VOLUME 30 · NUMBER 8 · MARCH 10 2012

JOURNAL OF CLINICAL ONCOLOGY

ORIGINAL REPORT

Comparative Effectiveness of Robotic Versus Laparoscopic Hysterectomy for Endometrial Cancer

Jason D. Wright, William M. Burke, Elizabeth T. Wilde, Sharyn N. Lewin, Abigail S. Charles, Jin Hee Kim, Noah Goldman, Alfred I. Neugut, Thomas J. Herzog, and Dawn L. Hershman

See accompanying editorial on page 767

Jason D. Wright, William M. Burke, Sharyn N. Lewin, Abigail S. Charles, Jin Hee Kim, Alfred I. Neugut, Thomas J. Herzog, and Dawn L. Hershman, Columbia University College of Physicians and Surgeons; Elizabeth T. Wilde, Alfred I. Neugut, and Dawn L. Hershman, Mailman School of Public Health, Columbia University; Jason D. Wright, Sharyn N. Lewin, Alfred I. Neugut, Thomas J. Herzog, and Dawn L. Hershman, Herbert Irving Comprehensive Cancer Center, Columbia University, New York, NY; and Noah Goldman, The Valley Hospital, Ridgewood, NJ.

Submitted April 25, 2011; accepted November 3, 2011; published online ahead of print at www.jco.org on January 30, 2012.

Supported by Grant No. R01 CA134964 from the National Cancer Institute, Bethesda, MD (D.L.H.).

Authors' disclosures of potential conflicts of interest and author contributions are found at the end of this article.

Corresponding author: Jason D. Wright, MD, Division of Gynecologic Oncology, Department of Obstetrics and Gynecology, Columbia University College of Physicians and Surgeons, 161 Fort Washington Ave, 8th Floor, New York, NY 10032; e-mail: jw2459@columbia.edu.

0732-183X/12/3008-783/$20.00

DOI: 10.1200/JCO.2011.36.7508

ABSTRACT

Purpose

Use of robotics in oncologic surgery is increasing; however, reports of safety and efficacy are from highly experienced surgeons and centers. We performed a population-based analysis to compare laparoscopic hysterectomy and robotic hysterectomy for endometrial cancer.

Patients and Methods

The Perspective database was used to identify women who underwent a minimally invasive hysterectomy for endometrial cancer from 2008 to 2010. Morbidity, mortality, and cost were evaluated using multivariable logistic and linear regression models.

Results

We identified 2,464 women, including 1,027 (41.7%) who underwent laparoscopic hysterectomy and 1,437 (58.3%) who underwent robotic hysterectomy. Women treated at larger hospitals, nonteaching hospitals, and centers outside of the northeast were more likely to undergo a robotic hysterectomy procedure, whereas black women, those without insurance, and women in rural areas were less likely to undergo a robotic hysterectomy procedure ($P < .05$ for all). The overall complication rate was 9.8% for laparoscopic hysterectomy versus 8.1% for robotic hysterectomy ($P = .13$). The adjusted odds ratio (OR) for any morbidity for robotic hysterectomy was 0.76 (95% CI, 0.56 to 1.03). After adjusting for patient, surgeon, and hospital characteristics, there were no significant differences in the rates of intraoperative complications (OR, 0.68; 95% CI, 0.42 to 1.08), surgical site complications (OR, 1.49; 95% CI, 0.81 to 2.73), medical complications (OR, 0.64; 95% CI, 0.40 to 1.01), or prolonged hospitalization (OR, 0.85; 95% CI, 0.64 to 1.14) between the procedures. The mean cost for robotic hysterectomy was $10,618 versus $8,996 for laparoscopic hysterectomy ($P < .001$). In a multivariable model, robotic hysterectomy was significantly more costly ($1,291; 95% CI, $985 to $1,597).

Conclusion

Despite claims of decreased complications with robotic hysterectomy, we found similar morbidity but increased cost compared with laparoscopic hysterectomy. Comparative long-term efficacy data are needed to justify its widespread use.

J Clin Oncol 30:783-791. © 2012 by American Society of Clinical Oncology

INTRODUCTION

Hysterectomy is the standard of care for endometrial cancer. The procedure is traditionally performed through a laparotomy and has been associated with substantial perioperative morbidity. In the 1990s, laparoscopic hysterectomy for endometrial cancer was introduced. Compared with open hysterectomy, the laparoscopic procedure is associated with lower morbidity and shorter hospital stays and has become the preferred treatment option for many surgeons.[1]

In the last decade, robotic surgery has emerged as an alternative minimally invasive surgical strategy for a number of cancers. Although initially used for radical prostatectomy, robotically assisted surgery has now been adopted for a wide range of procedures including hysterectomy.[2] Robotic assistance affords many advantages including three-dimensional visualization, increased freedom of instrument movement, and enhanced ergonomics and surgeon comfort.[2,3]

Despite the potential benefits of robotic hysterectomy, studies comparing it with laparoscopic hysterectomy have been small in size, nonrandomized, and limited to highly experienced surgeons and centers.[4-11] In one of the largest studies to date that included 103 robotic hysterectomies, median blood loss and operative times were lower for robotic compared with laparoscopic hysterectomy.[5] Although these studies are informative and demonstrate the feasibility of the procedure, its safety and efficacy in the community may be far different.

The use of robotic surgery is increasing.[2] Although a variety of factors influence the uptake of new technologies, marketing often plays a significant role.[12,13] Previous work has shown that many new surgical technologies are adopted when only minimal data are available.[12,14-16] This is problematic not only because these technologies may not improve clinical outcomes, but also because they are frequently associated with increased cost.[3,17,18] The goal of our analysis was to compare the perioperative morbidity, resource utilization, and cost of laparoscopic and robotic hysterectomy in a large cohort of women with endometrial cancer treated throughout the United States.

