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Comparative Effectiveness of Robotically Assisted Compared With Laparoscopic Adnexal Surgery for Benign Gynecologic Disease

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Abstract

Objective—To perform a population-based analysis to compare the complications and cost of laparoscopic and robotically assisted adnexal surgery.

Methods—A nationwide database was utilized to analyze the use and outcomes of robotically assisted adnexal surgery from 2009–2012. Multivariable mixed effects regression models were developed to examine predictors of use of robotic surgery. After propensity score matching, complications and cost were compared between robotically assisted and laparoscopic surgery.

Results—87,514 women were identified. From 2009 to 2012, performance of robotic-assisted oophorectomy increased from 3.5% (95% CI, 3.2–3.8%) to 15.0% (95% CI, 14.4–15.6%), while robotically assisted cystectomy rose from 2.4% (95% CI, 2.0–2.7%) to 12.9% (95% CI, 12.2–13.5%). The overall complication rate was 7.1% (95% CI, 4.0–10.2%) for robotically assisted vs. 6.0% (95% CI, 2.9–9.1%) for laparoscopic oophorectomy (OR=1.20; 95% CI, 1.00–1.45) (P=0.052). Robotic-assisted oophorectomy was associated with a higher rate of intraoperative complications (3.4% vs. 2.1%, OR=1.60; 95% CI, 1.21–2.13). The overall complication rate was 3.7% (95% CI –0.8–8.2%) after robotically assisted versus 2.7% (95% CI, –1.8–7.2%) for laparoscopic cystectomy (OR=1.38; 95% CI, 0.95–1.99). The intraoperative complication rate was higher for robotically assisted cystectomy (2.0% vs. 0.9%, OR=2.40; 95% CI, 1.31–4.38). Compared to laparoscopy, robotically assisted oophorectomy was associated with \$2504 (95% CI,

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\$2356–\$2652) increased total costs and robotically assisted cystectomy \$3310 (95% CI, \$3082–\$3581) higher costs.

Conclusion—Use of robotically assisted adnexal surgery increased rapidly. Compared to laparoscopic surgery, robotically assisted adnexal surgery is associated with substantially greater costs and a small, but statistically significant, increase in intraoperative complications.

Introduction

Robotically assisted surgical technology was developed to allow the completion of procedures by a minimally invasive surgical approach. Benefits of robotically assisted surgery compared to laparoscopy include increased range of motion of the instrumentation, improved visualization, and enhanced surgeon ergonomics. Robotically assisted surgery initially gained widespread application for the performance of radical prostatectomy.¹

Since the widespread use of robotically assisted prostatectomy, the surgical robot has been utilized for a number of other procedures.^{2–4} Unlike prostatectomy, however, laparoscopic alternatives were already in use for many of these operations and the comparative effectiveness of the robotically assisted procedures has been questioned.^{1–3,5,6} Criticism of robotically assisted surgery has often focused on the high cost of the technology.^{2,6,7} However, the availability of the surgical robot may afford access to minimally invasive surgery for a greater number of patients.^{2,8}

In the mid-1990's, laparoscopic adnexal surgery emerged as an alternative to laparotomy.^{9–12} Several studies suggested that, the morbidity profile of laparoscopic surgery for benign neoplasms was superior to laparotomy.^{9,11,12} A recent meta-analysis reported that laparoscopic adnexal surgery for benign ovarian masses was associated with decreased morbidity, decreased pain, a reduction in hospital length stay and a reduction in costs by over \$1000.¹⁰ Given the favorable outcomes of laparoscopy, the technology became the standard of care for benign adnexal surgery.

While robotically assisted surgery has been described for many procedures, little is known about the use and outcomes of robotically assisted adnexal surgery. We performed a population-based analysis to compare the complications and cost of laparoscopic and robotically assisted adnexal surgery.

Methods

The Perspective database (Premier, Inc., Charlotte, North Carolina) was utilized. Perspective is a nationwide database of hospitals from throughout the US. The database was initially developed to measure healthcare utilization, patterns of care, and quality. The database captures hospitalizations from over 500 acute care hospitals located across the U.S. The database captures clinical and demographic data, procedures, and all services during hospitalization. In 2006, Perspective logged approximately 5.5 million discharges, which represents approximately 15% U.S hospitalizations.¹³ Data undergoes a rigorous quality control process, has been validated, and has been utilized in a number of comparative

effectiveness studies. The study was deemed exempt by the Columbia University Institutional Review board.

