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Original Article

Comparing Robot-Assisted with Conventional Laparoscopic Hysterectomy: Impact on Cost and Clinical Outcomes

Resad P. Pasic, MD, PhD, John A. Rizzo, PhD, Hai Fang, PhD, Susan Ross, MD, Matt Moore, MHA, and Candace Gunnarsson, EdD*

From the University of Louisville, Louisville, Kentucky (Dr. Pasic), Stony Brook University, Stony Brook, New York (Dr. Rizzo), the University of Colorado, Denver, Colorado (Dr. Fang), S2 Statistical Solutions, Inc., Cincinnati, Ohio (Drs. Ross and Gunnarsson), and Ethicon Endo-Surgery, Inc., Cincinnati, Ohio (Mr. Moore).

ABSTRACT **Objective:** To compare clinical and economic outcomes (hospital costs) in women undergoing laparoscopic hysterectomy performed with and without robotic assistance in inpatient and outpatient settings.

Methods: Using the Premier hospital database, we identified women >18 years of age with a record of minimally invasive hysterectomy performed in 2007 to 2008. Univariable and multivariable analyses examined the association between robot-assisted hysterectomy and adverse events, hospital costs, surgery time, and length of stay.

Results: Of 36 188 patient records analyzed from 358 hospitals, 95% (n = 34 527) of laparoscopic hysterectomies were performed without robotic assistance. Inpatient and outpatient settings did not differ substantively in frequency of adverse events. For cardiac, neurologic, wound, and vascular complications, frequencies were <1% for robot and non-robot procedures. In inpatient and outpatient settings alike, use of robotic assistance was consistently associated with statistically significant, higher per-patient average hospital costs. Inpatient procedures with and without robotic assistance cost $9640 (95% confidence interval [CI] = $9621, $9659) versus $6973 (95% CI = $6959, $6987), respectively. Outpatient procedures with and without robotic assistance cost $7920 (95% CI = $7898, $7942) versus $5949 (95% CI = $5932, $5966), respectively. Inpatient surgery times were significantly longer for robot-assisted procedures, 3.22 hours (95% CI = 3.21, 3.23) compared with non-robot procedures at 2.82 hours (95% CI = 2.81, 2.83). Similarly, outpatient surgery times with robot averaged 2.99 hours (95% CI = 2.98, 3.00) versus 2.46 hours (2.45, 2.47) for non-robot procedures.

Conclusion: Our findings reveal little clinical differences in perioperative and postoperative events. This, coupled with the increased per-case hospital cost of the robot, suggests that further investigation is warranted when considering this technology for routine laparoscopic hysterectomies. Journal of Minimally Invasive Gynecology (2010) 17, 730–738 © 2010 AAGL. All rights reserved.

Keywords: Hysterectomy; Robot assisted; Laparoscopic

Laparoscopic hysterectomy represents a minority of the 600 000 hysterectomies performed annually in the United States, but it is increasing [1–3]. Its expanding use in comparison with conventional laparotomy has been fueled by widely recognized clinical benefits, including smaller surgical incisions, shorter recovery and hospitalization times, and less pain and intraoperative blood loss. Yet, despite its growth and clinical advantages, the use of laparoscopic hysterectomy continues to lag well behind conventional laparotomy. Key reasons for this are the real and perceived technical obstacles of performing minimally invasive hysterectomies. Robot-assisted laparoscopy is a technology that has emerged as one approach to help surgeons address these challenges, but, because of the lack of high-level clinical and economic evidence comparing robotic to traditional minimally invasive techniques, a comprehensive understanding of its value for routine hysterectomies remains uncertain.

Only one robotic device has been approved by the U.S. Food and Drug Administration for laparoscopic gynecologic procedures (da Vinci Surgical System; Intuitive Surgical, Inc.,

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Corresponding author: Candace L. Gunnarsson, EdD, S2 Statistical Solutions, Inc., 11176 Main Street, Cincinnati, OH 45241.
E-mail: candaceg@s2stats.com

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Sunnyvale, CA). It was first marketed in 2000 for general surgical procedures and in 2005 for gynecologic procedures [4]. Feasibility studies in women with benign disease support its technical advantages, particularly in patients with adhesions from prior surgery, inflammation, or endometriosis [5]. Clinical outcomes suggest that it is equivalent to conventional laparoscopy when considering important endpoints such as operative time, blood loss, and hospital stay [6–8]. Several authors have argued for its use in gynecologic oncology [9,10], but there is little evidence supporting its role in routine laparoscopic hysterectomy. Studies that have found benefits for this purpose are generally single-institution, retrospective case series involving small numbers of patients [8,11–13].

