Published in final edited form as:
Obstet Gynecol. 2014 May ; 123(5): 1038–1048. doi:10.1097/AOG.0000000000000244.

An Economic Analysis of Robotically Assisted Hysterectomy

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Abstract

OBJECTIVE—To perform an econometric analysis to examine the influence of procedure volume, variation in hospital accounting methodology, and use of various analytic methodologies on cost of robotically assisted hysterectomy for benign gynecologic disease and endometrial cancer.

METHODS—A national sample was used to identify women who underwent laparoscopic or robotically assisted hysterectomy for benign indications or endometrial cancer from 2006 to 2012. Surgeon and hospital volume were classified as the number of procedures performed before the index surgery. Total costs as well as fixed and variable costs were modeled using multivariable quantile regression methodology.

RESULTS—A total of 180,230 women, including 169,324 women who underwent minimally invasive hysterectomy for benign indications and 10,906 patients whose hysterectomy was performed for endometrial cancer, were identified. The unadjusted median cost of robotically assisted hysterectomy for benign indications was $8,152 (interquartile range [IQR] $6,011–10,932) compared with $6,535 (IQR $5,127–8,357) for laparoscopic hysterectomy (*P*<.001). The cost differential decreased with increasing surgeon and hospital volume. The unadjusted median cost of robotically assisted hysterectomy for endometrial cancer was $9,691 (IQR $7,591–12,428) compared with $8,237 (IQR $6,400–10,807) for laparoscopic hysterectomy (*P*<.001). The cost differential decreased with increasing hospital volume from $2,471 for the first 5 to 15 cases to $924 for more than 50 cases. Based on surgeon volume, robotically assisted hysterectomy for endometrial cancer was $1,761 more expensive than laparoscopy for those who had performed fewer than five cases; the differential declined to $688 for more than 50 procedures compared with laparoscopic hysterectomy.

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Financial Disclosure

The authors did not report any potential conflicts of interest.

CONCLUSION—The cost of robotic gynecologic surgery decreases with increased procedure volume. However, in all of the scenarios modeled, robotically assisted hysterectomy remained substantially more costly than laparoscopic hysterectomy.

Recent population-based studies have shown that robotic-assisted hysterectomy is now frequently performed for benign gynecologic diseases and for oncologic indications.[1,2] Despite the rapid uptake of robotic surgery, the comparative effectiveness of robotically assisted hysterectomy remains uncertain.[1–11]

To date, the majority of previous studies have been unable to demonstrate improved outcomes for robotic-assisted hysterectomy compared with laparoscopic hysterectomy.[1–11] Although the morbidity profile of robotic-assisted hysterectomy appears to be reasonable, a major concern for the procedure stems from the high costs associated with the operation.[1,4,9–12] Compared with laparoscopic hysterectomy, costs for robotic-assisted hysterectomy are 16% to 34% higher.[1,2,9,12] The high cost of robotic surgery is likely driven by a number of factors, including capital costs for the robotic system, maintenance, the cost of disposable instrumentation, and the longer operative times that these procedures often require.[12]

Although the high cost of robotic surgery represents a major public health concern, proponents of robotic surgery have suggested that the technology can be made more cost-effective. First, previous studies may, in part, reflect the learning curve of a new technology with longer operative times.[13–18] Second, many cost studies have reported data across multiple hospitals that capture costs from a variety of cost-reporting methods. Finally, cost data are often not normally distributed and thus are sensitive to the analytic methodology used.[19,20] Given these concerns, we performed a detailed economic analysis of the cost of robotic-assisted hysterectomy and examined the influence of procedural volume, hospital accounting systems, and the use of various analytic methodologies on cost for women undergoing robotic-assisted hysterectomy.

MATERIALS AND METHODS

The Perspective database was used for analysis. Perspective captures comprehensive billing data of all hospital admissions from more than 500 acute care facilities from throughout the United States. The database collected data for nearly 5.5 million discharges in 2006, which represents approximately 15% of hospitalizations in the United States.[21] The study was deemed exempt by the Columbia University Institutional Review Board.

Women 18 to 90 years of age who underwent a minimally invasive hysterectomy from 2006 to 2012 were analyzed. We initially selected patients who had a code for a laparoscopic hysterectomy (International Classification of Diseases, 9th Revision, Clinical Modification [ICD-9-CM] codes 68.31, 68.41, 68.51). Those women who had either an ICD-9-CM procedure code for a robotic-assisted procedure (ICD-9-CM 17.42 or 17.44) or a recorded charge code for robotic instrumentation were classified as having undergone a robotically assisted hysterectomy as previously described.[2,22] Women with a gynecologic malignancy other than endometrial cancer were excluded. The cohort was then stratified into the following two groups: those with endometrial cancer (ICD-9-CM 182.x) and those without gynecologic cancer who underwent hysterectomy for benign indications.