Women 18 years of age and older who underwent laparoscopic oophorectomy (with or without salpingectomy) (ICD-9 65.31, 65.41, 65.53, 65.54, 65.63, 65.64) or laparoscopic ovarian cystectomy (ICD-9 65.31, 65.41) from 2009–2012 were analyzed. We excluded patients who underwent either procedure at the time of a concurrent hysterectomy. Patients with codes for both oophorectomy and cystectomy were classified as having undergone oophorectomy. For each procedure, patients were classified as either having undergone a laparoscopic or robotically assisted procedure. Patients who had a code for a robotically assisted procedure (ICD-9 17.42 or 17.44, introduced October 2008) or a recorded charge code for robotic instrumentation in combination with any of the above adnexal surgery codes were classified as having undergone a robotic procedure as previously described.² Patients who underwent surgery for gynecologic malignancy (ICD-9 180–184.9) were excluded.

Demographic characteristics analyzed included age (<40, 40–49, 50–59, 60–69, and 70 years), year of surgery (2009–2012), race (white, black, and other), marital status (married, single, and unknown), and insurance status (commercial, Medicare, Medicaid, uninsured and unknown). Indications for the procedure included benign neoplasms, infections (oophoritis or salpingitis), endometriosis, functional ovarian cysts, torsion, and other miscellaneous benign adnexal conditions. These categories were not mutually exclusive.

The procedure hospitals that rendered patient care were classified based on area of residence (metropolitan, non-metropolitan), region of the country (northeast, midwest, west, south), size (<400 beds, 400–600 beds, and >600 beds) and teaching status (teaching, non-teaching). Risk adjustment for comorbid medical conditions was performed using the Elixhauser comorbidity index with patients categorized as: 0, 1, 2.¹⁴

Procedural volume for hospitals and surgeons was estimated for each procedure. Both hospital and surgeon volume were calculated individually for each patient and estimated as the number of procedures performed at a given patient's hospital or by a given patient's surgeon prior to the date of the patient's surgery.¹⁵ For surgeons and hospitals, separate volume-based calculations were performed for each procedure and for each route of surgery. Volume is included as a continuous variable in all analyses.

We analyzed perioperative morbidity, resource utilization, cost, and mortality. Perioperative morbidity was based on the occurrence of a coded diagnosis consistent with an acute complication during the hospitalization of the procedure. Complications were classified into the following groups: i) intraoperative complications (bladder, ureteric, intestinal, or vascular injury, and other operative injury), ii) surgical site complications (wound complications, abscess, hemorrhage, bowel obstruction, and ileus), and iii) medical complications (venous thromboembolism, myocardial infarction, cardiopulmonary arrest, acute renal failure, respiratory failure, stroke, bacteremia/sepsis, shock, and pneumonia).^{2,3} The overall complication rate was defined as the occurrence of any of the above complications. Transfusion of packed red cells during the hospitalization and readmission to

the index hospital after discharge are reported as metrics of resource utilization. Non-routine discharge was defined as discharge to a nursing home, skilled nursing facility, or acute or sub-acute rehabilitation center and mortality as death during the index hospitalization.

The database captures data on facility-specific costs (not charges) of hospital care and reports total, fixed, and variable costs for each patient's hospitalization. Cost is captured through an itemized log of all items that are billed to a patient during the hospital stay. Approximately three quarters of hospitals report direct cost based on procedural accounting, while the remainder estimate cost based on Medicare cost-to-charge ratios, a hospital-specific estimate of how much it costs the facility to provide care.^{13,16} These data represent cost and not charges. The aggregate cost of each hospitalization was recorded for each patient and adjusted from inflation using the Consumer Price Index and reported in 2012 U.S. dollars.¹⁷ We excluded patient costs that were extreme outliers that were unrealistically low and thought to be spurious (defined as costs that were <\$500).² Within the cohort, 19 patients (0.02%) patients had total costs of <\$500. We report total cost as well as separate analyses of fixed and variable costs. Fixed costs are due to capital equipment and maintenance and do not vary based on volume, while variable costs are those costs due to the operation and hospital stay and vary based on volume.¹⁸

