Robotically Assisted vs Laparoscopic Hysterectomy Among Women With Benign Gynecologic Disease

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HYSTERECTOMY FOR BENIGN gynecologic disease is one of the most commonly performed procedures for women. Overall, 1 in 9 women in the United States will undergo the procedure during her lifetime.[1-3] While hysterectomy has traditionally been performed abdominally via laparotomy, vaginally, or by laparoscopy, robotically assisted hysterectomy has been introduced as an alternative minimally invasive approach to hysterectomy.[1,2] The robotic surgical platform received approval from the US Food and Drug Administration in 2005 for the performance of gynecologic procedures and allows a surgeon to perform the procedure at a remote console.[3] Potential benefits of robotic surgery include increased range of motion with the instrumentation, 3-dimensional stereoscopic visualization, and improved ergonomics for the operating surgeon.[3,4] Unlike other procedures such

Author Video Interview available at www.jama.com.

Importance Although robotically assisted hysterectomy for benign gynecologic conditions has been reported, little is known about the incorporation of the procedure into practice, its complication profile, or its costs compared with other routes of hysterectomy.

Objectives To analyze the uptake of robotically assisted hysterectomy, to determine the association between use of robotic surgery and rates of abdominal and laparoscopic hysterectomy, and to compare the in-house complications of robotically assisted hysterectomy vs abdominal and laparoscopic procedures.

Design, Setting, and Patients Cohort study of 264 758 women who underwent hysterectomy for benign gynecologic disorders at 441 hospitals across the United States from 2007 to 2010.

Main Outcome Measures Uptake of and factors associated with utilization of robotically assisted hysterectomy. Complications, transfusion, reoperation, length of stay, death, and cost for women who underwent robotic hysterectomy compared with both abdominal and laparoscopic procedures were analyzed.

Results Use of robotically assisted hysterectomy increased from 0.5% in 2007 to 9.5% of all hysterectomies in 2010. During the same time period, laparoscopic hysterectomy rates increased from 24.3% to 30.5%. Three years after the first robotic procedure at hospitals where robotically assisted hysterectomy was performed, robotically assisted hysterectomy accounted for 22.4% of all hysterectomies. The rates of abdominal hysterectomy decreased both in hospitals where robotic-assisted hysterectomy was performed as well as in those where it was not performed. In a propensity score–matched analysis, the overall complication rates were similar for robotic-assisted and laparoscopic hysterectomy (5.5% vs 5.3%; relative risk [RR], 1.03; 95% CI, 0.86-1.24). Although patients who underwent a robotic-assisted hysterectomy were less likely to have a length of stay longer than 2 days (19.6% vs 24.9%; RR, 0.78, 95% CI, 0.67-0.92), transfusion requirements (1.4% vs 1.8%; RR, 0.80; 95% CI, 0.55-1.16) and the rate of discharge to a nursing facility (0.2% vs 0.3%; RR, 0.79; 95% CI, 0.35-1.76) were similar. Total costs associated with robotically assisted hysterectomy were $2189 (95% CI, $2030-$2349) more per case than for laparoscopic hysterectomy.

Conclusions and Relevance Between 2007 and 2010, the use of robotically assisted hysterectomy for benign gynecologic disorders increased substantially. Robotically assisted and laparoscopic hysterectomy had similar morbidity profiles, but the use of robotic technology resulted in substantially more costs.

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as prostatectomy for which robotic assistance is used more frequently than conventional laparoscopic approaches, both laparoscopic and vaginal hysterectomy are already widely available and used for hysterectomy.

Despite enthusiasm for robotic gynecologic surgery, the majority of information regarding robotically assisted hysterectomy comes from small observational studies.[3,5-17] Most of these reports are from single institutions and from highly experienced surgeons and centers, the results of which may not be applicable to the broader practice of gynecology.[3,5-18] A 2012 Cochrane review of randomized controlled trials of robotic surgery for benign gynecologic disease identified only 2 trials with 158 patients that met inclusion criteria. Based on the available data, the authors concluded that robotic surgery was not associated with improved effectiveness or safety.[3] A major concern regarding robotic surgery is the substantial cost of the procedure.[6,7,19,20]

To date, robotically assisted hysterectomy has not been shown to be more effective than laparoscopy. Nevertheless, robotic gynecologic surgery may confer benefits that are difficult to measure. Proponents of robotic surgery have argued that robotic technology allows women who otherwise would undergo laparotomy to have a minimally invasive procedure. However, there is little to support these claims, and because both laparoscopic and robotic-assisted hysterectomy are associated with low complication rates, it is unclear what benefits robotically assisted hysterectomy offers. We performed a population-based analysis to examine the diffusion of robotic-assisted hysterectomy and to determine the association between robotic surgery and the rates of abdominal and laparoscopic hysterectomy. We also assessed in-hospital outcomes and costs for robotically assisted hysterectomy compared with laparoscopic and abdominal procedures.

METHODS

We analyzed data from the Perspective database (Premier), an all-payer, fee-supported database created to measure resource utilization and quality. The database contains comprehensive data for all inpatient admissions from more than 600 acute care hospitals located across the United States. Perspective captures information on demographic and clinical characteristics. In 2006, Perspective included approximately 5.5 million discharges, representing approximately 15% of all hospitalizations in the United States.[21] Perspective has been validated and used in previously published outcomes studies.[21,22] A portion of the Perspective database, including data on all hysterectomies, was purchased using institutional resources. This investigation was deemed exempt from informed consent requirements by the Columbia University institutional review board.

Patients and Procedures

Women 18 years and older who underwent hysterectomy from 2007 through the first quarter of 2010 were included in the analysis. Patients were classified based on the type of hysterectomy performed: abdominal (*International Classification of Diseases, Ninth Revision* [*ICD-9*] codes 68.4, 68.49, 68.9), vaginal (*ICD-9* 68.5 or 68.59), and laparoscopic (*ICD-9* 68.31, 68.41, 68.51). Patients who had a code for a robotic-assisted procedure (*ICD-9* 17.42 or 17.44, introduced October 2008) or a recorded charge code for robotic instrumentation in combination with any of the hysterectomy codes were classified as having undergone a robotic procedure. Patients who underwent surgery for gynecologic malignancy (*ICD-9* 180-184.9) were excluded from the analysis.