PATIENTS AND METHODS

Data Source

The Perspective database (Premier, Charlotte, NC) was used. Perspective is a voluntary, fee-supported database originally developed to measure resource utilization and quality of care (Appendix, online only). Perspective samples more than 500 acute care hospitals throughout the United States that contribute data on inpatient admissions.[19] In addition to demographics, disease characteristics, and procedures, the database collects information on all billed services. The Perspective database is validated and has been used in a number of outcomes studies.[20,21] In 2006, Perspective recorded approximately 5.5 million hospital discharges, which represent approximately 15% of nationwide hospitalizations.[19,21]

Cohort Selection and Surgical Procedures

Our analysis included women who underwent a minimally invasive hysterectomy for endometrial cancer (International Classification of Diseases, Ninth Revision [ICD-9] codes 182.0 to 182.8) between October 2008 and March 2010. Patients were stratified into the following two groups based on the type of hysterectomy performed: laparoscopic (ICD-9 code 68.41 or 68.51) or robotic (ICD-9 code 17.42 or 17.44). Women who underwent either a laparoscopically assisted vaginal hysterectomy (ICD-9 code 68.51) or a total laparoscopic hysterectomy (ICD-9 code 68.51) were included. Patients who had ICD-9 codes for both a robotically assisted and a laparoscopic procedure were included in the robotic hysterectomy cohort. Performance of lymphadenectomy was noted for each patient and defined through identification of any ICD-9 code for nodal sampling.

Clinical and Demographic Characteristics

Demographic data analyzed included age ($< v \geq 60$ years of age), race (white, black, or other), marital status (married, single, or unknown), and insurance status (Medicare, Medicaid, commercial, self-pay, or unknown). The hospitals in which patients were treated were characterized based on location (urban or rural), region of the country (northeast, midwest, west, or south), size ($<$ 400, 400 to 600, and $>$ 600 beds), and teaching status (teaching or nonteaching). Risk adjustment for comorbid conditions was performed using the Charlson comorbidity index.[22] The ICD-9 coding to define the Charlson index as reported by Deyo et al[23] was used.

Procedure Volume

For each surgeon and hospital, we determined the total number of laparoscopic and robotic hysterectomies performed during the study period. Because not all physicians and hospitals contributed data for the entire study period, we calculated annualized procedure volumes. The annualized procedure volume was estimated by dividing the total number of patients who underwent a procedure by the number of years a given surgeon or hospital contributed at least one procedure. The volumes were then divided to create three approximately equal tertiles of surgeon and hospital volume (low, intermediate, and high).[24,25] Separate volume estimates were determined for laparoscopic and robotic procedures.

Outcomes

The primary outcome of the study was perioperative morbidity. Secondary outcomes included individual complications, rates of transfusion and reoperation, mortality, and resource utilization. Perioperative morbidity was classified into the following categories: intraoperative complications (bladder injury, ureteral injury, intestinal injury, vascular injury, and other operative injury), surgical site complications (wound complications, abscess, hemorrhage, and bowel obstruction), and medical complications (venous thromboembolism, myocardial infarction, cardiopulmonary arrest, acute renal failure, respiratory failure, cerebrovascular accident, bacteremia/sepsis, shock, and pneumonia). A composite score of overall morbidity was determined based on the occurrence of any one of the complications. For each cohort, we calculated the rates of transfusion and reoperation. Rates of readmission were calculated by determining the number of patients who were readmitted to the same facility within 60 days of the initial surgery for any of the complications previously described.

We also examined a number of process measures and utilization metrics. Patients who required more than 2 days of inpatient care after the procedure were considered to have a prolonged hospitalization. The Perspective database includes an itemized, data-stamped log of all items that are billed to a patient, including drugs, laboratory and radiologic tests, and therapeutic services. Within the Perspectives database, approximately three quarters of hospitals submit direct cost data taken from internal accounting systems. The remaining institutions provide estimates based on Medicare cost to charge ratios.[19,21,26] Cost data from the Perspective database have been used in a number of outcomes studies.[19,21,26] Cost data from the index admission were examined. The discharge status of each patient was noted. Women who were transferred from an acute care hospital to a skilled nursing facility, nursing home, or an acute or subacute rehabilitation center were considered to have a nonroutine discharge. Readmission for any of the morbidities described earlier was also examined. Perioperative mortality was defined as death during the primary hospitalization.

Statistical Analysis

Frequency distributions between categorical variables were compared using χ^2 tests, whereas continuous variables were compared with one-way analysis of variance. The association between the outcomes of interest and the type of procedure performed was assessed using multivariable logistic regression models that included patient, surgeon, and hospital characteristics. Results are reported with odds ratios (ORs) and 95% CIs. Cost estimates more than three standard deviations from the mean were removed, and the remaining cost data were assessed using linear regression models including the variables described earlier. The analysis of the secondary end points was exploratory, and the 95% CIs for these estimates are not adjusted for multiplicity. All analyses were performed with STATA version 11.0 (STATA, College Station, TX) and SAS version 9.2 (SAS Institute, Cary, NC). All statistical tests were two-sided.

RESULTS

A total of 2,464 women who underwent minimally invasive hysterectomy for endometrial cancer were identified. The cohort included 1,027 patients (41.7%) who had a laparoscopic hysterectomy and 1,437 patients (58.3%) who underwent a robotic procedure. The clinical and demographic characteristics of the cohort are listed in Table 1.

Use of robotic surgery increased with time (Fig 1). In October 2008, 46.2% of the minimally invasive hysterectomies for endometrial cancer were robotic. This increased to 58.2% in June 2009 and to 61.1% in March 2010. In a multivariable model, single women (OR, 1.27; 95% CI, 1.02 to 1.58), women treated at large hospitals (OR, 2.89; 95% CI, 2.21 to 3.78), women treated at nonteaching hospitals (OR, 1.28; 95% CI, 1.04 to 1.59), and women operated on at centers outside

Table 1. Demographics and Clinical Characteristics of the Cohort Stratified by Type of Hysterectomy Performed