Statistical Analysis

Frequency distributions between categorical variables were compared using χ^2 tests while continuous variables were compared with Wilcoxon rank-sum tests. Distributions of oophorectomy and cystectomy by year of surgery are reported stratified by surgical approach. The association between patient, surgeon, and hospital characteristics and performance of robotically assisted adnexal surgery were examined using multivariable mixed effects log-binomial regression models. Associations are reported as risk ratios and 95% confidence intervals.

A propensity score matched analysis was performed to limit the influence of confounding on the surgical approach for the procedure. A propensity score is the estimated probability that a patient will undergo the treatment of interest, in the case of the current study, a robotically assisted adnexal surgery.¹⁹ We calculated each patient's propensity score from a multivariable logistic regression model that include the demographic, clinical, hospital, and physician variables described above. After the calculation of each patient's propensity score, we performed a 1 to 1 match between robotically assisted and laparoscopic procedures. Separate matches were performed for the oophorectomy and cystectomy sub-cohorts. We evaluated the matches between the groups by calculating the standardized difference, with a standardized difference score 0.1 for every covariate considered to indicate a good match.²⁰ Outcomes were compared between the propensity-matched groups using conditional logistic regression procedures, with the matched odds ratios and 95% confidence intervals. A sensitivity analysis was performed in which the analysis was limited to patients with endometriosis, a condition that has been associated with increased operative complexity at the time of adnexal surgery. A second sensitivity analysis was performed limiting the cohort to patients operated on by physicians with a surgical volume in the highest quartile.

Cost data were reported as median and interquartile ranges. As cost data is typically right-skewed, we performed multivariable adjustment of costs using quantile (median) regression methodology.²¹ Quantile regression estimates the adjusted median costs and 95% confidence intervals were derived based on bootstrap resampling methods. We performed sensitivity analyses of cost analyzing only those hospitals that reported costs as direct procedural costs (excluding facilities that reported cost-to-charge ratios).² All analyses were performed with SAS version 9.4 (SAS Institute Inc, Cary, North Carolina). All statistical tests were two-sided. A P-value of <0.05 was considered statistically significant.

Results

A total of 87,514 women were identified. The cohort included 52,599 women who underwent oophorectomy (Table 1) and 34,915 patients who underwent cystectomy (Appendix 1). Use of robotic-assistance for oophorectomy increased yearly from 3.5% (95% CI, 3.2–3.8%) in 2009 to 15.0% (95% CI, 14.4–15.6%) in 2012 ($P<0.001$) (Figure 1). Similarly, robotically assisted cystectomy accounted for 2.4% (95% CI, 2.0–2.7%) of minimally invasive cystectomies in 2009 and increased annually to 12.9% (95% CI, 12.2–13.5%) in 2012 ($P<0.001$).

In a multivariable model of women who underwent minimally invasive oophorectomy, year of diagnosis was the strongest factor associated with undergoing a robotically assisted procedure (Table 2). Older women were more likely to undergo a robotically assisted oophorectomy while non-white, non-black women (RR=0.77; 95% CI, 0.70–0.85), uninsured patients (vs. commercially insured patients) (RR=0.71; 95% CI, 0.58–0.88), and residents in non-metropolitan areas (vs. residents of metropolitan areas) (RR=0.24; 95% CI, 0.20–0.30) were less likely to undergo a robotically assisted procedure. Women who underwent surgery outside of the eastern US and those treated at larger hospitals were more likely to undergo robotically assisted oophorectomy. Women undergoing surgery for endometriosis and patients requiring a bilateral oophorectomy more frequently had a robotically assisted procedure.