Despite limited evidence to support incremental value, hospitals are rapidly acquiring robotic technology and using it routinely in gynecologic surgery. This fast adoption and diffusion raises important questions about resource allocation and the economically responsible use of this technology, because the systems typically cost $1 million to $2.3 million (Intuitive Surgical Investor Presentation Q4 2009), not including ancillary equipment such as endoscopic wrist instruments, drapes, and disposable equipment or the reductions in number of procedures because of operating room specialization. In this era of health care reform and with concerns about optimal resource use at the forefront, this trend deserves further attention. Within this framework, we examined the use of the robot by evaluating clinical and economic outcomes (hospital costs) in women undergoing laparoscopic hysterectomy performed with and without robotic assistance.

Materials and Methods

Data Source

We used the Premier hospital database as the data source [14]. This database contains complete patient billing, hospital cost, and coding histories from more than 600 health care facilities throughout the United States. These data include information from more than 25 million inpatient discharges and 175 million hospital outpatient visits from acute care facilities, ambulatory surgery centers, and clinics across the nation. A protocol describing the analysis objectives, criteria for patient selection, data elements of interest, and statistical methods was submitted to the New England Institutional Review Board and exemption was obtained.

Eligible patients were female and at least 18 years of age with a record of a minimally invasive primary and nonemergent hysterectomy. They were categorized by type of hysterectomy: total laparoscopic hysterectomy (TLH), where the entire uterus is removed completely via laparoscopic instruments; laparoscopic-assisted vaginal hysterectomy (LAVH), where the uterus is removed combining a laparoscopic and vaginal approach; laparoscopic supracervical hysterectomy (LSH), where the uterus is only partially removed, leaving the cervix in place; and laparoscopic radical hysterectomy (LRH) without or with pelvic lymphadenectomy (LRHL). We selected only procedures performed in 2007 or 2008, and these patients were identified by Classification of Diseases, 9th edition (ICD-9) procedure codes and current procedural terminology (CPT) codes (Appendix). All patients had to have a minimum of 30 calendar days of follow-up after the date of hysterectomy.

For all eligible patients, we obtained data elements describing hospital cost, surgery time, length of stay, use of robot (identified by billing codes for use of robot-specific ancillaries), hysterectomy type, and indication for hysterectomy by ICD-9 codes. The cost analysis (calculation) reflected the cost of the robotic procedure to the hospital but did not include acquisition or maintenance costs of the robotic device over time. The preoperative Patient Refined Diagnosis Related Groups severity level was used as an index of comorbidity. Comorbid conditions that might influence procedure selection or outcomes of interest were obtained, such as the presence of cardiovascular or pulmonary disease, cancer, or diabetes mellitus. We also included information on sociodemographic characteristics and health insurance status. Descriptors of the care setting were captured, namely census region, surgical specialty, inpatient or outpatient setting, urban or rural setting, teaching hospital status, and facility bed count.

We extracted adverse events (identified by ICD-9 codes) that occurred during and within 30 days after surgery. Myocardial infarction was the primary cardiac event of interest. Genitourinary events included kidney failure, fistulas, ureteral and bladder injuries, and adhesions. Gastrointestinal events included fistulas, adhesions, perforations, and peritonitis. Hemorrhage was categorized as major or minor on the basis of ICD-9 codes, diagnosis, and procedure codes.

Included in the infection category was any infection at any site reported after surgery in the interval up to 30 days after discharge. Neurologic adverse events included transient ischemic attacks and strokes. Pulmonary complications of interest were atelectasis and pneumothorax. The primary vascular event was venous thromboembolism at any anatomic location. Wound complications included vaginal dehiscence or seroma or other sequelae of inadequate wound healing. The “other” category encompassed shock and perforations or fistulas of organs or vessels not included in the aforementioned organ systems.

Statistical Analyses

The main study objective was to compare clinical and economic outcomes in patients undergoing laparoscopic hysterectomy with and without the use of robotic assistance, including adverse events, hospital costs, length of stay, and surgery time. Costs were the actual costs incurred by the hospital for all treatments and services related to hysterectomy. Univariable and multivariable analyses were performed to examine the association between robot-assisted hysterectomy and adverse events, hospital costs, surgery time, and length of stay. Multivariable analyses were estimated by ordinary least squares regression. The multivariable analysis controlled for hysterectomy type, comorbidities, indication for surgery, patient sociodemographics, and hospital and physician characteristics.

Multivariable regression models were run by clustering the hospitals. For the patients treated in the same hospital, costs and clinical outcomes are not independent. Without controlling for this cluster issue, the standard errors in the multivariable regressions are incorrect (often underestimated). We have used hospital identification numbers as a cluster and control for this cluster issue in all the multivariable regressions. All the standard means and p-values are reported after having controlled for these robust cluster effects.