Clinical and demographic characteristics including age at the time of the procedure (younger than 50, 50–59, 60–69, and older than 70 years), race (white, black, other), marital status (married, single, unknown), year of diagnosis (2006 to 2012), and insurance status (commercial, Medicare, Medicaid, uninsured, and unknown) were recorded. For women who underwent hysterectomy for benign indications, we noted the following gynecologic conditions: leiomyomas; endometriosis; abnormal bleeding; benign ovarian neoplasms; and pelvic organ prolapse. The performance of concomitant gynecologic procedures, including anterior colporrhaphy, posterior colporrhaphy, salpingo-oophorectomy, incontinence surgery, and lymphadenectomy, were also noted.

Hospital characteristics including location (metropolitan and nonmetropolitan), region of the country (northeast, midwest, west, and south), size (fewer than 400 beds, 400–600 beds, and more than 600 beds), and teaching status (teaching and nonteaching) were recorded for each patient. Risk adjustment for comorbid medical conditions was performed using the Elixhauser comorbidity index. Women were classified based on the number of medical comorbidities as 0, 1, or 2 or more, as previously reported.[23]

Physician and hospital volume were determined for each patient. 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 before the index procedure. Separate volume-based calculations were performed for robotic-assisted and laparoscopic hysterectomy. Volume was calculated separately for procedures for endometrial cancer and benign indications. Volume was included as a continuous variable in all of the multivariable models.[24]

To determine the effect of complications on cost, we examined perioperative morbidity. The following perioperative complications were analyzed: intraoperative complications (bladder injury, ureteral injury, intestinal injury, vascular injury, and other operative injury); surgical site complications (wound complications, abscess, hemorrhage, bowel obstruction, ileus); and medical complications (venous thromboembolism, myocardial infarction, cardiopulmonary arrest, acute renal failure, respiratory failure, stroke, bacteremia or sepsis, shock, and pneumonia).[2,9] Any morbidity, a composite score of any of these complications, was analyzed.

The primary outcome of the analysis was cost. Cost represents the monetary value to perform a service, whereas charges are based on what a hospital bills for the service. We directly analyzed cost. Perspective captures cost data through an itemized log of all items and services billed to a patient during the acute hospitalization. Cost data represent the cost of the entire index hospitalization. Within the database, hospitals report cost either through direct internal accounting systems or through Medicare cost-to-charge ratios.[21,25] The type of accounting performed by each hospital was recorded and separate sensitivity analyses based on the type of accounting system were performed as described. All costs were adjusted for inflation using the Consumer Price Index and reported in 2012 U.S. dollars.[26]

Converted cost data were inspected and patients with spurious costs (less than $500) were removed from the cost analyses.[2] We examined total costs and performed separate analyses for fixed and variable costs. Fixed costs are those costs attributable to capital equipment and maintenance, whereas variable costs are attributable to the operation of the hospital irrespective of fixed costs.[27]

Women who underwent hysterectomy for benign disease and those who underwent hysterectomy for endometrial cancer were analyzed separately. Frequency distributions between categorical variables for those who underwent laparoscopic hysterectomy and those who underwent robotically assisted hysterectomy were compared using χ^2 tests, and median values of continuous variables were compared using Wilcoxon rank-sum tests. Cost data for each of the groups are reported as medians with interquartile ranges. Distributions of cost based on previous procedural volume are displayed graphically with previous surgical volume broken down into deciles.

Multivariable adjustments of cost were performed using quantile (median) regression methodology.[19] Quantile regression directly estimates the adjusted median costs and 95% confidence intervals (CIs) were derived based on bootstrap resampling methods. A series of cost models were developed. We first developed an unadjusted model based only on the route of hysterectomy. A similar model was constructed that only included hospitals that reported cost based on direct internal accounting systems. A fully adjusted model that reports cost after adjustment for all of the clinical, demographic, physician, and hospital characteristics was then described. Similarly, a fully adjusted model excluding patients with any perioperative complication was shown. Finally, a series of stratified models were developed that included only patients based on the volume of the attending surgeon (fewer than 5 procedures, 5–15 procedures, 16–30 procedures, and more than 50 procedures).

A series of sensitivity analyses of the adjusted and unadjusted cost models were performed after log-transformation of the data. All analyses were performed with SAS 9.2. All statistical tests were two-sided. $P<.05$ was considered statistically significant.

RESULTS

A total of 180,230 women were identified. The cohort included 169,324 women who underwent minimally invasive hysterectomy for benign indications and 10,906 patients whose hysterectomy was performed for endometrial cancer. Robotically assisted hysterectomy accounted for 30.4% of the hysterectomies for benign disorders and 59.6% of hysterectomies for endometrial cancer. The clinical and demographic characteristics of the cohort are displayed in Table 1.

The unadjusted median cost of robotically assisted hysterectomy for benign indications was $8,152 (interquartile range [IQR] $6,011–10,932) compared with $6,535 (IQR $5,127–8,357) for laparoscopic hysterectomy (Table 2). Median fixed costs were $3,591 (IQR $2,347–5,345) for robotic-assisted hysterectomy compared with $2,965 (IQR $2,137–4,051) for laparoscopic hysterectomy, whereas variable costs were $4,384 (IQR $3,170–5,883) and $3,440 (IQR $2,633–4,513) for the two procedures, respectively. The cost of both robotic-assisted and laparoscopic hysterectomy for benign indications decreased with increasing procedural volume. Figure 1 displays the median total cost of robotically assisted and laparoscopic hysterectomy for benign indications based on previous surgeon (Fig. 1A) and hospital (Fig. 1B) volume.