For women undergoing cystectomy, year of diagnosis was the strongest factor associated with undergoing a robotically assisted operation. Black women were more likely to undergo a robotically assisted cystectomy (RR=1.15; 95% CI, 1.00–1.32), while non-black, non-white women (RR=0.85; 95% CI, 0.76–0.96), those with Medicaid (RR=0.76; 95% CI, 0.65–0.89), and the uninsured (RR=0.64; 95% CI, 0.48–0.84) (vs. commercially insured patients), and those residing in non-metropolitan areas (vs. residents of metropolitan areas) (RR=0.21; 95% CI, 0.16–0.29) were less likely to undergo a robotically assisted cystectomy (Table 2). Women treated outside of the eastern US and those at larger hospitals were more likely to undergo robotically assisted surgery while patients at teaching hospitals (RR=0.85; 95% CI, 0.73–1.00) less often underwent robotically assisted cystectomy. Patients with benign ovarian neoplasms and endometriosis more commonly had a robotically assisted operation.

After propensity score matching, both the oophorectomy and cystectomy cohorts were well balanced (Table 1 and Appendix 1). Among women who underwent oophorectomy, the

overall rate of morbidity was 7.1% (95% CI, 4.0–10.2%) in those who underwent a robotically assisted procedure compared to 6.0% (95% CI, 2.9–9.1%) after laparoscopic oophorectomy (OR=1.20; 95% CI, 1.00–1.45) (P=0.052) (Table 3). Women who underwent robotically assisted oophorectomy had a higher rate of intraoperative complications (3.4% vs. 2.1%, P=0.0009) (OR=1.60; 95% CI, 1.21–2.13). When examining specific complications, women who had a robotically assisted oophorectomy more commonly experienced bladder injuries (0.6% vs. 0.3%, P=0.05), ureteric injuries (1.7% vs. 0.4%, P<0.0001), and renal failure (0.8% vs. 0.3%, P=0.004). There was no statistically significant difference in the transfusion rates, 0.8% for robotically assisted compared to 1.2% for laparoscopic oophorectomy (OR=0.64; 95% CI, 0.40–1.01).

Among women who underwent cystectomy, the overall complication rate was 3.7% (95% CI, –0.8–8.2%) in women undergoing robotically assisted cystectomy compared to 2.7% (95% CI, –1.8–7.2%) in those who had a laparoscopic procedure (OR=1.38; 95% CI, 0.95–1.99). The increased complication rate was the result of a higher rate of intraoperative complications for women who had a robotically assisted cystectomy (2.0% vs. 0.9%) (OR=2.40; 95% CI, 1.31–4.38). Compared to laparoscopic cystectomy, robotically assisted cystectomy was associated with a significantly increased risk of ureteric injury (0.7% vs. 0.1%, P=0.004).

The median total cost for robotically assisted oophorectomy was \$7426 (IQR, \$5123–\$10,791) compared to \$4922 (IQR, \$3724–\$6803) for laparoscopic oophorectomy (P<0.0001). Robotic-assisted oophorectomy was associated with \$2504 (95% CI, \$2356–\$2652) in increased total cost, \$1053 (95% CI, \$964–\$1141) in increased fixed costs, and \$1299 (95% CI, \$1222–\$1376) in higher variable costs. The median total cost for robotically assisted cystectomy was \$7444 (IQR, \$5356–\$10,672) versus \$4133 (IQR, \$3090–\$5868) for laparoscopic cystectomy (P<0.0001). Compared to laparoscopic cystectomy, robotically assisted cystectomy was associated with \$3310 (95% CI, \$3082–\$3581) higher total cost, \$1378 (95% CI, \$1254–\$1497) in increased fixed costs, and \$1894 (95% CI, \$1767–\$2036) increased variable costs. A sensitivity analysis was performed in which the results were limited to only those hospitals that utilized direct procedural costing methodology. In these analyses, the cost differential between robotically assisted and laparoscopic surgery was slightly larger than the analysis including all hospitals.