In addition, complexity of the procedure, defined as procedures for malignant indications or for removal of a large uterus, or patients with adhesions, was also included in the multivariable models. This controlled for confounding effects that might otherwise bias the relationship between robot-assisted hysterectomy and the outcomes of interest. Each of the variables used in these multivariable models is described in Table 1.

Multivariable models for hospital costs and surgery time were estimated separately for inpatients and outpatients. Following standard practice, hospital costs, surgery time, and length of stay were transformed to natural logarithms to normalize their distributions. In the inpatient data analyses, weights provided in the Premier database were used to transform the results in a manner that permitted generalizability to the U.S. population. These weights were available only for inpatients. All analyses were performed with SAS Version 9.1 (SAS Institute, Inc., Cary, NC).

Results

There were 38 982 elective primary hysterectomies in eligible patients in the database. Because key data were missing in 2794 patients, they were excluded from the analysis. As a result, a total of 36 188 patient records from 358 hospitals were analyzed. A patient attrition diagram is shown in Fig. 1.

Ninety-five percent of all laparoscopic hysterectomies were performed without the use of robot assistance (n = 34 527). Seventy-one percent of these (n = 25 789) were performed in an inpatient setting, but a substantial portion was performed in outpatient settings (n = 8738). Robot assistance was used in 1661 procedures, or slightly less than 5% of the total hysterectomies. The difference between inpatient and outpatient settings was comparable to the nonrobotic population, with 77% (n = 1282) of these procedures performed on inpatients, and the remainder performed on outpatients.

There were no differences in the age or racial distributions of patients undergoing robot-assisted laparoscopic hysterectomy compared with those undergoing laparoscopic hysterectomy without robotic assistance (Table 1). Furthermore, no differences in comorbidities or illness severity index were noted between robot and nonrobot groups. There were no apparent differences in types of primary insurance of these patients.

Differences were noted, however, with regard to indications for surgery. Malignant conditions were more common among robot-assisted hysterectomies, particularly malignancies involving the uterus. Complex surgeries, defined as procedures for malignant indications, or for removal of a large uterus, or patients with adhesions, comprised 32% of all inpatient robot procedures, and 19% of inpatient nonrobot hysterectomies. The outpatient procedures demonstrated similar differences between robot and nonrobot populations in terms of the frequency of complex surgeries.

Characteristics of the 358 hospitals with hysterectomy procedures in the database are summarized in Table 2. Of these, a small minority (n = 45, or 13%) had robot capabilities that were used in laparoscopic hysterectomy procedures in 2007 and 2008. Geographic location, care setting, and surgical specialty did not differ substantially between robot and nonrobot hospital groups. However, the types of hospitals did differ: urban hospitals and teaching hospitals were more likely to have robotic capabilities. Hospitals with higher numbers of beds were also more likely to have robotic capabilities.

Hospital costs per patient for laparoscopic hysterectomies with and without robot assistance were weighted by type of hysterectomy and by care setting (inpatient or outpatient) for unadjusted analyses (Table 3). Irrespective of whether robot assistance was used, inpatient procedures cost more than outpatient procedures across all hysterectomy types. For inpatient procedures, the use of robot assistance was consistently associated with higher per-patient average hospital costs when stratified by type of hysterectomy. In the outpatient setting, the same was true for most types of hysterectomy. LRHL was the only hysterectomy approach in which the use of robot assistance was associated with lower average hospital costs per patient. It should be noted, however, that the figures available for analysis of outpatient LRHL were very small, with only 11 patients for the robotic group. In outpatient LRH, the hospital costs of robot versus nonrobot procedures were approximately equal. In all other outpatient procedures, the average hospital cost per patient for robot-assisted procedures was higher.

Table 3 also shows the unadjusted results for surgery time and length of hospital stay for inpatients. For all inpatient procedures, the average surgical time was longer when the robot was used. This was similarly demonstrated in the outpatient setting, with the exception of LRHL, where the relationship was reversed. As previously noted, there were only 11 patients in this category.

The unadjusted results in Table 3 suggest that average length of stay was slightly shorter overall, less than 3 hours on average, for robot-assisted laparoscopic hysterectomies. For LRHL, however, hospital stay durations were nearly identical.