Table 2 displays the unadjusted median costs for hysterectomy for benign by procedural volume. At hospitals that had performed fewer than five previous cases, robotically assisted hysterectomy was $2,053 more expensive. The cost differential decreased with increasing hospital volume as follows: 5 to 15 cases (+$2,007), 16 to 30 cases (+$1,729), 31 to 50 cases (+$1,657), and more than 50 cases (+$1,560). Among surgeons, robotically assisted hysterectomy was $1,705 more expensive than laparoscopic hysterectomy for those who had performed fewer than five cases, whereas costs declined to +$1,467 for 5 to 15 cases, +$1,559 for 16 to 30 cases, +$1,390 for 31 to 50 cases, and +$1,619 for more than 50 procedures.

The unadjusted median cost of robotic-assisted hysterectomy for endometrial cancer was $9,691 (IQR $7,591–12,428) compared with $8,237 (IQR $6,400–10,807) for laparoscopic hysterectomy (Table 3). Median fixed costs were $4,543 (IQR $3,201–6,164) for robotic-assisted hysterectomy for endometrial cancer compared with $3,790 (IQR $2,832–5,406) for laparoscopic hysterectomy, whereas variable costs were $5,065 (IQR $3,994–6,536) and $4,215 ($3,098–5,644) for the two procedures, respectively. The cost of both robotically assisted and laparoscopic hysterectomy for endometrial cancer decreased with increasing procedural volume. Figure 2 displays the median total cost of robotically assisted and laparoscopic hysterectomy for endometrial cancer based on previous surgeon (Figure 2A) and hospital (Figure 2B) volume.

At hospitals that had performed fewer than five previous cases for endometrial cancer, robotically assisted hysterectomy was $2,471 more expensive than laparoscopic hysterectomy. The cost differential decreased with increasing hospital volume: 5 to 15 cases (+1,984), 16 to 30 cases (+$1,753), 31 to 50 cases (+$1,403), and more than 50 cases (+$924). Among surgeons, robotically assisted hysterectomy for endometrial cancer was $1,761 more expensive for those who had performed fewer than five cases, whereas costs declined to +$1,266 for 5 to 15 cases, +$1,565 for 16 to 30 cases, +$1,451 for 31 to 50 cases, and +$688 for more than 50 procedures.

In a series of adjusted models, these results were largely unchanged (Table 4). In a fully adjusted model, compared with laparoscopic hysterectomy, robotically assisted hysterectomy for benign indications was $1,225 (95% CI $1,177–1,272) more expensive and $1,328 (95% CI $1,164–1,491) more costly for endometrial cancer. When the analysis was limited to hospitals that used direct costing methods, the cost differential associated with robotic procedures was greater; robotically assisted benign hysterectomy was $1,995 (95% CI $1,948–2,041) more than laparoscopic hysterectomy. Removing patients who experienced complications had minimal effects on the estimates. Like the unadjusted models, cost declined with volume. Results were similar for fixed and variable costs and after log transformation of the data (not shown).

DISCUSSION

Our data suggests that the cost of robotic gynecologic surgery decreases with increasing procedural volume. The reduction in costs was most pronounced for women undergoing robotically assisted hysterectomy for endometrial cancer and was more modest when the surgery was performed for benign indications. Despite the reductions in cost associated with increased procedural volume, in all of the scenarios modeled, robotic-assisted hysterectomy remained substantially more costly than laparoscopic hysterectomy.

The introduction of new surgical technologies is often associated with a learning curve.[13,15–17] An institutional analysis of 325 patients who underwent robotic-assisted hysterectomy noted that although increasing surgical experience was associated with shorter operative times and decreased length of stay, surgical experience had no effect on complications. The investigators noted that operative time decreased from 3.5 hours during the first 6 months of robot use to 2.7 hours per procedure.[13] We noted that cost decreased with the number of previous procedures performed for both hospitals and surgeons.

The association between surgical volume and outcomes has been well-described over the course of the past two decades.[28,29] For high-risk oncologic and cardiovascular procedures, increased surgeon and hospital procedural volume are associated with decreased morbidity and mortality.[28,29] For lower-morbidity procedures, including most gynecologic operations, the association between increased volume and decreased complications is more modest.[30–33] However, for many gynecologic procedures, increased procedural volume is associated with lower resource use and decreased costs.[30–33] The current study suggests similar trends for robotically assisted hysterectomy.