Sensitivity analyses were performed limiting the cohort to only women who underwent surgery for endometriosis (Appendix 2, available online at <http://links.lww.com/xxx>). In these analyses, the overall results were similar. The overall complication rate was 6.4% vs. 5.0% (OR=1.30; 95% CI, 0.83–2.05) for robotically assisted compared to laparoscopic oophorectomy and 3.7% vs. 2.1% (OR=1.86; 95% CI, 1.04–3.32) for robotically assisted vs. laparoscopic cystectomy. For both oophorectomy and cystectomy, total, fixed, and variable costs were higher for robotically assisted compared to laparoscopic surgery. When limiting the analysis to the highest quartile of physicians by volume, the overall complication rates were 5.6% for laparoscopic vs. 5.2% for robotically assisted oophorectomy (OR=0.93; 95% CI, 0.63–1.36) and 2.1% for laparoscopic vs. 3.6% for robotically assisted cystectomy (OR=1.73; 95% CI, 0.84–3.58) (Appendix 3, available online at <http://links.lww.com/xxx>). Across the board, costs remained higher for robotically assisted procedures.

Discussion

Our findings suggest that the use of robotically assisted adnexal surgery has increased rapidly. Compared to laparoscopic surgery, robotically assisted adnexal surgery was associated with a small, but statistically significant, increase in intraoperative complications. Additionally, robotically assisted adnexal surgery was associated with a substantial increase in procedural costs.

Data describing the outcomes of robotically assisted adnexal surgery have been limited and based on single center experiences.^{22–25} A study of 85 patients who underwent robotically assisted adnexectomy compared to 91 women who underwent laparoscopic surgery noted that the mean blood loss, length of stay, and intraoperative complication rates were similar between the two groups while the mean operative time was 12 minutes longer in women who underwent a robotically assisted procedure.²⁴ A second observational analysis reported similar findings.²⁵

The additional cost associated with robotically assisted adnexal surgery is substantial. In their analysis of 20 surgical procedures, Barbash and Glied estimated that performing a procedure with robotic-assistance increased the average total costs by 13%.⁷ The cost differential we noted for robotically assisted adnexal surgery was much greater; robotically assisted oophorectomy was 50% more costly, while robotically assisted cystectomy was 80% more costly than their respective laparoscopic alternatives. The large cost differential may be due, at least in part, to the relatively low complexity of adnexal procedures that typically results in short operative times when performed laparoscopically and limited use of instrumentation.⁷

Of concern, we found that the intraoperative complication rate of robotically assisted adnexal surgery was higher than for laparoscopy. The increased intraoperative morbidity was driven by ureteral and bladder injuries. The increased rate of intraoperative morbidity may be in part the result of complications from gynecologic surgeons gaining experience on a new technology. Alternatively, surgeons may be attempting to perform more technically challenging cases via a minimally invasive approach. If this is indeed the case, our data raise an important concern from a patient perspective; that is whether the potential benefits of undergoing a minimally invasive procedure outweigh the increased risk of intraoperative complications.

The rapid dissemination of robotic adnexal surgery is likely driven by a multitude of factors. First, robotically assisted hysterectomy is now frequently performed for benign pelvic diseases and gynecologic cancers.^{2,3} As gynecologic surgeons gain familiarity with robotic technology, there will likely be diffusion to other pelvic procedures, including adnexectomy, despite limited data.⁴ Second, robotic surgery has been intensely marketed, often in the absence of data, to not only surgeons and hospitals, but also directly to patients.²⁶ Finally, among surgeons learning to use the robotic platform, use of robotic-assistance for relatively straightforward procedures, such as adnexal surgery, has been promoted to increase experience with the technology.²⁷

We acknowledge a number of limitations. To capture the initial uptake of robotic surgery, we made use of both ICD-9 procedure codes as well as hospital-level billing data. Although this classification schema has been validated in prior studies, we cannot exclude the possibility that a small number of procedures were misclassified.² We recognize that it is not possible to perform complete risk adjustment for patients undergoing adnexectomy using administrative data. In addition to potential differences in measured cofactors, a number of unmeasured covariates including size of the lesion, prior surgical history, and body habitus undoubtedly influenced treatment selection and outcomes. However, to limit this bias, we performed a series of sensitivity analyses and tried to rigorously adjust for measured confounders using propensity score methodology. Finally, we were unable to capture minor postoperative complications and subjective symptoms and our analysis was therefore focused on major perioperative morbidity.