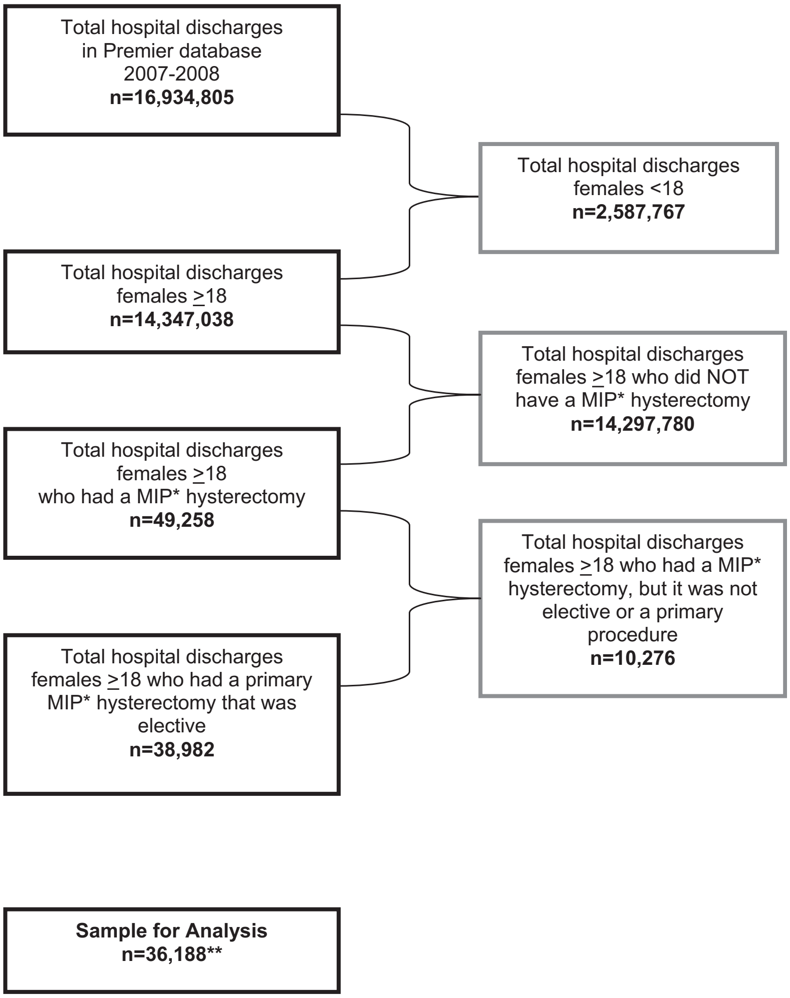
Table 1
Patient demographics

	Robot		Non-Robot	
	Inpatient	Outpatient	Inpatient	Outpatient
Total N (% of total N = 36 188)	1282 (4%)	379 (1%)	25 789 (71%)	8738 (24%)
Age: mean (SD, 95% CI)	48.84 (12.29, 48.17–49.51)	45.12 (10.31, 44.08–46.16)	45.37 (10.59, 45.24–45.50)	43.76 (8.76, 43.58–43.94)
18–40	0.25	0.31	0.33	0.38
41–50	0.40	0.44	0.44	0.46
51–60	0.18	0.16	0.15	0.11
61–70	0.10	0.06	0.06	0.03
71–80	0.05	0.02	0.02	0.01
>80	0.02	0.01	0.01	0.00
Race				
Caucasian	0.70	0.65	0.71	0.78
African American	0.11	0.09	0.09	0.11
Hispanic	0.01	0.01	0.04	0.02
Other	0.17	0.25	0.16	0.09
Married	0.55	0.53	0.61	0.65
Insurance Type				
Commercial	0.12	0.09	0.14	0.15
Medicare	0.14	0.07	0.08	0.04
Medicaid	0.07	0.07	0.07	0.07
Managed Care	0.61	0.70	0.65	0.65
Other	0.07	0.07	0.06	0.09
Year 2008	0.63	0.74	0.48	0.61
Indication for Surgery*				
Benign indication (n = 34 035)				
Dysfunctional uterine bleeding	0.49	0.54	0.55	0.59
Leiomyomas	0.46	0.56	0.45	0.53
Endometriosis	0.20	0.34	0.27	0.38
Prolapse	0.05	0.03	0.13	0.08
Other	0.07	0.08	0.08	0.06
Malignant indication (n = 2705)				
Cervix	0.03	0.02	0.01	0.00
Uterus	0.16	0.04	0.05	0.02
Other genitourinary	0.05	0.03	0.02	0.02
Other pelvic	0.00	0.00	0.00	0.00
Complex (n = 7640)				
Large uterus	0.00	0.11	0.00	0.09
Cancer = Malignancy Above	0.21	0.07	0.07	0.03
Adhesions	0.11	0.18	0.12	0.11
Non Complex (N = 28 548)	0.68	0.65	0.80	0.77
Illness Severity Level				
APR-DRG Severity Level (1, 2)	0.98	NA	0.99	NA
APR-DRG Severity Level (3, 4)	0.02	NA	0.01	NA
Comorbid Conditions†				
Myocardial infarction	0.01	0.00	0.00	0.00
Congestive heart failure	0.01	0.03	0.01	0.00
Peripheral vascular disease	0.01	0.01	0.00	0.00
Chronic pulmonary disease	0.12	0.12	0.11	0.10
Connective tissue disease	0.01	0.02	0.01	0.01
Liver disease	0.02	0.01	0.01	0.01
Renal insufficiency	0.01	0.00	0.00	0.00
Diabetes mellitus	0.11	0.09	0.06	0.05

* Total indications for surgery exceed the number of patients because some patients may have multiple indications.