Demographic or Clinical Characteristic	Laparoscopic Hysterectomy		Robotic Hysterectomy		
	No. of Patients	%	No. of Patients	%	*P*
All patients	1,027	41.7	1,437	58.3	
Age at surgery, years					.12
< 60	459	44.7	597	41.6	
≥ 60	568	55.3	840	58.5	
Race					< .001
White	725	70.6	1,117	77.7	
Black	77	7.5	65	4.5	
Other	225	21.9	255	17.8	
Year of diagnosis					.17
2008	152	14.8	175	12.2	
2009	688	67.0	992	69.0	
2010	187	18.2	270	18.8	
Marital status					.60
Married	548	53.4	739	51.4	
Single	236	23.0	351	24.4	
Unknown	243	23.7	347	24.2	
Insurance status					.01
Medicare	396	38.6	542	37.7	
Commercial	529	51.5	765	53.2	
Medicaid	41	4.0	43	3.0	
Self-pay	38	3.7	31	2.2	
Unknown	23	2.2	56	3.9	
Hospital location					.003
Urban	972	94.6	1,394	97.0	
Rural	55	5.4	43	3.0	
Hospital type					.49
Nonteaching	403	39.2	584	40.6	
Teaching	624	60.8	853	59.4	
Hospital size, No. of beds					< .001
< 400	297	28.9	292	20.3	
400-600	471	45.9	548	38.2	
> 600	259	25.2	597	41.6	
Hospital region					< .001
Midwest	264	25.7	377	26.2	
Northeast	251	24.4	184	12.8	
South	354	34.5	647	45.0	
West	158	15.4	229	15.9	
Charlson comorbidity index					.37
1	593	57.7	822	57.2	
2	280	27.3	422	29.4	
≥ 3	154	15.0	193	13.4	
Lymphadenectomy					< .001
No	454	44.2	330	23.0	
Yes	573	55.8	1,107	77.0	
Surgeon volume*					.57
Low	373	36.3	523	36.4	
Intermediate	312	30.4	461	32.1	
High	342	33.3	453	31.5	
Hospital volume†					.74
Low	348	33.9	494	34.4	
Intermediate	353	34.4	473	32.9	
High	326	31.7	470	32.7	

*Surgeon volume for laparoscopic hysterectomy is categorized as follows: low, ≤ 3 procedures per year; intermediate, 3.01 to 9.3 procedures per year; and high, > 9.3 procedures per year. Surgeon volume for robotic hysterectomy is categorized as follows: low, < 9 procedures per year; intermediate, 9.01 to 14 procedures per year; and high, > 14 procedures per year.

†Hospital volume for laparoscopic hysterectomy is categorized as follows: low, ≤ 4 procedures per year; intermediate, 4.01 to 11.67 procedures per year; and high, > 11.67 procedures per year. Hospital volume for robotic hysterectomy is categorized as follows: low, ≤ 3.67 procedures per year; intermediate, 3.68 to 10 procedures per year; and high, > 10 procedures per year.

the northeast were more likely to undergo a robotic procedure (Table 2). Black women (OR, 0.46; 95% CI, 0.32 to 0.67), women without insurance (OR, 0.56; 95% CI, 0.34 to 0.94), and women residing in rural areas (OR, 0.50; 95% CI, 0.32 to 0.94) were less likely to undergo robotic hysterectomy.

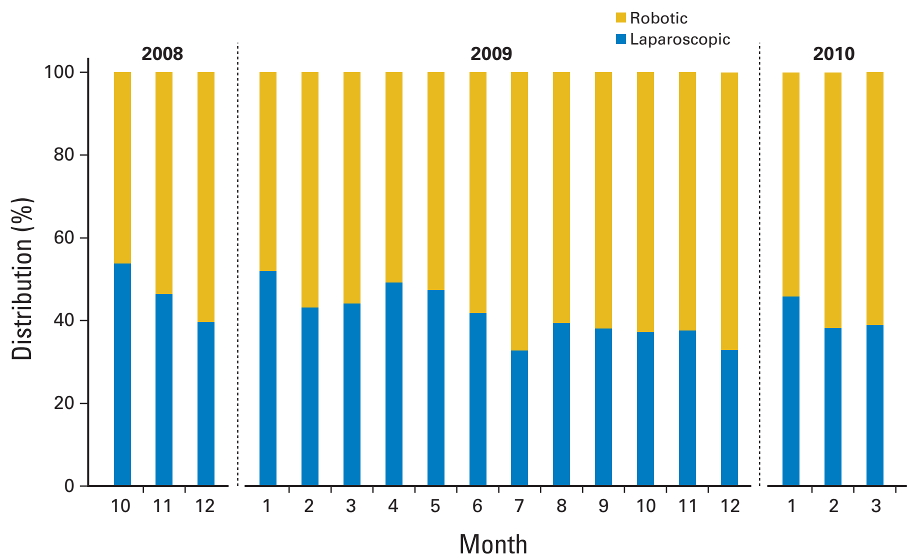
Rates of intraoperative complications (4.0% for laparoscopic *v* 3.0% for robotic; $P = .18$) and surgical site complications (1.8% for laparoscopic *v* 2.9% for robotic; $P = .08$) were similar for the two procedures, whereas medical complications (4.9% for laparoscopic *v* 2.9% for robotic; $P = .01$) were more common among women who underwent laparoscopic hysterectomy (Table 3). Prolonged length of stay (> 2 days) was noted in 11.4% of women who underwent laparoscopy compared with 9.9% of women who had a robotic procedure ($P = .23$). Although reoperation was more common in patients who underwent laparoscopy versus robotic hysterectomy (0.8% *v* 0.2%, respectively; $P = .04$), there were no differences in transfusion requirements, readmission, or rates of conversion to open laparotomy ($P > .05$ for all).

After adjusting for patient, surgeon, and hospital characteristics, there were no statistically significant differences in the rates of intraoperative complications (OR, 0.68; 95% CI, 0.42 to 1.08), surgical site complications (OR, 1.49; 95% CI, 0.81 to 2.73), medical complications (OR, 0.64; 95% CI, 0.40 to 1.01), or prolonged hospitalization (OR, 0.85; 95% CI, 0.64 to 1.14) between the cohorts (Table 4). The overall complication rate was 9.8% in women who underwent laparoscopic hysterectomy compared with 8.1% for women who underwent a robotic procedure ($P = .13$). The adjusted OR for any morbidity for robotic compared with laparoscopic hysterectomy was 0.76 (95% CI, 0.56 to 1.03). Perioperative mortality was noted in 0.2% of laparoscopic and 0.1% of robotic surgeries ($P = .74$).