Clinical and Demographic Characteristics

Clinical characteristics analyzed included age (<40, 40-44, 45-49, 50-54, 55-60, and >60 years), year of surgery (2007-2010), race (white, black, and other), marital status (married, single, and unknown), and insurance status (commercial, Medicare, Medicaid, uninsured, and unknown). Race was determined based on self-report and classified as white, black, and other/unknown. Overall, 15 patients (0.03%) had unknown information on race. Gynecologic indications for hysterectomy, including leiomyomata, endometriosis, abnormal bleeding, benign ovarian neoplasms, and pelvic organ prolapse, were recorded for each patient. The performance of concomitant gynecologic procedures, including anterior colporrhaphy, posterior colporrhaphy, salpingo-oophorectomy, and incontinence surgery, were also noted.

The hospitals where patients were treated were classified based on location (metropolitan, nonmetropolitan), region of the country (Northeast, Midwest, West, South), size (<400 beds, 400-600 beds, and >600 beds), and teaching status (teaching, nonteaching). Risk adjustment for medical comorbidities was performed using an index derived from the Elixhauser comorbidity variables. Patients were categorized based on the number of medical comorbidities present (0, 1, ≥2).[23]

Surgical volume for hospitals and surgeons was determined for each procedure. Both hospital and surgeon volume were calculated individually for each patient and estimated as the number of procedures performed at a given patient's hospital or by a given patient's surgeon in the 12-month period prior to the date of surgery.[24] For both surgeon and hospital volume, separate volume-based calculations were performed for each procedure. Volume was included as a continuous variable in all analyses. Because physician information was missing for 1.8% of the cohort, these data were imputed based on the multiple imputation procedure (with 5 sets of imputations).

Outcomes

Perioperative morbidity, mortality, and resource utilization were analyzed. Perioperative complications were classified as intraoperative complications (bladder injury, ureteral injury, intes-

tinal injury, vascular injury, and other operative injury), surgical site complications (wound complications, abscess, hemorrhage, bowel obstruction), or medical complications (venous thromboembolism, myocardial infarction, cardiopulmonary arrest, acute renal failure, respiratory failure, cerebrovascular accident, bacteremia/sepsis, shock, and pneumonia).[25] A composite score of any of these complications was also examined. Metrics of resource utilization analyzed included transfusion, reoperation, and length of stay. Length of stay was categorized as 2 days or less vs more than 2 days.

Cost data were captured through the recorded actual cost variables in Perspective. The data include an itemized log of all items that are billed to a patient during the hospitalization. Within the Perspectives database, approximately three-quarters of hospitals report direct cost while the remainder provide estimates based on Medicare cost-to-charge ratios.[21,26] Costs were adjusted for inflation using the consumer price index and reported in 2010 US dollars.[27] After conversion, cost data were visually inspected, and those patients with spurious costs (<$500) were removed from the analyses. Two estimates of cost were analyzed. First, total hospital cost was examined, which includes fixed costs (ie, costs that do not change with patient volume, such as the cost of purchasing the robotic platform) and variable costs (ie, disposable instrumentation and supplies). A second analysis was performed to include only variable and fixed costs reported separately.[28]

Nonroutine discharge was defined as discharge to a skilled nursing facility or acute or subacute rehabilitation center. In-hospital mortality rates, defined as death during the index hospitalization, were recorded for each procedure.

Statistical Analysis

Frequency distributions between categorical variables were compared using χ^2 tests while continuous variables were compared with the Kruskal-Wallis test. Utilization rates for each type of hys-

terectomy are reported based on the year and quarter in which the procedure was performed. To examine the association between the introduction of robotically assisted hysterectomy at individual hospitals and use of robotic-assisted hysterectomy at those hospitals, we performed a stratified analysis based on whether physicians had access to the robot. For each hospital, we noted the quarter in which the first robotically assisted hysterectomy was performed. Hysterectomy rates by quarter after the introduction of robotic-assisted hysterectomy are reported at these hospitals. The remainder of the hospitals, those that did not perform robotically assisted hysterectomy as well as hospitals prior to the first robotically assisted hysterectomy, were analyzed separately.

The association between patient, surgeon, and hospital characteristics and performance of robotic-assisted hysterectomy was examined using multivariate mixed-effects log-binomial regression models. To account for hospital-level clustering, these models included a random-intercept for the hospital in which the procedure was performed. In addition to a model including all patients, a series of sensitivity analyses were performed and models developed that included the following: only patients who underwent a minimally invasive (laparoscopic or robotic-assisted) hysterectomy; only women treated at a hospital that performed robotic surgery; and only patients who underwent surgery in 2009-2010, when specific *ICD-9* procedure codes were available for robotic-assisted hysterectomy.

To analyze the primary and secondary outcomes and minimize selection bias, we performed a propensity score–matched analysis. The propensity score is the probability that a patient will receive a given treatment based on the distribution of factors associated with the treatment. For the current study, the propensity to undergo a robotic-assisted hysterectomy was estimated. For each patient, a propensity score was generated from logistic regression mod-

els that included all of the clinical characteristics (hospital location, teaching status, bed size, region, hospital volume, physician volume, indication for surgery, concomitant procedures, and type of hysterectomy) and demographic characteristics (age, year of diagnosis, race, marital status, insurance status, comorbidity) of interest. The probabilities from these models were used to generate a propensity score ranging from 0 to 1 for each patient. Based on the resulting propensity score, matched groups (1 case to 1 control) were generated using a matching algorithm with a caliper of 0.005.[29] The caliper is the maximum distance allowed in propensity scores between cases and controls in order to identify a match between them. Sensitivity analyses were performed by matching different numbers of controls to cases, as well as using different caliper settings. Two separate propensity matches were performed, one for patients who underwent laparoscopic, or robotically assisted hysterectomy and one for women who underwent either abdominal or robotic-assisted hysterectomy. Complications and parameters of resource utilization were compared between the propensity-matched groups using univariable regression.

Procedural costs were estimated based on the type of hysterectomy performed (abdominal, laparoscopic, or robotic-assisted). Because cost data were heavily right-skewed, we report costs as medians with interquartile ranges (IQRs). Even after transformation, including logarithmic transformation, the cost data remained skewed. Given the skewed nature of the data, multivariable adjustment of costs based on the type of hysterectomy performed were compared based on quantile (median) regression methods.[32] This method directly estimates the adjusted median costs, and 95% confidence intervals were derived based on bootstrap resampling methods. The quantile regression methodology was necessary for analysis of cost data since the distribution of costs was not normally distributed (conditional on the set of ob-

served covariates), an important assumption for a linear regression analysis. All analyses were performed with SAS version 9.2 (SAS Institute). All statistical tests were 2-sided. A P value less than .05 was considered statistically significant.