The relationship between increased volume and decreased cost appeared to be greater when robotically assisted hysterectomy was performed for endometrial cancer than when the operation was used for benign indications. Further, for hysterectomy for benign indications, the relative magnitudes of cost reductions for robotically assisted and laparoscopic hysterectomy associated with increasing surgeon volume were similar. We noted that surgeon volume had a more meaningful influence on cost than hospital volume. Given that hysterectomy is performed much more frequently for benign indications than for cancer, the limited reduction in the cost differential for benign indications with higher volume has important public health implications.[34]

Our study addresses a number of methodologic concerns in the analysis of the cost. First, both hospital volume and surgeon procedural volume were measured as the number of operations performed before the index case and as continuous variables.[24] This approach was meant to account for the learning curve for the operation. Second, separate analyses were performed for hospitals that used direct internal accounting systems compared with those that estimate cost based on cost-to-charge ratios. When analyzing only those hospitals that directly report actual costs, we noted that the cost differential of robotic-assisted hysterectomy was greater than that in the analysis of all hospitals. We used a number of statistical methodologies to account for right skewed data such as cost.[19,20]

We recognize a number of important limitations. We cannot exclude the possibility that some procedures were misclassified. However, the classification system we used to identify robotic procedures has been used in previous work and was previously validated.[2] Our classification of physician volume only captured a surgeon's patients within a given hospital, and we were unable to link physicians across hospitals. There is likely variation across hospitals in fixed costs for the robotic platform and instrumentation based on different negotiated prices. We were unable to capture some factors, including tumor characteristics, weight, and surgical history, that undoubtedly influenced outcomes. Finally, our data present cost from a hospital perspective. Previous work has suggested that increased use of robotic-assisted hysterectomy is associated with a decreased rate of abdominal hysterectomy that likely provides important cost reductions from a societal standpoint.

Our study suggests that costs are reduced with both increased surgeon experience and hospital experience, although the reduction in cost is affected to a greater degree by surgeon rather than hospital volume. Although the cost reduction is multifactorial, the cost savings are likely from a combination of shorter operative times and reduced length of stay. Our findings are also notable in that no matter how the two procedures were modeled, in similar circumstances laparoscopic hysterectomy always remained less costly than robotically assisted hysterectomy. Even for very high-volume surgeons and centers, robotically assisted hysterectomy remained more costly. Based on these data, it appears unlikely that robotic-assisted hysterectomy can achieve cost parity with laparoscopic hysterectomy based on surgical experience alone and that reductions in the cost of robotic instrumentation will be required for the procedure to become cost-effective.[2,35] Strategies to reduce the cost of robotic instrumentation as well as initiatives to promote access to high-quality laparoscopic surgery are warranted.

Acknowledgments

Dr. Wright (NCI R01CA169121-01A1) and Dr. Hershman (NCI R01CA134964) are recipients of grants and Dr. Tergas is the recipient of a fellowship (NCI R25 CA094061-11) from the National Cancer Institute.

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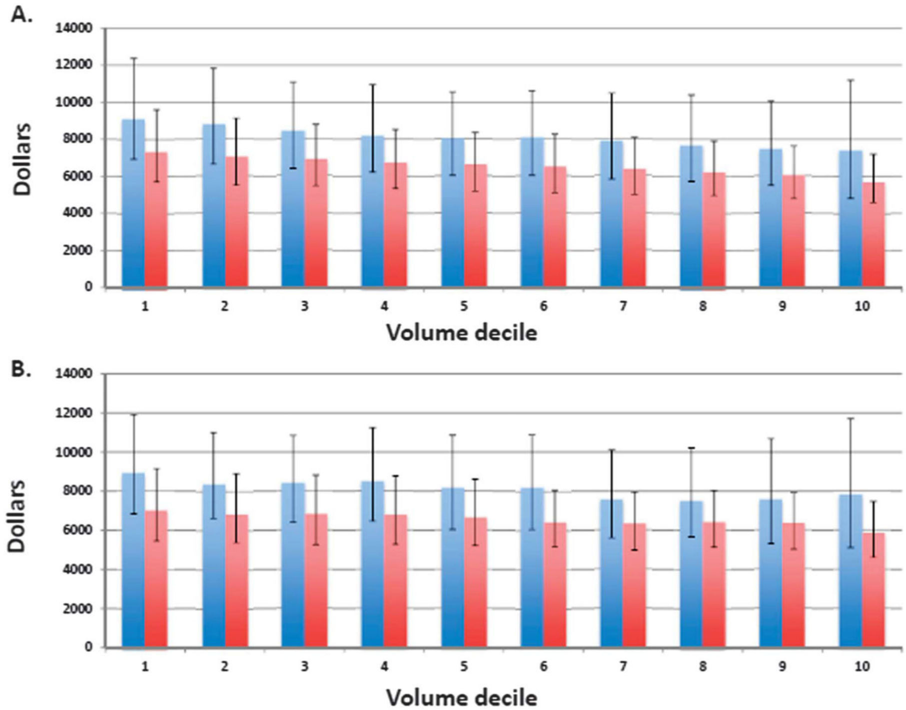

Fig. 1.

Cost based on previous surgical volume for robotically assisted hysterectomy for benign indications. Previous surgical volume is stratified by deciles and data are presented as medians with interquartile ranges. Blue bars represent robotically assisted hysterectomy; red bars represent laparoscopic hysterectomy. **A.** Cost based on previous surgeon volume. **B.** Cost based on previous hospital volume. Figure is truncated at 200 cases.

