assistance, applying different definitions for the market used to define HHI (eTable 5 in the Supplement). When a variable radius capturing 90% of hospital discharges was explored, our findings were largely unchanged. Using a fixed, 15-mile radius to define a market, our findings on the association between market competition and robotic-assisted surgery were similar, but the magnitude attenuated and in some cases was no longer statistically significant. Examining the total number of hospitals as a metric of competition as opposed to HHI yielded similar findings. Finally, when total margin was included in the analysis in place of operating margins, our main findings were similar (eTable 6 in the Supplement).

Discussion

Although patient characteristics are associated with the use of robotic-assisted surgery, our findings suggest that regional market forces also influence care. Patients treated at hospitals located in competitive regional markets are more likely to undergo robotic-assisted surgery. In contrast, hospital financial status appears to have a more limited association with the use of robotic-assisted surgery.

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Table 3. Multivariable Models of Patient-Level Factors Associated With the Use of Robotic-Assisted Surgery[a]

Characteristic	RR (95% CI)				
	Radical Prostatectomy (n = 30 345)	Total Nephrectomy (n = 20 802)	Partial Nephrectomy (n = 8060)	Hysterectomy (n = 134 985)	Oophorectomy (n = 27 445)
Age, y					
<40	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
40-49	1.37 (0.84-2.25)	1.19 (0.93-1.52)	1.07 (0.90-1.26)	0.98 (0.93-1.03)	2.10 (1.78-2.48)[b]
50-59	1.36 (0.83-2.22)	1.47 (1.18-1.83)[b]	1.09 (0.93-1.27)	0.96 (0.91-1.01)	2.56 (2.15-3.05)[b]
60-69	1.34 (0.82-2.20)	1.69 (1.35-2.11)[b]	1.05 (0.90-1.24)	0.98 (0.91-1.05)	2.98 (2.48-3.59)[b]
70-79	1.33 (0.81-2.19)	1.76 (1.37-2.27)[b]	1.02 (0.84-1.23)	0.86 (0.78-0.94)[b]	2.61 (2.08-3.28)[b]
≥80	1.16 (0.66-2.06)	1.93 (1.45-2.56)[b]	0.97 (0.73-1.29)	0.82 (0.72-0.94)[b]	1.82 (1.35-2.44)[b]
Sex					
Male	NA	1 [Reference]	1 [Reference]	NA	NA
Female	NA	0.90 (0.80-1.00)	1.00 (0.92-1.08)	NA	NA
Year of diagnosis					
2010	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
2011	1.10 (1.03-1.18)[b]	1.52 (1.24-1.85)[b]	1.23 (1.07-1.43)[b]	1.49 (1.38-1.61)[b]	1.51 (1.27-1.79)[b]
Race/ethnicity					
White	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
Black	0.99 (0.95-1.05)	0.85 (0.68-1.06)	0.94 (0.80-1.09)	0.72 (0.67-0.77)[b]	0.82 (0.68-0.99)[b]
Hispanic	0.99 (0.92-1.06)	0.77 (0.60-1.01)	0.87 (0.72-1.04)	0.85 (0.79-0.91)[b]	0.80 (0.66-0.97)[b]
Other/ unknown	1.02 (0.96-1.08)	1.00 (0.81-1.25)	1.00 (0.86-1.16)	0.89 (0.83-0.96)[b]	0.97 (0.81-1.17)
Insurance					
Commercial	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
Medicare	1.00 (0.97-1.04)	0.91 (0.78-1.06)	0.99 (0.89-1.11)	1.03 (0.97-1.10)	1.04 (0.90-1.21)
Medicaid	0.93 (0.84-1.04)	0.98 (0.77-1.25)	0.90 (0.75-1.07)	0.75 (0.70-0.81)[b]	0.76 (0.63-0.91)[b]
Self-pay	0.93 (0.82-1.07)	0.71 (0.49-1.04)	0.80 (0.59-1.08)	0.52 (0.45-0.60)[b]	0.50 (0.35-0.71)[b]
Other/ unknown	0.96 (0.88-1.05)	0.57 (0.42-0.78)[b]	0.99 (0.79-1.25)	0.98 (0.90-1.07)	0.84 (0.64-1.12)
No. of Comorbidities[c]					
0	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
1	1.01 (0.98-1.05)	0.89 (0.76-1.04)	1.00 (0.90-1.11)	0.98 (0.94-1.02)	0.96 (0.85-1.09)
≥2	0.99 (0.95-1.03)	0.81 (0.70-0.94)[b]	0.91 (0.82-1.01)	0.97 (0.93-1.01)	0.91 (0.80-1.02)
Gynecologic cancer					
No	NA	NA	NA	1 [Reference]	NA
Yes	NA	NA	NA	1.75 (1.66-1.83)[b]	NA