RESULTS

A total of 264 758 women were identified who underwent hysterectomy at 441 hospitals across the United States from 2007 to 2010. The cohort included 123 288 (46.6%) who underwent an abdominal hysterectomy, 54 912 (20.7%) who had a vaginal hysterectomy, 75 761 (28.6%) who had a laparoscopic procedure, and 10 797 (4.1%) who had a robotically assisted hysterectomy (TABLE 1 and eTable 1 and eTable 2, available at http://www.jama.com). The rate of vaginal hyster-

Table 1. Unadjusted and Propensity Score–Matched Comparison of Laparoscopic and Robotic-Assisted Hysterectomy[a]

	Unmatched, No. (%)		P Value	Propensity Score–Matched, No. (%)		P Value
	Laparoscopic (n = 75 761)	Robotic (n = 10 797)		Laparoscopic (n = 4971)	Robotic (n = 4971)	
Age, y						
<40	23 908 (31.6)	2826 (26.2)	<.001	1327 (26.7)	1323 (26.6)	.88
40-44	18 242 (24.1)	2416 (22.4)		1169 (23.5)	1183 (23.8)	
45-49	17 588 (23.2)	2581 (23.9)		1181 (23.8)	1190 (23.9)	
50-54	8404 (11.1)	1357 (12.6)		609 (12.3)	570 (11.5)	
55-60	3283 (4.3)	629 (5.8)		270 (5.4)	274 (5.5)	
>60	4336 (5.7)	988 (9.2)		415 (8.4)	431 (8.7)	
Race						
White	53 842 (71.1)	7670 (71)	<.001	3487 (70.2)	3517 (70.8)	.69
Black	8174 (10.8)	1308 (12.1)		587 (11.8)	590 (11.9)	
Other/unknown	13 745 (18.1)	1819 (16.9)		897 (18.0)	864 (17.4)	
Insurance status						
Commercial	60 767 (80.2)	8556 (79.2)	<.001	3932 (79.1)	3947 (79.4)	.96
Medicare	4263 (5.6)	884 (8.2)		368 (7.4)	374 (7.5)	
Medicaid	6013 (7.9)	829 (7.7)		382 (7.7)	375 (7.5)	
Uninsured	1965 (2.6)	187 (1.7)		115 (2.3)	114 (2.3)	
Unknown	2753 (3.6)	341 (3.2)		174 (3.5)	161 (3.2)	
Comorbidity score[b]						
0	36 757 (48.5)	4621 (42.8)	<.001	2132 (42.9)	2151 (43.3)	.88
1	21 743 (28.7)	3200 (29.6)		1461 (29.4)	1464 (29.5)	
≥2	17 261 (22.8)	2976 (27.6)		1378 (27.7)	1356 (27.3)	
Bed size						
<400	41 515 (54.8)	4177 (38.7)	<.001	1850 (37.2)	1898 (38.2)	.50
400-600	20 200 (26.7)	4257 (39.4)		1879 (37.8)	1874 (37.7)	
>600	14 046 (18.5)	2363 (21.9)		1242 (25.0)	1199 (24.1)	
Hospital volume[c]	92.0 (33.0-183.0)	43.0 (15.0-97.0)	<.001	34.0 (14.0-87.0)	31.0 (8.0-90.0)	.01
Physician volume[c]	8.0 (2.0-20.0)	9.0 (2.0-23.0)	<.001	4.0 (1.0-14.0)	5.0 (1.0-12.0)	<.001
Indication for surgery						
Leiomyoma	37 730 (49.8)	5641 (52.3)	<.001	2599 (52.3)	2558 (51.5)	.41
Endometriosis	25 174 (33.2)	3183 (29.5)	<.001	1461 (29.4)	1443 (29.0)	.69
Abnormal bleeding	46 532 (61.4)	6133 (56.8)	<.001	2806 (56.5)	2786 (56.1)	.69
Benign neoplasm	19 183 (25.3)	2924 (27.1)	<.001	1301 (26.2)	1307 (26.3)	.89
Pelvic organ prolapse	11 160 (14.7)	1067 (9.9)	<.001	585 (11.8)	569 (11.5)	.62
Concomitant procedures						
Salpingo-oophorectomy	38 582 (50.9)	6054 (56.1)	<.001	2702 (54.4)	2688 (54.1)	.78
Anterior colporrhaphy	3891 (5.1)	254 (2.4)	<.001	153 (3.1)	145 (2.9)	.64
Posterior colporrhaphy	3642 (4.8)	272 (2.5)	<.001	165 (3.3)	159 (3.2)	.73
Anti-incontinence procedure	7396 (9.8)	756 (7.0)	<.001	402 (8.1)	400 (8.1)	.94
Type of hysterectomy						
Total	55 116 (72.8)	9275 (85.9)	<.001	4049 (81.5)	4073 (81.9)	.53
Subtotal	20 645 (27.3)	1522 (14.1)		922 (18.6)	898 (18.1)	

[a] Refer to eTable 2 for more information in this table.
[b] Using index derived from the Elixhauser comorbidity variables, we categorized patients based on the number of medical comorbidities present.
[c] Median (interquartile range) for 12-mo period prior to the index cases. Separate volume calculations were performed for each type of hysterectomy and only included the same type of hysterectomy.

ectomy declined during the study and accounted for 21.7% of procedures in the first quarter of 2007 compared with 19.8% in the first quarter of 2010 (**FIGURE 1**). Performance of abdominal hysterectomy decreased from 53.6% to 40.1% during the same time period. The number of laparoscopic hysterectomies performed increased; laparoscopic hysterectomy accounted for 24.3% of the procedures in the first quarter of 2007 compared with 30.5% in 2010. Robotically assisted hysterectomy increased during the study period and accounted for 0.5% of the procedures in 2007 compared with 9.5% in 2010.

The analysis was then stratified based on whether patients were treated at a hospital that performed robotic-assisted hysterectomy. After the introduction of robotically assisted hysterectomy at a given hospital, use increased rapidly (**FIGURE 2**). For example, at 3 years (12 quarters) after the first robotic procedure in each hospital where robotics were used, robotic-assisted hysterectomy accounted for 22.4% of all hysterectomies. At these hospitals, use of vaginal (19.8% to 18.1%), laparoscopic (28.9% to 24.5%), and abdominal (44.4% to 35.1%) hysterectomy all declined. In contrast, at hospitals where robotically assisted hysterectomy was not performed, abdominal (53.7% to 44.3%) and vaginal (22.0% to 21.0%) hysterectomy declined, while use of laparoscopic (24.2% to 34.7%) hysterectomy increased (**FIGURE 3**).