† The proportions of comorbid conditions do not sum to 1 because some patients may have multiple comorbidities whereas others have none.

Given the possibility of confounders in our hospital cost and utilization comparisons, multivariable regression analyses were performed for all inpatient procedures. We adjusted for the following variables: type of hysterectomy, robot versus nonrobot, age, race, insurance type, marital status, year, indication for surgery, complex surgery, comorbid condition, census region, surgical specialty, location, hospital type, hospital size as measured by a series of categorical variables indicating hospital bed size, and illness severity index. The outpatient procedure analyses were adjusted for the same variables with the exception of illness severity index, which was not available. Results of these adjusted analyses of



*** MIP – Minimally Invasive Procedure**

**** 2794 patients had missing values in some of the model variables and, therefore, could not be included in the analysis**

Fig. 1. Patient attrition diagram. * MIP = Minimally invasive procedure. ** 2794 patients had missing values in some of the model variables and therefore could not be included in the analysis.

hospital costs, surgery time, and length of stay are shown in Table 4.

Even after adjusting for these variables and clustering on hospital, inpatient hospital costs remained substantially higher for robot-assisted laparoscopic hysterectomies than for procedures without robot assistance: \$9640 (95% CI = \$9621, \$9659) versus \$6973 (95% CI = \$6959, \$6987, respectively. This difference was statistically significant; $p < .01$). The hospital costs for outpatient procedures also differed significantly, with robot procedures costing on average \$7920 (95% CI = \$7898, \$7942) versus \$5949 (95% CI = \$5932, \$5966; $p < .01$). Finally, these regression analyses demonstrated that inpatient surgery times are significantly longer ($p < .01$) for robot-assisted procedures at 3.22 hours (95% CI = 3.21, 3.23) than for nonrobot procedures at 2.82 hours (95% CI = 2.81, 2.83). The same held true for outpatient surgery times, with robot procedures requiring an average of 2.99 hours (95% CI = 2.98, 3.00) compared with 2.46 hours (2.45, 2.47) for nonrobot procedures ($p < .01$). The difference in average length of stay was slightly shorter but not clinically relevant for robot procedures at 1.37 days versus 1.49 days for non-robot procedures. This difference did reach statistical significance ($p < .01$).

As previously noted, 13% of hospitals performed robot-assisted hysterectomy, raising the question of whether the multivariable models have adequately controlled for differences in hospitals with and without the robot. To address this, we performed a sensitivity analysis in which multivariable models for hospital costs, surgery times, and length of stay were reestimated for robot versus nonrobot procedures with only the 45 hospitals that had robot capabilities. The results were similar in all respects to those reported above. These results are omitted in the interest of brevity but are available from the authors on request.

Table 2
Hospital demographics

	Robot Hospital	Non-Robot Hospital
Total N (% of Hospitals)	45 (13%)	313 (87%)
Census region		
Northeast	0.13	0.13
Midwest	0.27	0.23
South	0.44	0.43
West	0.16	0.21
Surgical specialty		
Gynecologist	0.91	0.90
General surgeon	0.00	0.01
Other	0.09	0.09
Care setting		
Inpatient	0.87	0.82
Outpatient	0.13	0.18
Location		
Urban	0.93	0.79
Not urban	0.07	0.21
Type		
Teaching	0.51	0.26
Not-teaching	0.49	0.74
Bed count		
<200	0.02	0.36
201–400	0.42	0.37
401–600	0.27	0.19
>600	0.29	0.08