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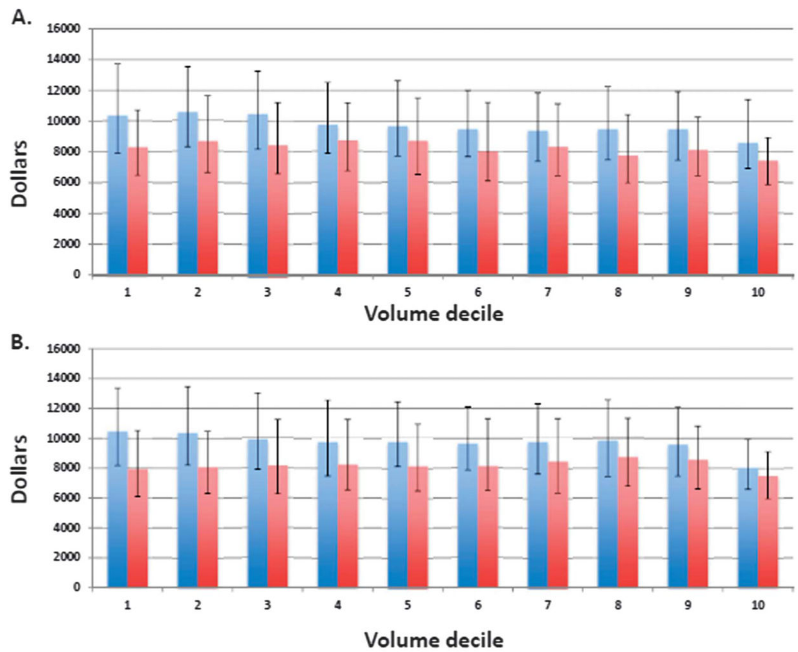

Fig. 2.

Cost based on previous surgical volume for robotically assisted hysterectomy for endometrial cancer. Previous surgical volume is stratified by deciles and data are presented as medians with interquartile ranges. Blue bars represent robotically assisted hysterectomy; red bars represent laparoscopic hysterectomy. **A.** Cost based on previous surgeon volume. **B.** Cost based on previous hospital volume.

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Table 1

Clinical and Demographic Characteristics for Women Who Underwent Minimally Invasive Hysterectomy

Characteristic	Benign Indications: Laparoscopic	Benign Indications: Robotically Assisted	*P*	Endometrial Cancer: Laparoscopic	Endometrial Cancer: Robotically Assisted	*P*
Total	117,832 (69.6)	51,492 (30.4)		4,404 (40.4)	6,502 (59.6)	
Age (y)			<.001			<.001
Younger than 50	90,346 (76.7)	37,088 (72.0)		536 (12.2)	683 (10.5)	
50–59	19,042 (16.2)	9,626 (18.7)		1,345 (30.5)	1,826 (28.1)	
60–69	6,120 (5.2)	3,371 (6.6)		1,413 (32.1)	2,348 (36.1)	
70 or older	2,324 (2.0)	1,407 (2.7)		1,110 (25.2)	1,645 (25.3)	
Race			<.001			<.001
White	86,233 (73.2)	36,319 (70.5)		3,039 (69.0)	4,886 (75.2)	
Black	11,420 (9.7)	6,405 (12.4)		332 (7.5)	390 (6.0)	
Other	20,179 (17.1)	8,768 (17.0)		1,033 (23.5)	1,226 (18.9)	
Year of diagnosis			<.001			<.001
2006	13,412 (11.4)	146 (0.3)		475 (10.8)	12 (0.2)	
2007	15,251 (12.9)	507 (1.0)		739 (16.8)	95 (1.5)	
2008	15,239 (12.9)	1,445 (2.8)		754 (17.1)	297 (4.6)	
2009	17,132 (14.5)	4,644 (9.0)		611 (13.9)	678 (10.4)	
2010	19,245 (16.3)	9,129 (17.7)		657 (14.9)	1,251 (19.2)	
2011	19,522 (16.6)	15,924 (30.9)		601 (13.7)	1,888 (29.0)	
2012	18,031 (15.3)	19,697 (38.3)		567 (12.9)	2,281 (35.1)	
Insurance			<.001			.10
Commercial	89,414 (75.9)	39,550 (76.8)		2,304 (52.3)	3,340 (51.4)	
Medicare	7,822 (6.6)	4,390 (8.5)		2,304 (38.7)	2,639 (40.6)	
Medicaid	11,897 (10.1)	4,548 (8.8)		158 (3.6)	223 (3.4)	
Uninsured	3,825 (3.3)	1,279 (2.5)		143 (3.3)	167 (2.6)	
Unknown	4,874 (4.1)	1,725 (3.5)		97 (2.2)	133 (2.1)	
Marital status			<.001			<.001
Married	72,221 (61.3)	30,337 (58.9)		2,126 (48.3)	3,236 (49.8)	
Single	33,348 (28.3)	15,873 (30.8)		1,640 (37.2)	2,518 (38.7)	