The mean cost for laparoscopic hysterectomy was $8,996 compared with $10,618 for robotic hysterectomy ($P < .001$; Table 3). In a multivariable model adjusted for patient characteristics, surgeon factors, and hospital characteristics, the cost for robotic surgery was $1,291 (95% CI, $985 to $1,597) higher than laparoscopic hysterectomy (Table 5). Hospital costs were also greater in single women, patients treated at teaching hospital, patients who underwent lymphadenectomy, and patients with the most comorbidities ($P < .05$ for all). Hospital costs were lower for patients treated by high-volume surgeons and patients operated on at intermediate-volume centers ($P < .05$ for both). These results did not change significantly when the cost variable was log-transformed. Separate models of cost for robotic and laparoscopic hysterectomy are also presented in Table 5. To examine whether the cost of robotic hysterectomy decreased with surgical volume, we developed separate models for low- and high-volume surgeons. For low-volume surgeons, the cost of robotic hysterectomy was $1,488 (95% CI, $938 to $2,038) higher than for a laparoscopic procedure; for high-volume surgeons, robotic hysterectomy was $818 (95% CI, $239 to $1,397) more costly than laparoscopy. In our cohort, if all 1,680 minimally invasive hysterectomies performed in 2009 were done robotically, direct hospital costs would have been increased by more than $2,000,000.

DISCUSSION

Our findings suggest that robotic hysterectomy offers little short-term benefit over a laparoscopic procedure for women with endometrial



Laparoscopic	56	52	44	65	44	57	64	71	51	37	65	62	51	61	60	67	57	63
Robotic	48	60	67	60	58	72	66	79	71	76	100	101	86	101	122	79	92	99

Fig 1. Distribution of minimally invasive laparoscopic hysterectomies and robotic hysterectomies performed from October 2008 to March 2010.

cancer. Perioperative morbidity was similar for the two procedures, whereas resource utilization is significantly higher for robotic hysterectomy. Robotic hysterectomy is associated with substantially higher direct hospital costs.

To date, there have been no randomized trials comparing laparoscopic and robotic hysterectomy for endometrial cancer. A recent systematic review of uncontrolled case series of robotic hysterectomy for endometrial cancer that identified 589 procedures found no differences in intraoperative or postoperative complications rates, transfusion requirements, rates of conversion to laparotomy, operative times, or length of stay between women who underwent laparoscopy and women who had a robotically assisted hysterectomy. However, compared with laparoscopy, robotic hysterectomy was associated with clinically insignificant lower blood loss (mean, 182 *v* 92 mL, respectively). Lymph node yield, a measure of surgical quality, was similar for the two modalities.[27] Most of the reports included in this review were from surgeons and centers that possess significant expertise in robotic surgery.[4-11] In our population-based analysis, there were no significant differences in the morbidity of robotic and laparoscopic surgery after adjusting for patient, physician, and systems characteristics.

A major concern surrounding the use of robotic surgery is the economic viability of the technology. A single-institution series of 110 patients with endometrial cancer noted that laparoscopic and robotic surgery had similar costs and that both modalities were significantly less costly than open hysterectomy.[7] In contrast, a decision model found that laparoscopic hysterectomy was the least expensive treatment from both a hospital and societal perspective.[3] In addition to the price of the robot, which ranges from $1 million to $2.25 million, an annual service contract of $140,000 is required, and disposable instruments cost $1,500 to $2,000 per case.[13,28] Modeling studies of endometrial cancer have suggested that even if the purchase price of the robot is excluded and the price of disposable instruments is substantially reduced, laparoscopic hysterectomy remains the most economically advantageous.[3] A recent analysis of 20 types of robotically assisted procedures noted that the addition of the robot added on average $1,600, or 6% of the total procedure cost.[17] In our multivariable model, use of the robot increased direct hospital costs by nearly $1,300, more than 14% of the total hospital cost of a laparoscopic procedure.

Our data are remarkable in that by 2010, more than 60% of all minimally invasive hysterectomies for endometrial cancer were performed robotically despite the limited available data. A number of factors including perceptions, characteristics of early users, and contextual factors have been shown to drive innovation of a new technology.[12] For surgical innovations, several studies have demonstrated that the introduction of a new technique often increases aggregate use of a surgical procedure.[17,28-30] The introduction of robotic prostatectomy in the United States between 2005 and 2008 was associated with a 60% increase in the number of prostatectomies performed despite a decreasing incidence of prostate cancer.[17] Although technologic innovation cannot follow the same developmental process as that of new drugs, there is increasing recognition that more formal regulation is needed.[31] The Balliol Collaboration's Innovation, Development, Exploration, Assessment, and Long-Term Study (IDEAL) model proposed that new surgical techniques should evolve from a concept through safety exploration followed by randomized trials before widespread implementation.[14,16,31,32] The US Food and Drug Administration is currently revising its regulatory process for medical devices after substantial public criticism.[33]

We identified a number of disparities in the use of robotic hysterectomy as the technology diffused into practice. Black women were 54% less likely than white women to undergo a robotic procedure, whereas uninsured patients were 44% less likely to have a robotic hysterectomy than patients with commercial insurance. The hospital setting in which patients received care also had a strong impact on the allocation of care. Women treated at large facilities and at nonteaching hospitals were more likely to undergo robotic surgery, whereas

Table 2. Multivariable Model of Factors Associated With Performance of Robotic Hysterectomy

Factor	Robotic Hysterectomy Odds Ratio	Robotic Hysterectomy 95% CI
Age at surgery, years		
< 60	Referent	
≥ 60	1.21	0.98 to 1.50
Race		
White	Referent	
Black	0.46*	0.32 to 0.67
Other	0.61*	0.49 to 0.76
Year of diagnosis		
2008	Referent	
2009	1.24	0.97 to 1.59
2010	1.34	0.99 to 1.80
Marital status		
Married	Referent	
Single	1.27*	1.02 to 1.58
Unknown	1.07	0.86 to 1.33
Insurance status		
Commercial	Referent	
Medicare	0.83	0.66 to 1.04
Medicaid	0.72	0.45 to 1.15
Self-pay	0.56*	0.34 to 0.94
Unknown	1.07	0.63 to 1.82
Hospital location		
Urban	Referent	
Rural	0.50*	0.34 to 0.94
Hospital type		
Teaching	Referent	
Nonteaching	1.28*	1.04 to 1.59
Hospital size, No. of beds		
< 400	Referent	
400-600	1.40*	1.10 to 1.79
> 600	2.89*	2.21 to 3.78
Hospital region		
Northeast	Referent	
Midwest	1.92*	01.49 to 2.49
South	2.41*	1.88 to 3.09
West	2.50*	1.85 to 3.38
Charlson comorbidity index		
1	Referent	
2	1.16	0.96 to 1.41
≥ 3	0.96	0.75 to 1.24

*$P < .05$.