Clinical endpoints and adverse events occurring in the postoperative period up to 30 days after discharge are summarized in Fig. 2. Inpatient and outpatient settings did not appear to differ substantively in the frequency of adverse events overall, or by robot versus nonrobot procedures. Regarding cardiac, neurologic, wound, and vascular complications, frequencies were <1% for both robot and nonrobot procedures. This was true in all patient care settings. Pulmonary adverse events occurred in <1% of patients, both robot and nonrobot, in the outpatient setting, but were slightly higher in the inpatient setting (robot 1.9% and nonrobot 1.1%). Gastrointestinal complications occurred in 6% to 9% of all patients, both robot and nonrobot, in both inpatient and outpatient care settings. Genitourinary adverse events in the inpatient setting were similar in patients in both the robot and nonrobot groups, but in the outpatient setting, the incidence was somewhat higher in the patients in the robot group (19.3%) than in the patients in the nonrobot group (11.8%). The frequency of postsurgical infections was comparable (5% to 7%) in patients in both the robot and nonrobot group in both outpatient and inpatient settings. Finally, the frequency of hemorrhage was slightly higher in patients in both the robot (5.1%) and nonrobot (5.9%) groups in the inpatient settings compared with the outpatient setting, at 4.0% and 2.7%, of patients in the robot and nonrobot groups, respectively.

Discussion

Our study demonstrated that there is no major or even incremental clinical benefit associated with robot assistance when considering perioperative and postoperative complications, even after adjusting for a host of covariates, particularly oncologic and complex cases and patient severity. Robot-assisted procedures are, however, associated with higher hospital costs, with an average incremental per procedure cost in excess of $2600. This finding was present in both unadjusted and adjusted analyses. Robot-assisted procedures are also associated with longer surgery times.

There is a lack of evidence in the published literature comparing laparoscopic procedures with and without the use of a robot. However, our findings of higher costs to the

Table 3
Unadjusted results for cost, surgery time, and length of stay

	Hospital Costs (Dollars)				Surgery Time (Hours)					
	Inpatient		Outpatient		Inpatient		Outpatient		Inpatient Length of Stay (Days)	
Unadjusted	Total (N)	Overall $ (mean [SD])	Total (N)	Overall $ (mean [SD])	Total (N)	Overall Hours (mean [SD])	Total (N)	Overall Hours (mean [SD])	Total (N)	Overall Days (mean [SD])
With ROBOT	1282	10 459 (3698)	379	8295 (3489)	1282	3.49 (1.14)	379	3.11 (1.00)	1282	1.37 (0.73)
TLH	603	10 790 (3749)	96	7374 (2771)	603	3.60 (1.08)	96	2.82 (0.79)	603	1.41 (0.74)
LSH	182	11 026 (3896)	98	8168 (3443)	182	3.38 (1.33)	98	2.82 (0.98)	182	1.25 (0.57)
LAVH	426	9609 (3368)	170	9014 (3845)	426	3.32 (1.06)	170	3.45 (1.03)	426	1.34 (0.73)
LRH	33	10 065 (3356)	4	6067 (714)	33	3.24 (1.04)	4	2.65 (0.79)	33	1.15 (0.36)
LRHL	38	12 367 (3848)	11	7147 (1317)	38	4.53 (1.47)	11	3.11 (0.94)	38	1.89 (1.09)
Without ROBOT	25 789	6942 (2881)	8738	5932 (2297)	25 789	2.81 (1.09)	8738	2.45 (0.92)	25789	1.49 (0.75)
TLH	3306	8031 (3260)	854	6534 (2372)	3306	3.30 (1.23)	854	2.71 (1.02)	3306	1.54 (0.86)
LSH	5272	6963 (2691)	2755	6347 (2203)	5272	2.73 (1.07)	2755	2.45 (0.99)	5272	1.29 (0.61)
LAVH	16 797	6666 (2752)	5012	5585 (2253)	16 797	2.72 (1.03)	5012	2.39 (0.84)	16 797	1.54 (0.76)
LRH	238	7635 (2886)	88	6044 (1859)	238	2.94 (1.08)	88	2.45 (0.89)	238	1.51 (0.73)
LRHL	176	11 416 (3933)	29	8229 (4896)	176	4.17 (1.37)	29	4.19 (1.33)	176	1.86 (1.00)

TLH, Total laparoscopic hysterectomy; LSH, laparoscopic supracervical hysterectomy; LAVH, laparoscopically assisted vaginal hysterectomy; LRH, laparoscopic radical hysterectomy; LRHL, laparoscopic radical hysterectomy with pelvic lymphadenectomy.

Table 4
Adjusted outcomes: hospital costs, surgery time, and length of stay (n = 31 688)

	Inpatient[*] (n = 27 071)					Outpatient[†] (n = 9177)				
	Mean	SD	p Value[‡]	95% CI[§]		Mean	SD	p Value[‡]	95% CI[§]	
Adjusted Costs (Dollars)										
Without ROBOT	6973	1167	<.01	6959	6987	5949	812	<.01	5932	5966
With ROBOT	9640	1614	<.01	9621	9659	7920	1082	<.01	7898	7942
Adjusted Surgery Time (Hours)										
Without ROBOT	2.82	0.46	<.01	2.81	2.83	2.46	0.40	<.01	2.45	2.47
With ROBOT	3.22	0.52	<.01	3.21	3.23	2.99	0.48	<.01	2.98	3.00
Adjusted Length of Stay (Days)										
Without ROBOT	1.49	0.20	<.01	1.49	1.49					
With ROBOT	1.37	0.18	<.01	1.37	1.37					

[*] GLM models adjusted for the following: type of hysterectomy; robot versus non-robot; age; race; insurance type; marital status; year; indication for surgery; complex surgery; comorbid condition; census region; surgical specialty; location; hospital type; bed count; and APR-DRG severity index.