Year of surgery had the strongest association with undergoing robotically assisted hysterectomy (**TABLE 2** and eTable 3). Black women (relative risk [RR], 0.86; 95% CI, 0.80-0.93) were less likely than white women to undergo a robotic procedure. Compared with patients with commercial insurance, Medicare recipients (RR, 0.88; 95% CI, 0.80-0.96), Medicaid recipients (RR, 0.84; 95% CI, 0.73-0.97), and uninsured patients (RR, 0.53; 95% CI, 0.42-0.66) less often underwent robotic-assisted hys-

terectomy. Patients treated at larger hospitals as well as metropolitan centers were more likely to undergo a robotically assisted procedure. Women undergoing surgery for abnormal bleeding more frequently had a robotic

Figure 1. Hysterectomy Rates by Route of Surgery Stratified by Year and Quarter
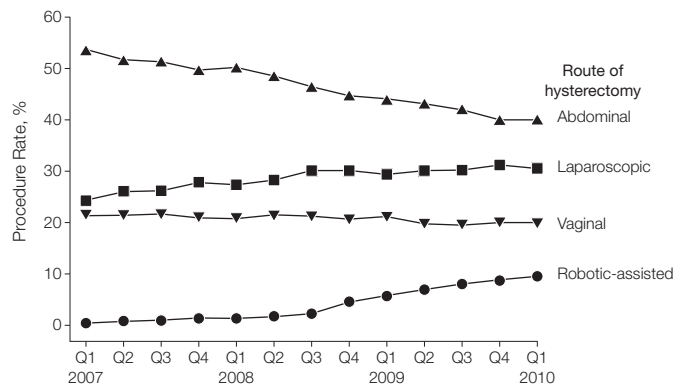

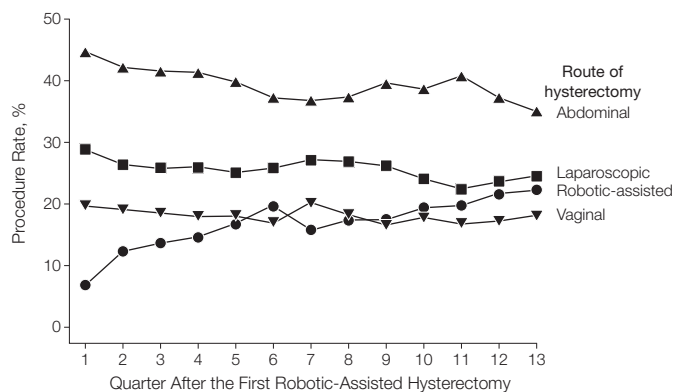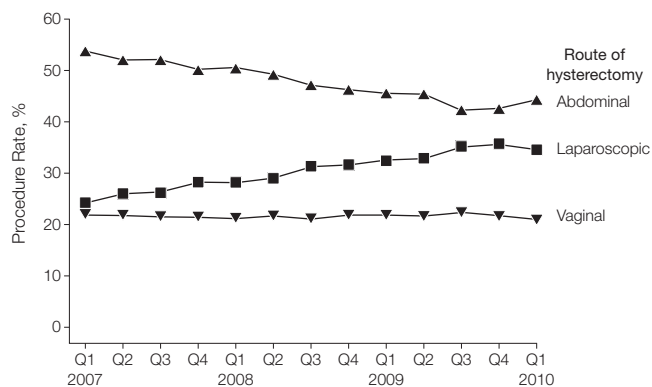**Figure 2.** Hysterectomy Rates by Route of Surgery at Hospitals Where Robotic Hysterectomy Was Performed

Figure 3. Hysterectomy Rates by Route of Surgery at Hospitals Where Robotic Hysterectomy Was Not Performed, by Quarter

procedure (P=.002) while those with pelvic organ prolapse less frequently had a robotically assisted hysterectomy (P<.001).

In a series of sensitivity analyses, these findings remained largely unchanged (Table 2). When evaluating only women who underwent a minimally invasive (laparoscopic or robotic-assisted) hysterectomy, year of diagnosis, insurance status, metropolitan location, hospital teaching status, area of residence, and hospital size were associated with use of robotically assisted hysterectomy. When the analysis was limited to only hospitals where robotic-assisted hysterectomy was performed, white women were more likely than black women to undergo a robotic procedure, and those with commercial

Table 2. Multivariable Models of Factors Associated With Undergoing Robotic Hysterectomy[a]