Table 3. Perioperative Morbidity, Mortality, and Resource Usage of Laparoscopic and Robotic Hysterectomy

Perioperative Morbidity, Mortality, and Resource Usage	Laparoscopic Hysterectomy No. of Patients	Laparoscopic Hysterectomy %	Robotic Hysterectomy No. of Patients	Robotic Hysterectomy %	*P*
All patients	1,027	41.7	1,437	58.3	
Any complication	101	9.8	116	8.1	.13
Intraoperative complications	41	4.0	43	3.0	.18
Bladder injury	10	1.0	5	0.3	.05
Ureteral injury	7	0.7	6	0.4	.37
Intestinal injury	5	0.5	8	0.6	.81
Vascular injury	1	0.1	2	0.1	.77
Other operative injury	32	3.1	31	2.2	.14
Surgical site complications	18	1.8	41	2.9	.08
Wound complication	15	1.5	25	1.7	.59
Abscess	3	0.3	2	0.1	.41
Hemorrhage	0	—	0	—	
Bowel obstruction	10	1.0	29	2.0	.41
Medical complications	50	4.9	42	2.9	.01
Venous thromboembolism	4	0.4	11	0.8	.24
Myocardial infarction	0	—	0	—	
Cardiopulmonary arrest	1	0.1	0	—	.24
Respiratory failure	33	3.2	31	2.2	.10
Renal failure	12	1.2	8	0.6	.10
Stroke	2	0.2	0	—	.09
Bacteremia/sepsis	3	0.3	2	0.1	.41
Shock	7	0.7	5	0.3	.24
Pneumonia	3	0.3	2	0.1	.41
Resource usage					
Subcutaneous emphysema	2	0.2	2	0.1	.74
Transfusion	33	3.2	31	2.2	.10
Reoperation	8	0.8	3	0.2	.04
Length of stay > 2 days	117	11.4	142	9.9	.23
Readmission	0	—	2	0.1	
Mean hospital cost, $	8,996		10,618		< .001
Nonroutine discharge	20	1.9	22	1.5	.62
Death	2	0.2	2	0.1	.74

women treated at rural hospitals were 50% less likely to undergo a robotic hysterectomy. These disparities mirror those seen with the introduction of laparoscopy for a number of different procedures.[34-36]

We recognize several important limitations in our study. Because the primary purpose of claims data is for billing, complications are often under-reported. To minimize this bias, we focused our analysis on major perioperative complications that are likely to generate a claim. Any under-reporting of complications would have been equally likely in both cohorts. Although the Perspective database contains a sample of women from throughout the United States, our findings may not be generalizable to the entire US health care system. Perspective lacks data on tumor characteristics such as histology, grade, stage, and depth of invasion that impact treatment. Although we included only patients who underwent minimally invasive surgery, and the indications are the same for both procedures, some degree of procedure selection likely occurred based on tumor characteristics. We cannot exclude the possibility that some patients' procedures were misclassified. However, even during the early months of the study, the relative number of patients who underwent robotic surgery was high, suggesting that ICD-9 coding for robotic surgery was well recognized. With any new procedure, a learning curve exists for physicians, and this is certainly true for robotic surgery.[11] We attempted to account for this by including surgical volume as a covariate in our analysis, but we recognize that costs may be lower as surgeons become more familiar with the technology and operative times decrease. Our costing data are based on a nationwide sample of directly reported hospital costs or estimates. Certainly wide variations in cost exist based on whether acquisition and maintenance costs are included and whether costs of disposable instruments are included; however, we feel that, if anything, our costs are likely to underestimate the true costs. A number of factors, including lymphadenectomy, which was more common in the robotic hysterectomy group, also had a strong influence on cost. Finally, it should be recognized that both procedures were associated with low overall morbidity, limiting our power to detect statistically

Table 4. Multivariable Analysis of Factors Associated With Morbidity for Women Undergoing Minimally Invasive Hysterectomy for Endometrial Cancer