Questions of the utility of robotically assisted surgery for other procedures has led to increased debate on how best to manage the use of the technology in scenarios of uncertain benefit.^{2,5,7} At the local level, some institutions have implemented policies to limit utilization of robotically assisted surgery for procedures where efficacy has not been demonstrated. Nationally, there are ongoing efforts by the Centers for Medicare and Medicaid Services and others to explore bundled reimbursement for episodic care.²⁸ If bundled reimbursement were implemented for adnexal surgery, based on current costs, hospital margins would be substantially lower for a robotically assisted compared to laparoscopic procedure. It seems likely that some of these costs would be passed on to physicians in the form of lower reimbursement and, perhaps, to patients in the way of higher out-of-pocket expenses.²⁹ In summary, these findings highlight the need for more prudent policies to guide the development, testing, and utilization of surgical innovations. Prior to widespread acceptance, additional rigorous data supporting the safety and comparative effectiveness of robotically assisted adnexal surgery should be collected.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Figure 1. Percentage of oophorectomies and cystectomies performed robotically (compared to laparoscopic), stratified by year of surgery ($P<.001$).

Table 1
Clinical and demographic characteristics of women who underwent minimally invasive oophorectomy

	Unadjusted				Propensity score matched				Standardized difference
	Laparoscopic n	(%)	Robotic n	(%)	P-value	Laparoscopic n	(%)	Robotic n	(%)
<i>Age</i>	47,733	(90.8)	4866	(9.3)		3791	(50.0)	3791	(50.0)
<40	16,336	(93.2)	1185	(6.8)	<0.001	990	(50.5)	969	(49.5)
40–49	15,338	(90.7)	1565	(9.3)		1231	(50.0)	1233	(50.0)
50–59	8580	(90.3)	919	(9.7)		715	(49.9)	718	(50.1)
60–69	4503	(86.1)	725	(13.9)		513	(49.4)	526	(50.6)
70	2976	(86.3)	472	(13.7)		342	(49.8)	345	(50.2)
<i>Race</i>					<0.001				
White	34,726	(90.7)	3542	(9.3)		2738	(49.6)	2787	(50.4)
Black	4240	(88.2)	567	(11.8)		427	(50.9)	412	(49.1)
Other	8767	(92.1)	757	(8.0)		626	(51.4)	592	(48.6)
<i>Year of surgery</i>					<0.001				
2009	10,989	(96.5)	399	(3.5)		390	(49.4)	399	(50.6)
2010	12,146	(93.3)	872	(6.7)		809	(50.1)	807	(49.9)
2011	12,827	(89.4)	1523	(10.6)		1242	(50.3)	1226	(49.7)
2012	11,771	(85.0)	2072	(15.0)		1350	(49.8)	1359	(50.2)
<i>Insurance</i>					<0.001				
Commercial	32,143	(90.7)	3287	(9.3)		2556	(49.5)	2610	(50.5)
Medicare	6265	(87.0)	935	(13.0)		689	(50.8)	668	(49.2)
Medicaid	5616	(93.7)	379	(6.3)		333	(51.2)	317	(48.8)
Uninsured	2115	(94.8)	115	(5.2)		101	(51.5)	95	(48.5)
Unknown	1594	(91.4)	150	(8.6)		112	(52.6)	101	(47.4)
<i>Marital status</i>					0.27				
Married	26,356	(90.6)	2746	(9.4)		2079	(49.1)	2153	(50.9)
Single	16,601	(91.0)	1646	(9.0)		1273	(50.5)	1247	(49.5)
Unknown	4776	(91.0)	474	(9.0)		439	(52.9)	391	(47.1)