Abbreviation: NA, not applicable.

[a] Restricted pseudolikelihood estimation method was used to fit the model.

[b] $P < .05$.

[c] Elixhauser Comorbidity Index.[20]

Previous studies[6,7,24] have suggested that hospital competition is associated with the diffusion of novel technologies. Patients undergoing abdominal aortic aneurysm repair were 13% more likely to undergo an endovascular procedure if they were treated at a hospital in a competitive market environment.[7] Similarly, patients undergoing colectomy more often underwent a laparoscopic operation if treated at a hospital in a competitive market.[6] We found that patients undergoing surgery in a hospital in a competitive market were more likely to undergo a robotic-assisted procedure. However, when the analysis was limited to hospitals that performed robotic-assisted surgery, competition was no longer associated with the use of robotic technology. These data imply that regional competition may influence a hospital's decision to acquire a surgical robot, but once the device is in place, market competition exerts less influence on actual within-hospital use.

Economic theory suggests that increased competition should decrease costs; however, this is not necessarily true for health care. Studies from the 1980s[25-27] suggested that market competition among hospitals led to increased costs. Although this trend may have been attenuated somewhat in the 1990s with the introduction of the Medicare Prospective Payment System and increased managed care, more recent data again suggest that hospital competition increases costs.[8,28] A recent report[8] on 5 surgical procedures noted higher gross hospital charges across all procedures at facilities that operated in more competitive markets.

Several factors likely contribute to the higher costs incurred by hospitals that operate in competitive marketplaces.[8] One phenomenon, referred to as the "medical arms race," in which hospitals offer technologically advanced treatments of questionable benefit has been posited to be an important driver of costs in competitive markets and is likely

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Table 4. Multivariable Models of Hospital-Level Factors Associated With the Use of Robotic-Assisted Surgery[a]