	RR (95% CI)							
	All Patients	P Value	Patients Who Underwent Minimally Invasive Surgery	P Value	Patients Treated at Hospitals Performing Robotic Hysterectomy	P Value	Patients Who Underwent Hysterectomy in 2009-2010	P Value
Age								
<40	1 [Reference]		1 [Reference]		1 [Reference]		1 [Reference]	
40-44	0.99 (0.95-1.05)	.82	1.02 (0.97-1.08)	.39	0.98 (0.92-1.04)	.45	0.95 (0.89-1.02)	.14
45-49	0.96 (0.91-1.02)	.23	1.04 (0.98-1.11)	.15	0.94 (0.89-1.01)	.06	0.90 (0.84-0.97)	.003
50-54	0.97 (0.91-1.03)	.28	1.08 (1.00-1.16)	.04	0.95 (0.88-1.02)	.14	0.91 (0.83-0.98)	.02
55-60	1.00 (0.91-1.09)	.94	1.15 (1.05-1.27)	.003	0.97 (0.88-1.06)	.49	0.89 (0.80-0.99)	.04
>60	0.95 (0.85-1.07)	.39	1.19 (1.08-1.31)	<.001	0.93 (0.85-1.03)	.16	0.83 (0.74-0.93)	.001
Race								
White	1 [Reference]		1 [Reference]		1 [Reference]		1 [Reference]	
Black	0.86 (0.80-0.93)	<.001	1.00 (0.94-1.07)	.91	0.86 (0.80-0.92)	<.001	0.85 (0.78-0.92)	<.001
Other/unknown	1.10 (0.88-1.38)	.41	1.21 (1.13-1.29)	<.001	1.09 (1.02-1.16)	.01	0.93 (0.86-1.01)	.11
Insurance status								
Commercial	1 [Reference]		1 [Reference]		1 [Reference]		1 [Reference]	
Medicare	0.88 (0.80-0.96)	.005	0.99 (0.91-1.08)	.81	0.88 (0.80-0.96)	.003	0.89 (0.81-0.98)	.02
Medicaid	0.84 (0.73-0.97)	.02	0.92 (0.86-1.00)	.04	0.83 (0.77-0.90)	<.001	0.83 (0.76-0.90)	<.001
Uninsured	0.53 (0.42-0.66)	<.001	0.74 (0.63-0.87)	<.001	0.54 (0.46-0.62)	<.001	0.49 (0.41-0.59)	<.001
Unknown	1.01 (0.89-1.15)	.84	1.08 (0.96-1.22)	.18	1.05 (0.94-1.18)	.38	0.95 (0.82-1.08)	.42
Comorbidity score[b]								
0	1 [Reference]		1 [Reference]		1 [Reference]		1 [Reference]	
1	1.01 (0.97-1.05)	.74	1.03 (0.98-1.07)	.28	1.00 (0.96-1.05)	.97	1.04 (0.98-1.10)	.22
≥2	0.97 (0.92-1.04)	.42	1.02 (0.97-1.07)	.38	0.97 (0.92-1.02)	.24	0.98 (0.93-1.05)	.63
Bed size								
<400	1 [Reference]		1 [Reference]		1 [Reference]		1 [Reference]	
400-600	7.70 (2.17-27.28)	.002	8.04 (2.62-24.70)	<.001	1.21 (0.77-1.89)	.41	4.67 (1.70-12.87)	.003
>600	72.15 (15.24-341.61)	<.001	53.25 (11.89-238.58)	<.001	1.11 (0.66-1.88)	.69	18.33 (4.82-69.73)	<.001
Indication for surgery								
Leiomyoma	1.02 (0.97-1.07)	.46	1.03 (0.99-1.07)	.19	1.02 (0.98-1.07)	.32	1.02 (0.98-1.08)	.34
Endometriosis	1.06 (0.99-1.13)	.09	1.00 (0.95-1.04)	.85	1.06 (1.01-1.11)	.01	1.04 (0.99-1.10)	.10
Abnormal bleeding	1.08 (1.03-1.13)	.002	0.98 (0.94-1.02)	.40	1.08 (1.03-1.12)	<.001	1.07 (1.01-1.12)	.01
Benign neoplasm	1.02 (0.96-1.09)	.44	1.01 (0.97-1.06)	.56	1.03 (0.98-1.08)	.20	1.00 (0.95-1.06)	.99
Pelvic organ prolapse	0.38 (0.28-0.50)	<.001	0.90 (0.83-0.98)	.02	0.39 (0.35-0.42)	<.001	0.40 (0.37-0.45)	<.001
Concomitant procedures								
Salpingo-oophorectomy	1.20 (1.12-1.28)	<.001	0.98 (0.94-1.03)	.38	1.20 (1.15-1.26)	<.001	1.20 (1.14-1.27)	<.001
Anterior colporrhaphy	1.00 (0.78-1.28)	.99	0.68 (0.58-0.79)	<.001	0.98 (0.85-1.14)	.82	1.02 (0.87-1.21)	.77
Posterior colporrhaphy	1.57 (1.13-2.19)	.009	0.81 (0.70-0.95)	.008	1.44 (1.24-1.66)	<.001	1.57 (1.34-1.84)	<.001
Anti-incontinence procedure	1.02 (0.89-1.16)	.81	1.09 (1.01-1.19)	.03	1.03 (0.95-1.13)	.45	1.03 (0.94-1.14)	.51
Type of hysterectomy								
Total	1 [Reference]		1 [Reference]		1 [Reference]		1 [Reference]	
Subtotal	0.99 (0.93-1.05)	.65	1.47 (1.38-1.57)	<.001	0.95 (0.89-1.01)	.95	1.02 (0.94-1.10)	.61

Abbreviation: RR, relative risk.
[a] All models were adjusted for both physician and hospital volumes that were continuous variables. Refer to eTable 3 for more information in this table.
[b] Using index derived from the Elixhauser comorbidity variables, we categorized patients based on the number of medical comorbidities present.

Table 3. Propensity Score–Matched Comparison of Complications and Resource Utilization for Patients Who Underwent Laparoscopic vs Robotic Hysterectomy

| | No. (%) | | | Robotic vs Laparoscopic Hysterectomy, Univariate RR (95% CI) | |
	Laparoscopic Hysterectomy (n = 4971)	Robotic Hysterectomy (n = 4971)	P Value		P Value
Complications					
Any	264 (5.3)	271 (5.5)	.76	1.03 (0.86-1.24)	.73
Intraoperative	120 (2.4)	126 (2.5)	.70	1.05 (0.75-1.47)	.76
Surgical site	100 (2.0)	85 (1.7)	.27	0.85 (0.64-1.13)	.27
Medical	59 (1.2)	79 (1.6)	.09	1.35 (0.97-1.88)	.08
Utilization					
Transfusion	87 (1.8)	68 (1.4)	.12	0.80 (0.55-1.16)	.24
Reoperation	5 (0.1)	5 (0.1)	>.99	1.00 (0.26-3.84)	>.99
Length of stay >2 d	1237 (24.9)	974 (19.6)	<.001	0.78 (0.67-0.92)	.002
Total cost, $	6679 (5197-8673)	8868 (6787-11 830)	<.001	2189 (2030-2349)	<.001
Fixed cost, $[a]	3040 (2281-4148)	4002 (2868-5780)	<.001	962 (878-1047)	<.001
Variable cost, $[a]	3493 (2597-4691)	4700 (3420-6237)	<.001	1207 (1110-1304)	<.001
Nonroutine discharge	14 (0.3)	11 (0.2)	.56	0.79 (0.35-1.76)	.79
Death	0	0			

Abbreviation: RR, relative risk.
[a] Median (interquartile range).

insurance were more likely to undergo robotically assisted hysterectomy. When specifically analyzing patients treated in 2009 or 2010, race, insurance status, and hospital characteristics remained associated with use of robotic assistance.