	Unadjusted				Propensity score matched				Standardized difference
	Laparoscopic n (%)	Robotic n (%)	P-value		Laparoscopic n (%)	Robotic n (%)			
<i>Area of residence</i>									
Metropolitan	41,359 (89.8)	4694 (10.2)		<0.001	3639 (50.0)	3636 (50.0)		-	
Non-metropolitan	6374 (97.4)	172 (2.6)			152 (49.5)	155 (50.5)		0.004	
<i>Region</i>									
Eastern	6738 (94.0)	431 (6.0)		<0.001	392 (51.0)	377 (49.0)		-	
Midwest	8881 (91.8)	789 (8.2)			706 (51.8)	657 (48.2)		0.072	
South	22,364 (88.7)	2842 (11.3)			2071 (49.5)	2110 (50.5)		0.020	
West	9750 (92.4)	804 (7.6)			622 (49.0)	647 (51.0)		0.040	
<i>Comorbidity</i>									
0	19,468 (91.7)	1770 (8.3)		<0.001	1417 (49.9)	1423 (50.1)		-	
1	11,173 (90.5)	1170 (9.5)			945 (51.0)	908 (49.0)		0.040	
2	17,092 (89.9)	1926 (10.1)			1429 (49.5)	1460 (50.5)		0.020	
<i>Hospital type</i>									
Non-teaching	31,018 (91.7)	2811 (8.3)		<0.001	2195 (50.1)	2188 (49.9)		-	
Teaching	16,715 (89.1)	2055 (11.0)			1596 (49.9)	1603 (50.1)		0.004	
<i>Hospital size</i>									
<400 beds	28,661 (93.1)	2134 (6.9)		<0.001	1796 (50.9)	1731 (49.1)		-	
400–600 beds	11,693 (87.4)	1680 (12.6)			1232 (49.5)	1255 (50.5)		0.020	
>600 beds	7379 (87.5)	1052 (12.5)			763 (48.7)	805 (51.3)		0.052	
<i>Hospital volume (median, IQR)</i>	18 (8–30)	10 (4–19)		<0.001	11 (5–19)	11 (5–21)		0.03	
<i>Surgeon volume (median, IQR)</i>	1 (0–4)	1 (0–3)		<0.001	1 (0–3)	1 (0–3)		0.008	
<i>Laterality</i>									
Unilateral	30,529 (93.4)	2175 (6.7)		<0.001	1834 (50.2)	1821 (49.8)		-	
Bilateral	17,204 (86.5)	2691 (13.5)			1957 (49.8)	1970 (50.2)		0.007	
<i>Procedure</i>									
Benign	12,785 (26.8)	1306 (26.8)		0.93	1002 (26.4)	1022 (27.0)			
neoplasm								0.012	
Infection	3329 (7.0)	345 (7.1)		0.76	271 (7.2)	260 (6.9)		0.011	
Endometriosis	8079 (16.9)	934 (19.2)		<0.001	700 (18.5)	702 (18.5)		0.001	

	Unadjusted				<i>P-value</i>	Propensity score matched				<i>Standardized difference</i>
	Laparoscopic <i>n</i>	(%)	Robotic <i>n</i>	(%)		Laparoscopic <i>n</i>	(%)	Robotic <i>n</i>	(%)	
Functional	28,586	(59.9)	2626	(54.0)	<0.001	2094	(55.2)	2071	(54.6)	
cyst										0.012
Torsion	2287	(4.8)	79	(1.6)	<0.001	71	(1.9)	70	(1.9)	0.002
Other	9241	(19.4)	949	(19.5)	0.81	767	(20.2)	756	(19.9)	0.007

P-values and standardized difference represent overall values for each covariate.
Unadjusted results and data after propensity score matching are reported.

Table 2

Multivariable models of factors associated with robotically assisted adnexal surgery