	Intraoperative Complications		Surgical Site Complications		Medical Complications		Prolonged Hospitalization		Any Morbidity	
Factor	Odds Ratio	95% CI	Odds Ratio	95% CI	Odds Ratio	95% CI	Odds Ratio	95% CI	Odds Ratio	95% CI
Surgery										
Laparoscopic	Referent		Referent		Referent		Referent		Referent	
Robotic	0.68	0.42 to 1.08	1.49	0.81 to 2.73	0.64	0.40 to 1.01	0.85	0.64 to 1.14	0.76	0.56 to 1.03
Age at surgery, years										
< 60	Referent		Referent		Referent		Referent		Referent	
≥ 60	0.73	0.41 to 1.29	1.07	0.53 to 2.16	1.12	0.62 to 2.01	0.82	0.56 to 1.18	1.03	0.72 to 1.50
Race										
White	Referent		Referent		Referent		Referent		Referent	
Black	0.34	0.08 to 1.45	2.84*	1.21 to 6.70	2.19*	1.06 to 4.55	1.19	0.70 to 2.05	1.36	0.79 to 2.36
Other	0.50	0.26 to 0.98	1.32	0.65 to 2.70	1.85*	1.05 to 3.29	1.27	0.89 to 1.81	0.90	0.60 to 1.35
Year of diagnosis										
2008	Referent		Referent		Referent		Referent		Referent	
2009	1.23	0.61 to 2.45	1.04	0.46 to 2.39	0.81	0.43 to 1.55	0.88	0.59 to 1.31	0.96	0.62 to 1.49
2010	1.14	0.52 to 2.50	0.72	0.28 to 1.82	0.80	0.38 to 1.68	0.70	0.43 to 1.14	0.99	0.60 to 1.61
Marital status										
Married	Referent		Referent		Referent		Referent		Referent	
Single	2.02*	1.21 to 3.39	1.26	0.64 to 2.48	1.34	0.77 to 2.33	1.25	0.88 to 1.76	1.54*	1.09 to 2.19
Unknown	0.98	0.52 to 1.82	1.14	0.58 to 2.23	0.88	0.50 to 1.54	1.46	1.05 to 2.04	0.91	0.62 to 1.33
Insurance status										
Commercial	Referent		Referent		Referent		Referent		Referent	
Medicare	1.26	0.69 to 2.31	1.57	0.77 to 3.20	1.88*	1.05 to 3.38	2.31*	1.59 to 3.38	1.41	0.96 to 2.06
Medicaid	1.55	0.52 to 4.60	0.54	0.07 to 4.22	1.17	0.38 to 3.62	3.21*	1.76 to 5.83	1.64	0.81 to 3.32
Self-pay	0.82	0.19 to 3.58	2.85	0.90 to 8.99	0.77	0.17 to 3.45	1.10	0.45 to 2.69	1.42	0.64 to 3.17
Unknown	1.15	0.26 to 5.17	1.77	0.37 to 8.42	1.57	0.43 to 5.74	0.86	0.29 to 2.51	0.94	0.35 to 2.60
Hospital location										
Urban	Referent		Referent		Referent		Referent		Referent	
Rural	0.77	0.24 to 2.61	1.15	0.25 to 5.28	1.14	0.32 to 3.97	0.50	0.19 to 1.28	0.67	0.28 to 1.62
Hospital type										
Teaching	Referent		Referent		Referent		Referent		Referent	
Nonteaching	1.69	0.94 to 3.04	0.52	0.23 to 1.18	0.85	0.45 to 1.61	1.05	0.74 to 1.49	1.02	0.69 to 1.52
Hospital size, No. of beds										
< 400	Referent		Referent		Referent		Referent		Referent	
400-600	2.33*	1.19 to 4.55	0.98	0.35 to 2.72	2.61*	1.14 to 5.98	1.41	0.93 to 2.15	1.84*	1.14 to 2.98
> 600	1.21	0.56 to 2.60	1.71	0.62 to 4.73	2.03	0.86 to 4.80	1.27	0.80 to 2.00	1.62	0.97 to 2.69
Hospital region										
Northeast	Referent		Referent		Referent		Referent		Referent	
Midwest	1.05	0.55 to 1.99	1.46	0.68 to 3.17	1.14	0.63 to 2.05	1.12	0.75 to 1.68	1.16	0.76 to 1.76
South	0.50	0.25 to 1.01	0.77	0.35 to 1.71	0.60	0.32 to 1.11	0.77	0.52 to 1.15	0.73	0.48 to 1.11
West	0.74	0.34 to 1.61	0.74	0.24 to 2.25	0.23*	0.08 to 0.66	0.73	0.44 to 1.22	0.60	0.35 to 1.06
Charlson comorbidity index										
1	Referent		Referent		Referent		Referent		Referent	
2	1.05	0.63 to 1.77	1.27	0.68 to 2.36	1.68	0.97 to 2.90	1.43*	1.04 to 1.97	1.23	0.87 to 1.73
≥ 3	1.45	0.79 to 2.65	2.15*	1.08 to 4.26	4.41*	2.59 to 7.50	3.27*	2.32 to 4.60	2.58*	1.79 to 3.71
Lymphadenectomy										
No	Referent		Referent		Referent		Referent		Referent	
Yes	1.58	0.92 to 2.70	2.10*	1.01 to 4.37	1.08	0.65 to 1.78	1.16	0.85 to 1.58	1.42*	1.01 to 2.01
Surgeon volume										
Low	Referent		Referent		Referent		Referent		Referent	
Intermediate	0.70	0.38 to 1.29	0.67	0.32 to 1.43	0.60	0.31 to 1.15	0.57*	0.40 to 0.82	0.70	0.47 to 1.06
High	0.88	0.45 to 1.71	0.85	0.39 to 1.84	1.06	0.65 to 1.78	0.42*	0.28 to 0.65	1.06	0.70 to 1.62
Hospital volume										
Low	Referent		Referent		Referent		Referent		Referent	
Intermediate	0.57	0.31 to 1.05	0.83	0.40 to 1.70	0.90	0.48 to 1.70	1.25	0.87 to 1.79	0.69	0.46 to 1.03
High	0.62	0.30 to 1.30	0.54	0.22 to 1.33	0.99	0.48 to 2.04	0.97	0.61 to 1.54	0.66	0.41 to 1.07

*$P < .05$.

Table 5. Multivariable Analysis of Factors Associated With Cost for Women Undergoing Minimally Invasive Hysterectomy for Endometrial Cancer