Laparoscopic and robotically assisted hysterectomy were compared after propensity score matching (**TABLE 3**). The unadjusted rate of complications was 5.5% for women who underwent robotic-assisted hysterectomy vs 5.3% for those who had a laparoscopic procedure (*P* = .47). In addition to the overall complication rate, the rates of intraoperative complications (2.5% vs 2.4%; RR, 1.05; 95% CI, 0.75-1.47), surgical site complications (1.7% vs 2.0%; RR, 0.85; 95% CI, 0.64-1.13), and medical complications (1.6% vs 1.2%; RR, 1.35; 95% CI, 0.97-1.88) were similar between the robotically assisted and laparoscopic hysterectomy groups. Hospitalization for longer than 2 days was more common in the laparoscopic hysterectomy cohort (24.9% vs 19.6%, *P* < .001), while rates of transfusion (1.4% vs 1.8%; RR, 0.80; 95% CI, 0.55-1.16), reoperation (0.1% vs 0.1%; RR, 1.00; 95% CI, 0.26-3.84), nonroutine discharge (0.2% vs 0.3%; RR, 0.79; 95% CI, 0.35-1.76), and

in-hospital mortality were similar (*P* > .05 for all). A comparison of the morbidity of robotic-assisted and abdominal hysterectomy is shown in eTable 4 and eTable 5.

The median total cost for laparoscopic hysterectomy was $6679 (IQR, $5197-$8673) compared with $8868 (IQR, $6787-$11 830) for robotic-assisted hysterectomy. The median fixed cost for laparoscopic hysterectomy was $3040 (IQR, $2281-$4148) compared with $4002 (IQR, $2868-$5780) for robotic-assisted hysterectomy (*P* < .001). Similarly, variable costs were lower for laparoscopic ($3493; IQR, $2597-$4691) than robotic-assisted ($4700; IQR, $3420-$6237) hysterectomy. This translated into $2189 (95% CI, $2073-$2377) increased total costs, $962 (95% CI, $878-$1047) increased fixed costs, and $1207 (95% CI, $1110-$1304) increased variable costs for robotic compared with laparoscopic surgery.

A series of sensitivity analyses were performed to examine the relationship between the cost of robotic-assisted hysterectomy and physician and hospital volume. In a fully adjusted model with physician and hospital volume as continuous variables, total cost increased by $9 (95% CI, $7

to $12) with each additional robotic case per physician and decreased by $0.28 (95% CI, −$1 to $0.80) for each additional robotic case per hospital. When stratified by cumulative surgeon robotic procedure volume, the total cost per case for a physician's first 10 cases was $8875 (IQR, $6806-$11 602). These costs decreased to $8174 (IQR, $6319-$11 278) for cases 21-30 and then increased to $8307 (IQR, $6616-$11 058) for cases 31-40 and to $8220 (IQR, $6029-$10 864) for cases after the 40th robotic-assisted hysterectomy. Similarly, variable cost for a physician's first 10 robotic cases was $4718 (IQR, $3394-$6570), decreased to $4328 (IQR, $3229-$6284) for cases 21-30, and then increased to $4404 (IQR, $3313-$6411) for cases 31-40 and to $4754 (IQR, $3157-$6368) after the 40th robotic-assisted hysterectomy.

We performed a number of sensitivity analyses to examine the accuracy of the coding schema. In 2009, when *ICD-9* coding for robotic procedures was available, we noted that more than 95% of robotic hysterectomies were captured with *ICD-9* coding. Furthermore, when cost was examined, we found a strong correlation between total cost for robotic procedures captured by

ICD-9 codes ($8623; 95% CI, $6423-$11 602) and billing codes ($8923; 95% CI, $6821-$11 450) that was clearly distinct from laparoscopic procedures ($6246; 95% CI, $4906-$7897).

COMMENT

Our population-based analysis suggests that despite limited data, the use of robotically assisted hysterectomy for benign gynecologic disease increased substantially over a 3-year period. The introduction of robotic-assisted hysterectomy was paralleled by a decrease in the rate of abdominal hysterectomy both in hospitals where robotic-assisted hysterectomy was performed and in those where robotic procedures were not performed. The perioperative morbidity profile was similar for robotic-assisted and laparoscopic hysterectomy. Robotically assisted hysterectomy is substantially more expensive than any other modality of hysterectomy.

Recent studies have raised concerns regarding the comparative effectiveness of robotic-assisted surgery for a variety of procedures.[25,33] A comparative analysis of robotic-assisted vs laparoscopic hysterectomy for endometrial cancer noted that the 2 procedures were associated with similar morbidity, but robotically assisted hysterectomy was accompanied by substantially greater cost.[25] To date, most studies of robotically assisted hysterectomy for benign gynecologic disease have been of limited size and retrospective in nature.[3,5-18] A review of published observational data comparing robotic-assisted and laparoscopic hysterectomy noted that clinical outcomes were similar while operative times and costs were higher for robotic procedures.[6] A meta-analysis of prospective trials comparing robotic and laparoscopic surgery for benign gynecologic disease found that both procedures were associated with similar outcomes, complications, length of stay, and quality of life.[3] We noted that perioperative outcomes were similar for robotic-assisted and laparoscopic hysterectomy.

Despite the fact that laparoscopic hysterectomy has been performed since the 1990s, uptake of the procedure has been slow.[34-36] Population-level data from the United States suggest that in 2003 only 12% of hysterectomies were performed laparoscopically, and this had increased to only 14% by 2005.[34,35] Our findings are notable in that the uptake of robotically assisted hysterectomy was rapid; only 3 years after the introduction of robotic hysterectomy, the procedure accounted for nearly 10% of all operations. Furthermore, at hospitals where robotically assisted hysterectomy was performed, robotic procedures accounted for more than 20% of hysterectomies within 3 years of adoption of the technology.

One of the purported benefits of robotic surgery is that it allows more patients to undergo a minimally invasive procedure, but this assumption has been poorly documented for gynecologic surgery.[36] Our findings suggest that this is in fact the case and that the introduction of robotic gynecologic surgery was associated with a decrease in the rate of abdominal hysterectomy and an increase the use of minimally invasive surgery as a whole, including both laparoscopic and robotic hysterectomy. The rapid uptake of robotic gynecologic surgery likely stems from a multitude of factors. First, robotic surgery may be easier to learn than laparoscopy because it is more analogous to traditional open surgery.[37] Second, robotic assistance may allow for the completion of more technically demanding cases that would otherwise have required laparotomy. Third, robotic surgery has been the subject of extensive marketing not only to surgeons and hospitals, but also to medical consumers.[38,39] The potential effect of this marketing has been the subject of a number of reports.[38,39] The increased use of laparoscopic hysterectomy that we noted was almost solely at hospitals where robotic surgery was not performed and may have been due to competitive pressures or an increased awareness and appreciation of minimally invasive surgical options for hysterectomy.