Characteristic	Benign Indications			Endometrial Cancer		
	Laparoscopic	Robotically Assisted	*P*	Laparoscopic	Robotically Assisted	*P*
Unknown	12,263 (10.4)	5,282 (10.3)		638 (14.5)	748 (11.5)	
Area of residence			<.001			<.001
Metropolitan	102,532 (87.0)	45,785 (88.9)		4,207 (95.5)	6,302 (96.9)	
Nonmetropolitan	15,300 (13.0)	5,707 (11.1)		197 (4.5)	200 (3.1)	
Region			<.001			<.001
Eastern	9,308 (7.9)	4,693 (9.1)		876 (19.9)	1,227 (18.9)	
Midwest	24,277 (20.6)	11,784 (22.9)		966 (21.9)	1,313 (20.2)	
South	60,850 (51.6)	27,928 (54.2)		1,802 (40.9)	2,654 (40.8)	
West	23,397 (19.9)	7,087 (13.8)		760 (17.3)	1,308 (20.1)	
Comorbidity			<.001			.12
0	48,460 (41.1)	19,679 (38.2)				
1	32,666 (27.7)	14,444 (28.1)		768 (17.4)	1,039 (16.0)	
2	17,434 (67.9)	8,254 (16.0)		1,053 (23.9)	1,555 (23.9)	
3 or more	19,272 (16.4)	9,115 (17.7)		2,583 (58.7)	3,908 (60.1)	
Hospital type			<.001			<.001
Nonteaching	81,850 (69.5)	32,998 (64.1)		2,074 (47.1)	2,674 (41.1)	
Teaching	35,982 (30.5)	18,494 (35.9)		2,330 (52.9)	3,828 (58.9)	
Hospital size (beds)			<.001			<.001
Fewer than 400	70,809 (60.1)	25,509 (49.5)		1,805 (41.0)	2,029 (31.2)	
400–600	28,020 (23.8)	16,668 (32.4)		1,633 (37.1)	2,610 (40.1)	
More than 600	19,003 (16.1)	9,315 (18.1)		966 (21.9)	1,863 (28.7)	
Hospital volume						
Lowest	19,561 (25.1)	12,888 (25.0)		1,137 (25.8)	1,624 (25.0)	
Second	29,377 (24.9)	12,877 (25.0)		1,055 (24.0)	1,625 (25.0)	
Third	29,410 (25.0)	12,839 (24.9)		1,103 (25.1)	1,610 (24.8)	
Highest	29,484 (25.0)	12,888 (25.0)		1,109 (25.2)	1,643 (25.3)	
Surgeon volume						
Lowest	29,961 (25.4)	12,142 (23.6)		1,177 (26.7)	1,471 (22.6)	
Second	28,289 (24.0)	13,161 (25.6)		954 (21.7)	1,697 (26.1)	
Third	30,409 (25.8)	13,249 (25.7)		1,189 (27.0)	1,739 (26.8)	

	Benign Indications			Endometrial Cancer		
Characteristic	**Laparoscopic**	**Robotically Assisted**	***P***	**Laparoscopic**	**Robotically Assisted**	***P***
Highest	29,173 (24.8)	12,940 (25.1)		1,084 (24.6)	1,595 (24.5)	
Procedure						
Anterior repair	7,217 (6.1)	1,187 (2.3)	<.001	52 (1.2)	19 (0.3)	<.001
Posterior repair	6,690 (5.7)	1,200 (2.3)	<.001	40 (0.9)	17 (0.3)	<.001
Anti-incontinence	11,884 (10.1)	3,139 (6.1)	<.001	69 (1.6)	68 (1.1)	.02
Oophorectomy	63,058 (53.5)	26,693 (51.8)	<.001	4,218 (95.8)	6,316 (97.1)	.001
Lymphadenectomy				2,446 (55.5)	4,489 (69.0)	<.001
Indication						
Leiomyoma	54,662 (46.4)	27,390 (53.2)	<.001			
Endometriosis	39,106 (33.2)	16,125 (31.3)	<.001			
Abnormal bleeding	70,149 (59.5)	30,128 (58.5)	<.001			
Benign neoplasm	32,131 (27.3)	15,032 (29.2)	<.001			
Pelvic organ prolapse	20,940 (17.8)	4,682 (9.1)	<.001			
Cost data			<.001			<.001
Direct costing	85,679 (72.7)	40,530 (78.7)		3,173 (72.1)	5,217 (80.2)	
Cost-to-charge ratio	32,153 (27.3)	10,962 (21.3)		1,231 (28.0)	1,285 (19.8)	

Table 2

Unadjusted Cost Estimates for Minimally Invasive Hysterectomy for Benign Indications Stratified by Route of Surgery and Hospital and Physician Volume