	All Patients		Laparoscopic Hysterectomy		Robotic Hysterectomy	
Factor	Cost ($)	95% CI	Cost ($)	95% CI	Cost ($)	95% CI
Surgery						
Laparoscopic	Referent		—		—	
Robotic	1,291*	985 to 1,597	—		—	
Age at surgery, years						
< 60	Referent		Referent		Referent	
≥ 60	290	−67 to 648	361	−137 to 856	109	−355 to 573
Race						
White	Referent		Referent		Referent	
Black	676*	41 to 1,311	−33	−822 to 756	1,055*	132 to 1,977
Other	1,469*	1,078 to 1,859	547*	6 to 1,088	2,167*	1,642 to 2,691
Year of diagnosis						
2008	Referent		Referent		Referent	
2009	−806*	−1,256 to −356	−438	−995 to 119	−886*	−1,565 to −206
2010	−1,043*	−1,554 to −532	−711*	−1,390 to −32	−1,179*	−1,867 to −491
Marital status						
Married	Referent		Referent		Referent	
Single	545*	177 to 913	98	−407 to 602	866*	378 to 1,354
Insurance status						
Commercial	Referent		Referent		Referent	
Medicare	217	−163 to 597	155	−368 to 677	186	−308 to 680
Medicaid	929*	129 to 1,729	1,680*	653 to 2,707	−80	−1,201 to 1,040
Self-pay	4	−871 to 880	303	−737 to 1,343	−302	−1,600 to 996
Unknown	1,266*	405 to 2,127	327	−1,020 to 1,673	807	−281 to 1,896
Hospital location						
Urban	Referent		Referent		Referent	
Rural	−587	−1,342 to 166	−456	−1,374 to 462	−412	−1,564 to 741
Hospital type						
Teaching	Referent		Referent		Referent	
Nonteaching	−1,908*	−2,280 to −1,537	−1,069*	−1,607 to −531	−1,904*	−2,411 to −1,397
Hospital size, No. of beds						
< 400	Referent		Referent		Referent	
400-600	−7	−434 to 448	−237	−836 to 363	−42	−705 to 621
> 600	−417	−886 to 53	213	−426 to 852	−774*	−1,463 to 85
Hospital region						
Northeast	Referent		Referent		Referent	
Midwest	−138	−598 to 321	303	−262 to 867	−937*	−1,626 to −247
South	232	−205 to 670	−486	−1,039 to 68	171	−483 to 825
West	893*	358 to 1,429	227	−507 to 960	856*	97 to 1,616
Charlson comorbidity index						
1	Referent		Referent		Referent	
2	92	−234 to 419	484*	34 to 933	−2	−426 to 422
≥ 3	1,102*	668 to 1,536	825*	244 to 1,406	1,058	477 to 1,639
Lymphadenectomy						
No	Referent		Referent		Referent	
Yes	1,171*	841 to 1,500	1,414*	986 to 1,842	631*	181 to 1,082
Surgeon volume						
Low	Referent		Referent		Referent	
Intermediate	165	−234 to 564	−410	−1,017 to 197	240	−301 to 781
High	−1,336*	−1,776 to −897	−1,168*	−1,871 to −465	−1,441*	−2,043 to −840
Hospital volume						
Low	Referent		Referent		Referent	
Intermediate	−416*	−815 to −16	690*	31 to 1,348	−1,013*	−1,562 to −464
High	280	−200 to −762	547	−227 to 1,321	365	−335 to 1,065

*$P < .05$.

significant differences between groups. Although there were no statistically significant differences in morbidity, there was a trend toward fewer medical complications in the robotic hysterectomy group.

Our findings raise questions as to the role of robotic surgery in the treatment of endometrial cancer. Robotic technology initially gained widespread utilization in urology.[2] Because laparoscopic prostatectomy is technically demanding and not routinely performed, robotics introduced a minimally invasive surgical option for prostatectomy.[2] In contrast, laparoscopic hysterectomy is well described, technically feasible, and now taught in most training programs.[1] However, despite the availability of laparoscopic hysterectomy, a 2008 survey demonstrated that only 8% of gynecologic oncologists used the procedure in more than 50% of their patients.[37] Even though laparoscopy is less costly, surgeon preferences for robotics may allow some women to undergo a minimally invasive procedure who may otherwise have undergone laparotomy. Proponents of robotic hysterectomy also argue that robotic capabilities allow surgeons to perform more technically challenging procedures without resorting to laparotomy.[3,27] Although difficult to measure, this may be an important advantage of robotics. Finally, further data are needed to compare the oncologic outcomes of robotic and laparoscopic hysterectomy and to compare quality of life after the procedures.

Our study demonstrates that both robotic hysterectomy and laparoscopic hysterectomy are well tolerated and associated with similar morbidity profiles. Despite the rapid uptake of robotic hysterectomy, there seems to be little short-term benefit for the procedure. Compared with laparoscopic hysterectomy, robotic procedures are associated with substantially greater direct hospital costs. Our findings highlight the potential pitfalls of the rapid uptake of new technology before the availability of rigorous data to demonstrate efficacy and cost effectiveness. Defining the comparative effectiveness for new technologies and surgical approaches is necessary before rapid dissemination.

AUTHORS' DISCLOSURES OF POTENTIAL CONFLICTS OF INTEREST

Although all authors completed the disclosure declaration, the following author(s) indicated a financial or other interest that is relevant to the subject matter under consideration in this article. Certain relationships marked with a "U" are those for which no compensation was received; those relationships marked with a "C" were compensated. For a detailed description of the disclosure categories, or for more information about ASCO's conflict of interest policy, please refer to the Author Disclosure Declaration and the Disclosures of Potential Conflicts of Interest section in Information for Contributors.
Employment or Leadership Position: None **Consultant or Advisory Role:** None **Stock Ownership:** None **Honoraria:** William M. Burke, Intuitive Surgical **Research Funding:** None **Expert Testimony:** None **Other Remuneration:** None

AUTHOR CONTRIBUTIONS

Conception and design: Jason D. Wright, William M. Burke, Dawn L. Hershman
Financial support: Jason D. Wright
Administrative support: Jason D. Wright
Collection and assembly of data: Jason D. Wright, Abigail S. Charles, Dawn L. Hershman
Data analysis and interpretation: All authors
Manuscript writing: All authors
Final approval of manuscript: All authors

REFERENCES

1. Walker JL, Piedmonte MR, Spirtos NM, et al: Laparoscopy compared with laparotomy for comprehensive surgical staging of uterine cancer: Gynecologic Oncology Group Study LAP2. J Clin Oncol 27:5331-5336, 2009

2. Wilson EB: The evolution of robotic general surgery. Scand J Surg 98:125-129, 2009

3. Barnett JC, Judd JP, Wu JM, et al: Cost comparison among robotic, laparoscopic, and open hysterectomy for endometrial cancer. Obstet Gynecol 116:685-693, 2010

4. Veljovich DS, Paley PJ, Drescher CW, et al: Robotic surgery in gynecologic oncology: Program initiation and outcomes after the first year with comparison with laparotomy for endometrial cancer staging. Am J Obstet Gynecol 198:679.e1-9, 2008