Our findings also raise concern regarding the economic viability of the procedure. In a decision model examining the cost of hysterectomy, Barnett and colleagues[20] noted that from a hospital perspective, laparoscopic ($6581) and open ($7009) hysterectomy were significantly less expensive than robotically assisted hysterectomy ($8770). We found relatively similar results; the hospital costs of open ($6712) and laparoscopic hysterectomy ($6671) were similar while robotic-assisted hysterectomy was clearly more costly ($8854). The cost of robotically assisted hysterectomy is largely driven by equipment costs while length of stay is the predominant cost center for open procedures.[20] Even when we excluded the fixed cost of the robotic platform and examined only variable costs, we noted that robotic hysterectomy remained the most costly modality for hysterectomy. When cost is examined from a societal perspective, including postoperative recovery, robotic-assisted hysterectomy is less costly than open hysterectomy but remains more costly than a laparoscopic procedure.[20] Additionally, some studies have suggested that adoption of robotically assisted hysterectomy actually reduces hospital costs as the rate of laparotomy declines.[40] Although the cost of robotic surgery will likely decrease as the cost of instrumentation is reduced, Barbash and Glied[19] estimated that if robotic surgery replaced conventional surgery, health care costs would increase by more than $2.5 billion.

Although our analysis benefits from the inclusion of a large cohort of women, we recognize a number of important limitations. To capture initial uptake of robotically assisted hysterectomy, we used both billing codes and *ICD-9* procedural codes. This methodology has been validated in prior studies, and we performed a number of sensitivity analyses to examine the accuracy of this coding schema. However, despite these analyses, we cannot ex-

clude the possibility that a small number of procedures were misclassified.[14] We recognize that the primary purpose of claims data is billing and that not all perioperative complications may have been captured. To limit this bias, we analyzed only major perioperative complications that were likely to generate a claim. Further, any underreporting of complications was likely balanced between the cohorts. Our analysis of cost included only direct hospital costs incurred for the procedure and did not capture societal costs. Our data set lacked a number of important factors, such as body mass index, uterine weight, and prior surgical history, that likely influenced the surgical approach chosen. A priori we chose not to compare the outcomes of vaginal and robotic-assisted hysterectomy given that vaginal hysterectomy is predominately performed for pelvic organ prolapse often in conjunction with additional pelvic reconstructive procedures. Because race was self-reported, we cannot exclude the possibility that race was misclassified for a small number of patients. We were unable to capture individual patient and physician perceptions and attitudes that undoubtedly influenced operative planning.

Our findings highlight the importance of developing rational strategies to implement new surgical technologies. Robotic surgery first gained prominence for prostatectomy as it essentially offered the only minimally invasive surgical approach for the procedure.[33] Hysterectomy is unlike prostatectomy in that a number of alternatives to open surgery are available; laparoscopic hysterectomy is a well-accepted procedure and vaginal hysterectomy allows removal of the uterus without any abdominal incisions.[2] Our study indicates that while robotic assistance was associated with increased use of minimally invasive surgery for hysterectomy, when compared with laparoscopic hysterectomy, the robotic procedure offers little short-term benefit and is accompanied by significantly greater costs. From a public health standpoint, defining subsets of

patients with benign gynecologic disorders who derive benefit from robotic hysterectomy, reducing the cost of robotic instrumentation, and developing initiatives to promote laparoscopic hysterectomy are warranted.

REFERENCES

1. ACOG Committee. ACOG Committee Opinion No. 444: choosing the route of hysterectomy for benign disease. *Obstet Gynecol*. 2009;114(5):1156-1158.
2. Nieboer TE, Johnson N, Lethaby A, et al. Surgical approach to hysterectomy for benign gynaecological disease. *Cochrane Database Syst Rev*. 2009;(3): CD003677.
3. Liu H, Lu D, Wang L, Shi G, Song H, Clarke J. Robotic surgery for benign gynaecological disease. *Cochrane Database Syst Rev*. 2012;2:CD008978.
4. Maeso S, Reza M, Mayol JA, et al. Efficacy of the da Vinci surgical system in abdominal surgery compared with that of laparoscopy: a systematic review and meta-analysis. *Ann Surg*. 2010;252(2):254-262.
5. Reza M, Maeso S, Blasco JA, Andradas E. Meta-analysis of observational studies on the safety and effectiveness of robotic gynaecological surgery. *Br J Surg*. 2010;97(12):1772-1783.
6. Sarlos D, Kots LA. Robotic versus laparoscopic hysterectomy: a review of recent comparative studies. *Curr Opin Obstet Gynecol*. 2011;23(4):283-288.
7. Sarlos D, Kots L, Stevanovic N, Schaer G. Robotic hysterectomy versus conventional laparoscopic hysterectomy: outcome and cost analyses of a matched case-control study. *Eur J Obstet Gynecol Reprod Biol*. 2010;150(1):92-96.
8. Payne TN, Dauterive FR. A comparison of total laparoscopic hysterectomy to robotically assisted hysterectomy: surgical outcomes in a community practice. *J Minim Invasive Gynecol*. 2008;15(3):286-291.
9. Payne TN, Dauterive FR, Pitter MC, et al. Roboti-