[†] GLM models adjusted for the following: type of hysterectomy; robot vs. non-robot; age; race; insurance type; marital status; year; indication for surgery; complex surgery; comorbid condition; census region; surgical specialty; location; hospital type; and bed count.

[‡] The p values are based on Student's *t* test.

[§] Confidence intervals are narrow because the standard errors of the estimates ($SD/\sqrt{N}$) are quite small.

hospital when the robot is used are consistent with the limited studies in the published literature. Moreover, some of these studies do not report hospital costs but rather what the hospital charged for the procedure. Although there is a differential between the costs to the hospital versus what the hospital charges, the trend is still the same, with the robot consistently costing more money. For example, Advincula et al. [15] evaluated the cost of robot-assisted laparoscopic myomectomy compared with conventional laparotomy and found that hospital charges were significantly higher in the robotic group. Rodgers et al. [16] compared the cost of robot-assisted tubal anastomosis with minilaparotomy and also found that the cost of the robotic procedure was higher, with a median cost difference of $1446 (95% CI =: $1112–1812; p <.001). Although these studies did not compare robotic procedures with minimally invasive procedures without the use of the robot, these results do provide directional understanding of cost comparisons for other robot-assisted gynecologic procedures.

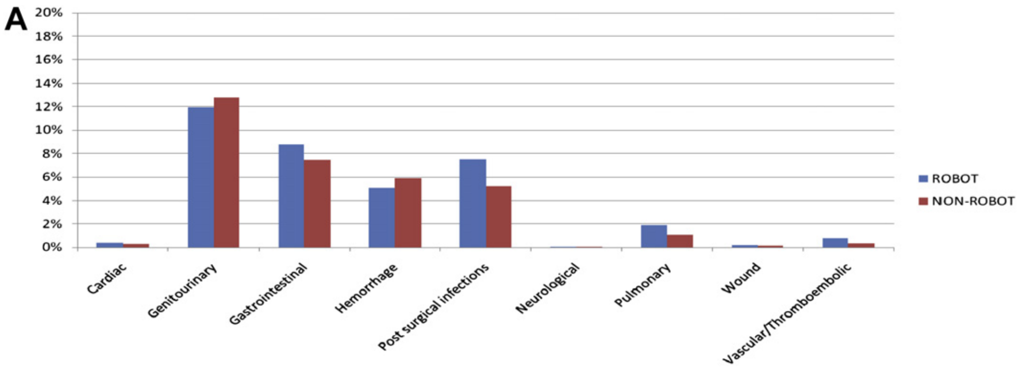
Another important consideration is that our findings of higher hospital costs associated with robotic surgery are specific to perioperative and postoperative costs and do not account for acquisition costs. The robotic unit costs between $1 million and $2.3 million and is associated with annual maintenance costs of $100 000 to $180 000 a year (Intuitive Surgical Investor Presentation Q4 2009). The combination of limited clinical evidence to date and relatively high acquisition and maintenance costs raises important questions about the cost-effectiveness of this technology.

Although some authors suggest that robotics can be a useful method for shortening the learning curve in physicians performing minimally invasive gynecologic surgery [17], this study would suggest that robotic surgery should not serve as a wholesale substitute for a skilled laparoscopic surgeon, especially in procedures where standard laparoscopy is routine. Furthermore, although the robot may prove useful in certain procedures such as urology or gynecologic oncology, it should not be used by physicians who are unwilling to invest time and effort into laparoscopic training. The robotic surgical approach may thus have an unintended negative effect on resident and fellow training as it relates to their overall laparoscopic competencies.