5. Boggess JF, Gehrig PA, Cantrell L, et al: A comparative study of 3 surgical methods for hysterectomy with staging for endometrial cancer: Robotic assistance, laparoscopy, laparotomy. Am J Obstet Gynecol 199:360.e1-9, 2008

6. Gehrig PA, Cantrell LA, Shafer A, et al: What is the optimal minimally invasive surgical procedure for endometrial cancer staging in the obese and morbidly obese woman? Gynecol Oncol 111:41-45, 2008

7. Bell MC, Torgerson J, Seshadri-Kreaden U, et al: Comparison of outcomes and cost for endometrial cancer staging via traditional laparotomy, standard laparoscopy and robotic techniques. Gynecol Oncol 111:407-411, 2008

8. Holloway RW, Ahmad S, DeNardis SA, et al: Robotic-assisted laparoscopic hysterectomy and lymphadenectomy for endometrial cancer: Analysis of surgical performance. Gynecol Oncol 115:447-452, 2009

9. Seamon LG, Bryant SA, Rheaume PS, et al: Comprehensive surgical staging for endometrial cancer in obese patients: Comparing robotics and laparotomy. Obstet Gynecol 114:16-21, 2009

10. Seamon LG, Cohn DE, Henretta MS, et al: Minimally invasive comprehensive surgical staging for endometrial cancer: Robotics or laparoscopy? Gynecol Oncol 113:36-41, 2009

11. Lim PC, Kang E, Park do 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 120: 413-418, 2011

12. Berwick DM: Disseminating innovations in health care. JAMA 289:1969-1975, 2003

13. Kolata G: Results unproven, robotic surgery wins converts. The New York Times. http://www.nytimes.com/2010/02/14/health/14robot.html?pagewanted=all

14. Barkun JS, Aronson JK, Feldman LS, et al: Evaluation and stages of surgical innovations. Lancet 374:1089-1096, 2009

15. Karamlou T, Diggs BS, Ungerleider RM, et al: The rush to atrial septal defect closure: Is the introduction of percutaneous closure driving utilization? Ann Thorac Surg 86:1584-1590, 2008

16. McCulloch P, Altman DG, Campbell WB, et al: No surgical innovation without evaluation: The IDEAL recommendations. Lancet 374:1105-1112, 2009

17. Barbash GI, Glied SA: New technology and health care costs: The case of robot-assisted surgery. N Engl J Med 363:701-704, 2010

18. Breitenstein S, Nocito A, Puhan M, et al: Robotic-assisted versus laparoscopic cholecystectomy: Outcome and cost analyses of a case-matched control study. Ann Surg 247:987-993, 2008

19. Lagu T, Rothberg MB, Nathanson BH, et al: The relationship between hospital spending and mortality in patients with sepsis. Arch Intern Med 171:292-299, 2011

20. Lindenauer PK, Pekow P, Wang K, et al: Perioperative beta-blocker therapy and mortality after major noncardiac surgery. N Engl J Med 353: 349-361, 2005

21. Lindenauer PK, Pekow PS, Lahti MC, et al: Association of corticosteroid dose and route of administration with risk of treatment failure in acute exacerbation of chronic obstructive pulmonary disease. JAMA 303:2359-2367, 2010

22. Charlson ME, Pompei P, Ales KL, et al: A new method of classifying prognostic comorbidity in longitudinal studies: Development and validation. J Chronic Dis 40:373-383, 1987

23. Deyo RA, Cherkin DC, Ciol MA: Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. J Clin Epidemiol 45:613-619, 1992

24. Hollenbeck BK, Wei Y, Birkmeyer JD: Volume, process of care, and operative mortality for cystectomy for bladder cancer. Urology 69:871-875, 2007

25. Birkmeyer JD, Sun Y, Wong SL, et al: Hospital volume and late survival after cancer surgery. Ann Surg 245:777-783, 2007

26. Rothberg MB, Pekow PS, Lahti M, et al: Antibiotic therapy and treatment failure in patients hospitalized for acute exacerbations of chronic obstructive pulmonary disease. JAMA 303:2035-2042, 2010

27. Gaia G, Holloway RW, Santoro L, et al: Robotic-assisted hysterectomy for endometrial cancer compared with traditional laparoscopic and laparotomy approaches: A systematic review. Obstet Gynecol 116:1422-1431, 2010

28. Makarov DV, Yu JB, Desai RA, et al: The association between diffusion of the surgical robot and radical prostatectomy rates. Med Care 49:333-339, 2011

29. Steiner CA, Bass EB, Talamini MA, et al: Surgical rates and operative mortality for open and laparoscopic cholecystectomy in Maryland. N Engl J Med 330:403-408, 1994

30. Tunis SR, Bass EB, Steinberg EP: The use of angioplasty, bypass surgery, and amputation in the management of peripheral vascular disease. N Engl J Med 325:556-562, 1991

31. McCulloch P, Schuller F: Innovation or regulation: IDEAL opportunity for consensus. Lancet 376: 1034-1036, 2010

32. Johnson J, Rogers W, Lotz M, et al: Ethical challenges of innovative surgery: A response to the IDEAL recommendations. Lancet 376:1113-1115, 2010

33. Walker EP: FDA's fast-track medical device approval process under fire. ABC News. http://abcnews.go.com/Health/Wellness/medical-devices-government-office-accountability-finds-holes-fdas/story?id=13368464#.TvnMXtQ7XNU

34. Abenhaim HA, Azziz R, Hu J, et al: Socioeconomic and racial predictors of undergoing laparoscopic hysterectomy for selected benign diseases: Analysis of 341487 hysterectomies. J Minim Invasive Gynecol 15:11-15, 2008

35. Guller U, Jain N, Curtis LH, et al: Insurance status and race represent independent predictors of undergoing laparoscopic surgery for appendicitis: Secondary data analysis of 145,546 patients. J Am Coll Surg 199:567-575, 2004

36. Csikesz NG, Tseng JF, Shah SA: Trends in surgical management for acute cholecystitis. Surgery 144:283-289, 2008

37. Naumann RW, Coleman RL: The use of adjuvant radiation therapy in early endometrial cancer by members of the Society of Gynecologic Oncologists in 2005. Gynecol Oncol 105:7-12, 2007