Case volume	Laparoscopic ($)	Robotically Assisted ($)	*P*	Cost Differential (Robotically Assisted vs Laparoscopic) ($)
Hospital volume				
Any volume				
Total cost	6,535 (5,127–8,357)	8,152 (6,011–10,932)	<.001	1,617
Variable cost	2,965 (2,137–4,051)	3,591 (2,347–5,345)	<.001	626
Fixed cost	3,440 (2,633–4,513)	4,384 (3,170–5,883)	<.001	944
Fewer than 5 cases				
Total cost	7,262 (5,579–9,638)	9,315 (6,956–12,495)	<.001	2,053
Variable cost	3,865 (2,819–5,257)	4,859 (3,704–6,759)	<.001	994
Fixed cost	3,288 (2,335–4,671)	4,260 (2,788–5,989)	<.001	972
5–15 cases				
Total cost	7,024 (5,475–9,149)	9,031 (6,934–12,044)	<.001	2,007
Variable cost	3,766 (2,767–5,087)	4,788 (3,644–6,487)	<.001	1,022
Fixed cost	3,223 (2,290–4,386)	4,035 (2,754, –5,794)	<.001	812
16–30 cases				
Total cost	6,862 (5,357–8,983)	8,591 (6,649–11,371)	<.001	1,729
Variable cost	3,643 (2,760–4,893)	4,723 (3,537–6,255)	<.001	1,080
Fixed cost	3,120 (2,208–4,252)	3,722 (2,597–5,309)	<.001	602
31–50 cases				
Total cost	6,888 (5,404–8,985)	8,545 (6,678–11,147)	<.001	1,657
Variable cost	3,639 (2,763–4,893)	4,661 (3,440–6,183)	<.001	1,022
Fixed cost	3,137 (2,234–4,278)	3,806 (2,640–5,298)	<.001	669
More than 50 cases				
Total cost	6,466 (5,076–8,225)	8,026 (5,838–10,789)	<.001	1,560
Variable cost	3,399 (2,610–4,431)	4,299 (3,095–5,791)	<.001	900
Fixed cost	2,929 (3,119–3,997)	3,525 (2,274–5,312)	<.001	596
Physician volume				
Any volume				
Total cost	6,535 (5,127–8,357)	8,152 (6,011–10,932)	<.001	1,617
Variable cost	2,965 (2,137–4,051)	3,591 (2,347–5,345)	<.001	626
Fixed cost	3,440 (2,633–4,513)	4,384 (3,170–5,883)	<.001	944
Fewer than 5 cases				
Total cost	7,113 (5,574–9,168)	8,818 (6,660–11,837)	<.001	1,705
Variable cost	3,678 (2,805–4,882)	4,718 (3,485–6,327)	<.001	1,040
Fixed cost	3,284 (2,372–4,480)	3,994 (2,659–5,739)	<.001	710
5–15 cases				
Total cost	6,674 (5,252–8,419)	8,141 (6,153–10,732)	<.001	1,467
Variable cost	3,488 (2,609–4,384)	4,429 (3,240–4,811)	<.001	941
Fixed cost	2,865 (2,076–3,939)	3,592 (2,384–5,212)	<.001	727

Case volume	Laparoscopic ($)	Robotically Assisted ($)	*P*	Cost Differential (Robotically Assisted vs Laparoscopic) ($)
16–30 cases				
Total cost	6,400 (5,029–8,144)	7,959 (5,921–10,584)	<.001	1,559
Variable cost	3,388 (2,609–4,384)	4,314 (3,070–5,773)	<.001	926
Fixed cost	2,865 (2,076–3,939)	3,473 (2,280–5,114)	<.001	608
31–50 cases				
Total cost	6,234 (4,952–7,856)	7,624 (5,636–10,243)	<.001	1,390
Variable cost	3,353 (2,591–4,311)	4,095 (2,983–5,558)	<.001	742
Fixed cost	2,772 (2,009–3,720)	3,319 (2,136–4,913)	<.001	547
More than 50 cases				
Total cost	5,854 (4,668–7,399)	7,473 (5,075–10,645)	<.001	1,619
Variable cost	3,135 (2,409–4,097)	4,025 (2,881–5,574)	<.001	890
Fixed cost	2,620 (1,905–3,567)	3,267 (2,053–5,364)	<.001	647

Data are median (interquartile range) unless otherwise specified.

Table 3

Unadjusted Cost Estimates for Minimally Invasive Hysterectomy for Endometrial Cancer Stratified by Route of Surgery and Hospital and Physician Volume