Characteristic	RR (95% CI) Radical Prostatectomy (n = 30 345)	Total Nephrectomy (n = 20 802)	Partial Nephrectomy (n = 8060)	Hysterectomy (n = 134 985)	Oophorectomy (n = 27 445)
Region					
Northeast	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
Midwest	1.56 (0.96-2.52)	2.19 (1.24-3.89)[b]	1.61 (1.03-2.51)[b]	1.38 (0.57-3.31)	1.08 (0.65-1.78)
South	1.43 (0.92-2.23)	1.21 (0.71-2.07)	1.13 (0.75-1.72)	1.66 (0.70-3.89)	0.85 (0.53-1.35)
West	1.12 (0.68-1.84)	1.48 (0.80-2.71)	1.25 (0.78-2.01)	0.96 (0.40-2.27)	1.02 (0.61-1.71)
Teaching status[c]					
Teaching	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
Nonteaching	0.52 (0.40-0.69)[b]	0.76 (0.54-1.06)	0.89 (0.68-1.16)	0.30 (0.21-0.44)[b]	0.61 (0.46-0.80)[b]
Bed size[d]					
Small	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
Medium	2.15 (1.41-3.28)[b]	1.00 (0.59-1.68)	1.08 (0.71-1.64)	3.24 (1.84-5.70)[b]	1.07 (0.70-1.65)
Large	2.56 (1.71-3.85)[b]	1.38 (0.86-2.22)	1.25 (0.85-1.84)	4.66 (2.71-8.01)[b]	1.52 (1.03-2.25)[b]
Safety-net status					
Non-SNH	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
SNH	0.83 (0.63-1.09)	0.57 (0.37-0.88)[b]	0.72 (0.51-1.03)	1.00 (0.79-1.27)	0.87 (0.59-1.27)
Unknown	2.21 (0.96-5.08)	4.17 (1.31-13.20)[b]	2.73 (1.26-5.89)[b]	2.00 (0.65-6.18)	2.14 (0.88-5.17)
Operating margin[e]					
Low	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
Medium	1.21 (0.96-1.52)	1.52 (0.95-2.44)	1.58 (1.08-2.31)[b]	0.60 (0.47-0.77)[b]	1.12 (0.74-1.68)
Medium high	1.14 (0.88-1.46)	1.43 (0.88-2.33)	1.67 (1.13-2.48)[b]	0.76 (0.56-1.04)	1.42 (0.94-2.16)
High	1.23 (0.88-1.71)	1.27 (0.76-2.11)	1.50 (0.98-2.29)	0.99 (0.69-1.43)	1.20 (0.76-1.90)
Unknown	0.29 (0.13-0.66)[b]	0.17 (0.05-0.56)[b]	0.31 (0.14-0.69)[b]	0.20 (0.07-0.61)[b]	0.37 (0.15-0.92)[b]
Herfindahl-Hirschman Index[f]					
Noncompetitive	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]	1 [Reference]
Moderately competitive	2.20 (1.50-3.24)[b]	1.90 (1.22-2.98)[b]	1.59 (1.10-2.29)[b]	3.75 (2.26-6.25)[b]	2.29 (1.57-3.33)[b]
Highly competitive	2.64 (1.84-3.78)[b]	2.01 (1.32-3.06)[b]	1.71 (1.22-2.38)[b]	5.30 (3.27-8.57)[b]	2.59 (1.81-3.71)[b]
Unknown	1.85 (1.25-2.74)[b]	1.73 (1.09-2.75)[b]	1.69 (1.17-2.44)[b]	4.07 (1.51-10.97)[b]	1.19 (0.78-1.82)

Abbreviations: RR, risk ratio; SNH, safety-net hospital.

[a] Restricted pseudolikelihood estimation method was used to fit the model.

[b] $P < .05$.

[c] Hospitals with unknown teaching status were excluded from the analysis because of multicollinearity.

[d] The data set used lists the categories of bed size but not the number of beds. Hospitals with unknown bed size were excluded from the analysis because of multicollinearity.

[e] Operating margin is classified into quartiles for each procedure.

[f] Described in the Data Sources subsection of the Methods section.

at play for robotic surgical technology.[8,25,26] Robotic-assisted surgery has been intensely marketed to physicians and hospitals as well as directly to patients.[5] Hospitals in competitive market environments are thus faced with the challenge of whether to offer a service of questionable value or potentially lose market share to competitors who choose to offer the service. Our data suggest that market competition is strongly associated with utilization of robotic-assisted surgery. Robotic-assisted surgery is associated with substantially higher costs than alternatives; thus, technologies such as this are likely one driver of the high costs associated with operating in competitive markets.[1,29]

We found that hospital financial status was not strongly associated with the use of robotic-assisted surgery. We noted that hospitals with stronger underlying fiscal performance were more likely to use robotic-assisted surgery only for partial nephrectomy. Previous studies[30-34] have reported that hospital financial distress is associated with decreased staffing and reduced investment in technology and infrastructure. Although robotic-assisted surgery may not be a medically essential service, variation in use of the technology based on hospital financial status may exacerbate treatment disparities since socioeconomically disadvantaged patients are more likely to be treated at hospitals under fiscal pressure.[35] For example, at the hospital level, we noted that safety-net hospitals, which are likely to be under financial distress, are less likely to use robotic surgery.[35]

Competition was an important factor associated with the use of robotic surgery, and several other patient and hospital characteristics were also associated with its use. Safety-net hospitals, nonteaching facilities, and smaller hospitals were less likely to perform robotic-assisted surgery. Similarly, race/ethnicity and insurance status were associated with use of robotic-assisted surgery, particularly for gynecologic procedures. For both hysterectomy and oophorectomy we found that nonwhite women, uninsured individuals, and Medicaid recipients were less likely to undergo robotic-assisted surgery.