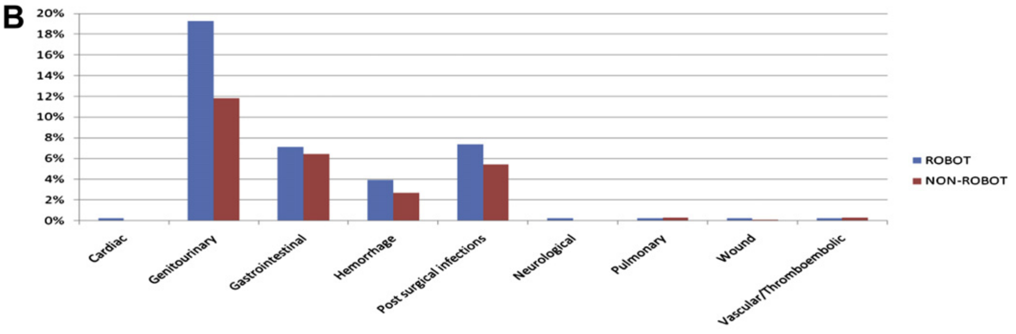
We acknowledge that the robot offers a potential advancement in minimally invasive procedures, particularly in complex or highly technical cases such as laparoscopic prostatectomy or certain cardiac cases, for example. We also acknowledge that robotic surgery is exciting because it is innovative and cutting-edge. However, our research indicates this value proposition tends to be offset when robotics is used in cases where traditional laparoscopic approaches can achieve the same clinical outcomes, but at far less cost to the hospital. Although subsequent generations of robots may represent the future, it is difficult economically to justify the exuberant uptake of robotic surgery for routine hysterectomies.

Important strengths of this analysis included the prospectively developed protocol that directed the analysis, the very large sample size in terms of both patients and hospitals, the broad geographic and demographic representation of U.S. hospitals included in our sample, and the fact that these data are relatively recent and come from a real-world setting.

Our study also has important limitations. We did not have a randomized study design and relied on multivariable regression analysis to control for confounding effects. It is possible that some important confounding factors were not controlled for in this analysis. The billing data used in this study did not include some potentially important factors such as obesity and procedure complexity and may have missed some complications as well. Second, although we found no safety advantage for robot procedures, there may be clinical advantages, specifically long term that we were unable to ascertain in terms of clinical effectiveness, particularly in patients undergoing complex surgeries or with cancer. Thirteen percent of the hospitals in our study had



	Cardiac	Genitourinary	Gastrointestinal	Hemorrhage	Post-surgical Infections	Neurological	Pulmonary	Wound	Vascular/ Thromboembolic
Robot	0.39%	11.93%	8.74%	5.07%	7.49%	0.08%	1.87%	0.23%	0.78%
Non-Robot	0.26%	12.76%	7.48%	5.88%	5.22%	0.05%	1.07%	0.17%	0.32%
P value	0.38	0.39	0.10	0.23	<0.01	0.62	<0.01	0.60	<0.01



	Cardiac	Genitourinary	Gastrointestinal	Hemorrhage	Post-surgical Infections	Neurological	Pulmonary	Wound	Vascular/ Thromboembolic
Robot	0.26%	19.26%	7.12%	3.96%	7.39%	0.26%	0.26%	0.26%	0.26%
Non-Robot	0.05%	11.80%	6.42%	2.66%	5.41%	0.01%	0.27%	0.08%	0.31%
P value	0.08	<0.01	0.59	0.13	0.10	<0.01	0.97	0.24	0.88

Fig. 2. **(A)** Adverse events by system for all inpatients. **(B)** Adverse events by system for all outpatients.

a robot. While acknowledging this limitation, we note that the experience of the 45 hospitals using robot assistance as represented in our study is significantly larger than what has previously been published in the literature. When only robot-equipped hospitals were examined in subgroup analyses, our findings were essentially unchanged.

Conclusion

To our knowledge, this study represents the most up-to-date and expansive analysis of costs and safety outcomes associated with robot-assisted laparoscopic hysterectomy in a real world setting. Our findings reveal little clinical differences in perioperative and postoperative events. This, coupled with the increased per-case cost of the robot, suggests that further investigation is warranted when considering this technology for routine laparoscopic hysterectomies. Randomized controlled studies of comparative effectiveness are needed to inform further decisions regarding the diffusion of robot technology in routine laparoscopic hysterectomy.

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Appendix

Laparoscopic hysterectomy types and CPT code and ICD-9 codes sets

Surgery Type	ICD-9 & CPT Code
Total Laparoscopic Hysterectomy (TLH)	68.41 58570–58573
Laparoscopically Assisted Vaginal Hysterectomy (LAVH)	68.51 58550, 58552-58554
Laparoscopic Supracervical Hysterectomy (LSH)	68.31 58541–58544
Laparoscopic Radical Hysterectomy with Pelvic Lymphadenectomy (LRHL)	68.61 and 68.71 when they are accompanied by any of 40.11, 40.24, 40.29, 40.3, or 40.5X 58548
Laparoscopic Radical Hysterectomy (LRH)	68.61 and 68.71 when they are NOT also accompanied by any of 40.11, 40.24, 40.29, 40.3, or 40.5X