Case volume	Laparoscopic ($)	Robotically Assisted ($)	*P*	Cost Differential (Robotically Assisted vs Laparoscopic) ($)
Hospital volume				
Any volume				
Total cost	8,237 (6,400–10,807)	9,691 (7,591–12,428)	<.001	1,454
Variable cost	3,790 (2,832–5,406)	4,543 (3,201–6,164)	<.001	753
Fixed cost	4,215 (3,098–5,644)	5,065 (3,994–6,536)	<.001	850
Fewer than 5 cases				
Total cost	7,998 (6,230–10,476)	10,469 (8,181–13,362)	<.001	2,471
Variable cost	4,096 (3,021–5,510)	5,453 (3,959–7,240)	<.001	1,357
Fixed cost	3,653 (2,610–5,106)	4,791 (3,384–6,677)	<.001	1,138
5–15 cases				
Total cost	8,204 (6,423–11,261)	10,188 (8,039–13,273)	<.001	1,984
Variable cost	4,286 (3,123–5,729)	5,379 (4,223–6,876)	<.001	1,093
Fixed cost	3,807 (2,740–5,711)	4,708 (3,276–6,408)	<.001	901
16–30 cases				
Total cost	8,122 (6,450–11,199)	9,875 (7,720–12,646)	<.001	1,753
Variable cost	4,199 (3,167–5,754)	5,283 (4,191–6,717)	<.001	1,084
Fixed cost	3,644 (2,839–5,511)	4,473 (3,194–6,173)	<.001	829
31–50 cases				
Total cost	8,288 (6,533–11,110)	9,691 (7,986–12,271)	<.001	1,403
Variable cost	4,243 (3,006–5,829)	5,212 (4,302–6,619)	<.001	972
Fixed cost	3,990 (2,960–5,605)	4,538 (3,328–6,011)	<.001	548
More than 50 cases				
Total cost	8,332 (6,426–10,606)	9,256 (7,257–11,914)	<.001	924
Variable cost	4,270 (3,150–5,559)	4,701 (3,804–5,985)	<.001	431
Fixed cost	4,270 (3,150–5,559)	4,502 (3,101–5,973)	<.001	232
Physician volume				
Any volume				
Total cost	8,237 (6,400– 10,807)	9,691 (7,591–12,428)	<.001	1,454
Variable cost	3,790 (2,832–5,406)	4,543 (3,201–6,164)	<.001	753
Fixed cost	4,215 (3,098–5,644)	5,065 (3,994–6,536)	<.001	850
Fewer than 5 cases				
Total cost	8,491 (6,572–11,009)	10,252 (8,008–13,231)	<.001	1,761
Variable cost	4,306 (3,181–5,681)	5,362 (4,092–7,006)	<.001	1,056
Fixed cost	3,921 (2,874–5,499)	4,784 (3,339–6,510)	<.001	863
5–15 cases				
Total cost	8,265 (6,370–11,211)	9,531 (7,609–12,054)	<.001	1,266
Variable cost	4,294 (3,054–5,812)	5,103 (4,118–6,365)	<.001	809
Fixed cost	3,866 (2,765–5,652)	4,471 (3,097–5,987)	<.001	605

Case volume	Laparoscopic ($)	Robotically Assisted ($)	*P*	Cost Differential (Robotically Assisted vs Laparoscopic) ($)
16–30 cases				
Total cost	7,812 (6,170–10,412)	9,377 (7,432–12,039)	<.001	1,565
Variable cost	3,931 (2,938–5,698)	4,902 (3,933–6,215)	<.001	971
Fixed cost	3,710 (2,929–5,147)	4,398 (3,266–5,920)	<.001	688
31–50 cases				
Total cost	8,213 (6,252–10,531)	9,664 (7,539–12,195)	<.001	1,451
Variable cost	4,096 (2,798–5,532)	4,974 (3,870–6,268)	<.001	878
Fixed cost	3,573 (2,906–5,543)	4,697 (3,445–6,052)	<.001	1,124
More than 50 cases				
Total cost	7,267 (5,924–8,611)	7,955 (6,574–10,457)	<.001	688
Variable cost	3,898 (2,996–4,651)	4,210 (3,487–5,039)	<.001	312
Fixed cost	3,128 (2,522–4,005)	3,602 (2,977–5,654)	<.001	474

Data are median (interquartile range) unless otherwise specified.

Table 4

Cost Models of Minimally Invasive Hysterectomy

Analysis	Benign Indications	Endometrial Cancer
Unadjusted		
Total cost	1,617 (1,581–1,653)	1,454 (1,279–1,629)
Variable cost	943 (918–969)	850 (752–948)
Fixed cost	626 (602–649)	753 (672–835)
Unadjusted direct costing hospitals only		
Total cost	1,995 (1,948–2,041)	1,875 (1,670–2,081)
Variable cost	1,132 (1,107–1,158)	1,017 (907–1,128)
Fixed cost	801 (774–828)	922 (799–1,046)
Fully adjusted*		
Total cost	1,225 (1,177–1,272)	1,328 (1,164–1,491)
Variable cost	922 (895–948)	936 (847–1,024)
Fixed cost	374 (349–399)	453 (361–544)
Fully adjusted, complications removed		
Total cost	1,222 (1,171–1,272)	1,375 (1,219–1,530)
Variable cost	920 (896–944)	956 (867–1,045)
Fixed cost	372 (347–396)	432 (347–517)
Fully adjusted, physician volume fewer than 5 cases		
Total cost	1,443 (1,362–1,524)	1,495 (1,284–1,705)
Variable cost	974 (927–1,021)	985 (850–1,120)
Fixed cost	566 (412–619)	560 (418–701)
Fully adjusted, physician volume 16–30 cases		
Total cost	1,084 (976–1,192)	1,687 (1,317–2,056)
Variable cost	920 (855–986)	1,421 (1,203–1,640)
Fixed cost	303 (234–372)	332 (82–582)
Fully adjusted, physician volume more than 50 cases		
Total cost	1,290 (1,170–1,409)	832 (393–1,270)†
Variable cost	892 (837–947)	311 (73–549)†
Fixed cost	334 (271–396)	585 (313–858)†

Data are U.S. dollars (95% confidence interval).

Cost differential of robotically assisted compared with laparoscopic hysterectomy.

* Fully adjusted model incorporates all clinical, demographic, physician, and hospital characteristics.

† Provider area excluded from models because of absence of patients in one cell.