cally assisted hysterectomy in patients with large uteri: outcomes in five community practices. *Obstet Gynecol*. 2010;115(3):535-542.
10. Soto E, Lo Y, Friedman K, et al. Total laparoscopic hysterectomy versus da Vinci robotic hysterectomy: is using the robot beneficial? *J Gynecol Oncol*. 2011;22(4):253-259.
11. Kilic GS, Moore G, Elbatanony A, Radecki C, Phelps JY, Borahay MA. Comparison of perioperative outcomes of total laparoscopic and robotically assisted hysterectomy for benign pathology during introduction of a robotic program. *Obstet Gynecol Int*. 2011; 2011:683703.
12. Shah NT, Wright KN, Jonsdottir GM, Jorgensen S, Einarsson JI, Muto MG. The feasibility of societal cost equivalence between robotic hysterectomy and alternate hysterectomy methods for endometrial cancer. *Obstet Gynecol Int*. 2011;2011:570464.
13. Geppert B, Lönnerfors C, Persson J. Robot-assisted laparoscopic hysterectomy in obese and morbidly obese women: surgical technique and comparison with open surgery. *Acta Obstet Gynecol Scand*. 2011;90(11):1210-1217.
14. Pasic RP, Rizzo JA, Fang H, Ross S, Moore M, Gunnarsson C. Comparing robot-assisted with conventional laparoscopic hysterectomy: impact on cost and clinical outcomes. *J Minim Invasive Gynecol*. 2010; 17(6):730-738.
15. Shashoua AR, Gill D, Locher SR. Robotic-assisted total laparoscopic hysterectomy versus conventional total laparoscopic hysterectomy. *JSLS*. 2009; 13(3):364-369.
16. Boggess JF, Gehrig PA, Cantrell L, et al. Perioperative outcomes of robotically assisted hysterectomy for benign cases with complex pathology. *Obstet Gynecol*. 2009;114(3):585-593.
17. Nezhat C, Lavie O, Lemyre M, Gemer O, Bhagan L, Nezhat C. Laparoscopic hysterectomy with and without a robot: Stanford experience. *JSLS*. 2009;13 (2):125-128.
18. Giep BN, Giep HN, Hubert HB. Comparison of minimally invasive surgical approaches for hysterectomy at a community hospital: robotic-assisted laparoscopic hysterectomy, laparoscopic-assisted vaginal hysterectomy and laparoscopic supracervical hysterectomy. *J Robot Surg*. 2010;4(3):167-175.
19. Barbash GI, Glied SA. New technology and health care costs: the case of robot-assisted surgery. *N Engl J Med*. 2010;363(8):701-704.
20. Barnett JC, Judd JP, Wu JM, Scales CD Jr, Myers ER, Havrilesky LJ. Cost comparison among robotic, laparoscopic, and open hysterectomy for endometrial cancer. *Obstet Gynecol*. 2010;116(3):685-693.
21. Lindenauer PK, Pekow PS, Lahti MC, Lee Y, Benjamin EM, Rothberg MB. Association of corticosteroid dose and route of administration with risk of treatment failure in acute exacerbation of chronic obstructive pulmonary disease. *JAMA*. 2010;303 (23):2359-2367.
22. Lindenauer PK, Pekow P, Wang K, Mamidi DK, Gutierrez B, Benjamin EM. Perioperative beta-blocker therapy and mortality after major noncardiac surgery. *N Engl J Med*. 2005;353(4):349-361.
23. van Walraven C, Austin PC, Jennings A, Quan H, Forster AJ. A modification of the Elixhauser comorbidity measures into a point system for hospital death using administrative data. *Med Care*. 2009;47 (6):626-633.
24. Stukenborg GJ, Kilbridge KL, Wagner DP, et al. Present-at-admission diagnoses improve mortality risk adjustment and allow more accurate assessment of the relationship between volume of lung cancer operations and mortality risk. *Surgery*. 2005;138(3): 498-507.
25. Wright JD, Burke WM, Wilde ET, et al. Comparative effectiveness of robotic versus laparoscopic hys-

terectomy for endometrial cancer. *J Clin Oncol*. 2012; 30(8):783-791.

26. Rothberg MB, Pekow PS, Lahti M, Brody O, Skiest DJ, Lindenauer PK. Antibiotic therapy and treatment failure in patients hospitalized for acute exacerbations of chronic obstructive pulmonary disease. *JAMA*. 2010;303(20):2035-2042.

27. Consumer price index: 2011. US Department of Labor Bureau of Labor Statistics. ftp://ftp.bls.gov/pub /special.requests/cpi/cpiai.txt. Accessed September 1, 2011.

28. Kollef MH, Hamilton CW, Ernst FR. Economic impact of ventilator-associated pneumonia in a large matched cohort. *Infect Control Hosp Epidemiol*. 2012; 33(3):250-256.

29. Hemmila MR, Birkmeyer NJ, Arbabi S, Osborne NH, Wahl WL, Dimick JB. Introduction to propensity scores: a case study on the comparative effectiveness of laparoscopic vs open appendectomy. *Arch Surg*. 2010;145(10):939-945.

30. D'Agostino RB Jr. Propensity score methods for bias reduction in the comparison of a treatment to a non-randomized control group. *Stat Med*. 1998; 17(19):2265-2281.

31. Stukel TA, Fisher ES, Wennberg DE, Alter DA, Gottlieb DJ, Vermeulen MJ. Analysis of observational studies in the presence of treatment selection bias: effects of invasive cardiac management on AMI survival using propensity score and instrumental variable methods. *JAMA*. 2007;297(3): 278-285.

32. Koenker R. *Quantile Regression*. New York, NY: Cambridge University Press; 2005.

33. Hu JC, Gu X, Lipsitz SR, et al. Comparative effectiveness of minimally invasive vs open radical prostatectomy. *JAMA*. 2009;302(14):1557-1564.

34. Wu JM, Wechter ME, Geller EJ, Nguyen TV, Visco AG. Hysterectomy rates in the United States, 2003. *Obstet Gynecol*. 2007;110(5):1091-1095.

35. Jacoby VL, Autry A, Jacobson G, Domush R, Nakagawa S, Jacoby A. Nationwide use of laparoscopic hysterectomy compared with abdominal and vaginal approaches. *Obstet Gynecol*. 2009;114 (5):1041-1048.

36. Jonsdottir GM, Jorgensen S, Cohen SL, et al. Increasing minimally invasive hysterectomy: effect on cost and complications. *Obstet Gynecol*. 2011; 117(5):1142-1149.

37. Lim PC, Kang E, Park H. A comparative detail analysis of the learning curve and surgical outcome for robotic hysterectomy with lymphadenectomy versus laparoscopic hysterectomy with lymphadenectomy in treatment of endometrial cancer: a case-matched controlled study of the first one hundred twenty two patients. *Gynecol Oncol*. 2011;120(3):413-418.

38. Kolata G. Results unproven, robotic surgery wins converts. *New York Times*. February 14, 2010:A1.

39. Jin LX, Ibrahim AM, Newman NA, Makarov DV, Pronovost PJ, Makary MA. Robotic surgery claims on United States hospital websites. *J Healthc Qual*. 2011; 33(6):48-52.

40. Lau S, Vaknin Z, Ramana-Kumar AV, Halliday D, Franco EL, Gotlieb WH. Outcomes and cost comparisons after introducing a robotics program for endometrial cancer surgery. *Obstet Gynecol*. 2012; 119(4):717-724.

> Happiness is the test of all rules of conduct and the end of life. But . . . this end was only to be attained by not making it the direct end. Those only are happy, I thought, who have their minds fixed on some object other than their own happiness; on the happiness of others, on the improvement of mankind, even on some art of pursuit, followed not as a means, but as itself an ideal end. Aiming thus at something else, they find happiness by the way.
>
> —John Stuart Mill (1806-1873)