We recognize a number of limitations of this study. Using administrative data, we lack some clinical details that may have influenced the surgical modality chosen. However, differences in clinical characteristics would affect the choice

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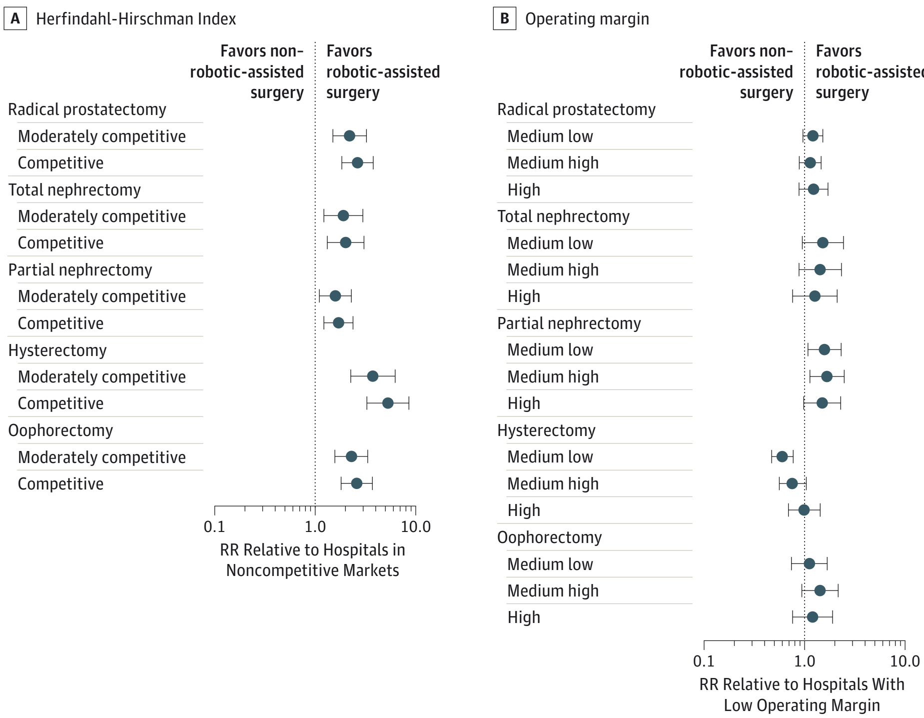
Figure. Risk Ratios (RRs) of Performance of Robotic-Assisted Surgery



A, Herfindahl-Hirschman Index with noncompetitive reference group. B, Operating margin with low operating margin reference group. Dashed vertical lines indicate RRs of 0.1 and 10; data markers, RR; and limit lines, 95% CI.

of surgical approach across all hospitals and thus should not have influenced our main findings. Because we examined only 5 robotic-assisted procedures, our findings may not be generalizable to other robotic-assisted operations. A priori, we chose to examine the procedures that most commonly use robotic assistance, and the operations analyzed ranged from established robotic-assisted procedures, such as prostatectomy, to procedures in which the use of robotic assistance is less common. We used the HHI as our metric of competition. Although the HHI is commonly used and validated, we cannot exclude the possibility of misclassification of a small number of hospitals. To mitigate this bias, we performed a wide range of sensitivity analyses to examine the robustness of our findings. We corrected for measured confounders; however, we acknowledge that unmeasured confounders may have influenced the decision to perform robotic-assisted surgery. Finally, the hospital financial data reported were derived from self-reported hospital fiscal status. The data are unaudited, but these reports have been widely used in other studies.[16,17]

Conclusions

From a policy perspective, it remains unclear how to balance access to surgical innovations against excessive cost for procedures that could be performed in less costly ways. Once a hospital acquires a new technology, costs must be offset through utilization and increased volume. For robotic-assisted surgery, most commercial payers reimburse physicians at rates similar to those provided for nonrobotic procedures and do not alter out-of-pocket expenses for patients; thus, there is little price sensitivity on the part of either patients or physicians. Payment reform to better align procedural reimbursement with comparative effectiveness data and to pass costs, in the form of lower physician reimbursements or higher copayments for patients, has been widely suggested for interventions of questionable value.[36] As cost reduction becomes an imperative in health care, interventions to reduce the influence of nonmedical factors on clinical decision making will clearly be of value.

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