	Robotically assisted oophorectomy	Robotically assisted cystectomy
<i>Age</i>		
<40	Referent	Referent
40–49	1.13 (1.03–1.23) *	1.04 (0.93–1.17)
50–59	1.14 (1.03–1.27) *	1.03 (0.75–1.42)
60–69	1.28 (1.13–1.45) *	1.02 (0.54–1.96)
70	1.28 (1.09–1.52) *	0.90 (0.38–2.13)
<i>Race</i>		
White	Referent	Referent
Black	1.11 (1.00–1.23)	1.15 (1.00–1.32) *
Other	0.77 (0.70–0.85) *	0.85 (0.76–0.96) *
<i>Year of surgery</i>		
2009	Referent	Referent
2010	4.62 (4.07–5.25) *	4.92 (4.03–6.00) *
2011	16.70 (14.68–19.00) *	18.55 (15.33–22.44) *
2012	51.68(45.05–59.29) *	58.60 (48.05–71.47) *
<i>Insurance</i>		
Commercial	Referent	Referent
Medicare	0.97 (0.86–1.09)	0.80(0.56–1.15)
Medicaid	0.91 (0.80–1.03)	0.76 (0.65–0.89) *
Uninsured	0.71 (0.58–0.88) *	0.64 (0.48–0.84) *
Unknown	0.94 (0.78–1.13)	0.76 (0.59–0.98) *
<i>Marital status</i>		
Married	Referent	Referent
Single	0.97 (0.90–1.04)	0.96 (0.86–1.06)
Unknown	0.57 (0.50–0.65) *	0.67 (0.56–0.80)
<i>Area of residence</i>		
Metropolitan	Referent	Referent
Non-metropolitan	0.24 (0.20–0.30) *	0.21(0.16–0.29) *
<i>Region</i>		
Eastern	Referent	Referent
Midwest	1.69 (1.44–2.00) *	1.79 (1.37–2.34) *
South	2.55 (2.20–2.97) *	3.08 (2.41–3.94) *
West	2.28 (1.93–2.71) *	2.25 (1.71–2.97) *
<i>Comorbidity</i>		
0	Referent	Referent
1	0.97 (0.89–1.05)	1.03 (0.92–1.15)

	Robotically assisted oophorectomy	Robotically assisted cystectomy
2	0.97 (0.90–1.04)	1.00 (0.87–1.14)
<i>Hospital type</i>		
Non-teaching	Referent	Referent
Teaching	1.06 (0.95–1.17)	0.85 (0.73–1.00)*
<i>Hospital size</i>		
<400 beds	Referent	Referent
400–600 beds	2.69 (2.42–2.99)*	2.61 (2.23–3.05)*
>600 beds	2.41(2.11–2.76)*	1.99 (1.60–2.47)*
<i>Laterality</i>		
Unilateral	Referent	-
Bilateral	1.57 (1.44–1.72)*	-
<i>Procedure</i>		
Benign neoplasm	0.94 (0.87–1.01)	1.30 (1.15–1.47)*
Infection	1.02 (0.90–1.15)	1.13 (0.92–1.38)
Endometriosis	1.18 (1.08–1.28)*	1.26 (1.13–1.40)*
Functional cyst	0.89 (0.84–0.95)*	0.97 (0.87–1.07)
Torsion	0.56 (0.44–0.72)*	0.56 (0.35–0.90)*
Other	0.99 (0.91–1.07)	1.09 (0.95–1.25)

Data are risk ratios with (95% confidence intervals).

* P<0.05

Table 3

Morbidity, mortality, and resource utilization of adnexal surgery stratified by route of surgery.

	Oophorectomy				P-value	PS Matched OR or difference Laparoscopic vs. Robotic	Cystectomy			
	Laparoscopic		Robotic				Laparoscopic		Robotic	
	n	(%)	n	(%)			n	(%)	n	(%)
Any complication	227	(6.0)	269	(7.1)	0.05	1.20 (1.00–1.45)	51	(2.7)	69	(3.7)
Intraoperative complications	80	(2.1)	127	(3.4)	0.0009	1.60(1.21–2.13)	16	(0.9)	37	(2.0)
Bladder injury	10	(0.3)	21	(0.6)	0.05*		0	-	3	(0.2)
Ureteric injury	16	(0.4)	63	(1.7)	<0.0001		2	(0.1)	13	(0.7)
Intestinal injury	28	(0.7)	39	(1.0)	0.18		7	(0.4)	7	(0.4)
Vascular injury	0	-	0	-	-		0	-	0	-
Other operative injury	48	(1.3)	42	(1.1)	0.52		10	(0.5)	19	(1.0)
Surgical site complications	77	(2.0)	61	(1.6)	0.17	0.79 (0.57–1.11)	15	(0.8)	19	(1.0)
Wound complication	5	(0.1)	6	(0.2)	0.76		1	(0.1)	1	(0.1)
Abscess	21	(0.6)	14	(0.4)	0.24		6	(0.3)	3	(0.2)
Hemorrhage	14	(0.4)	16	(0.4)	0.71		5	(0.3)	8	(0.4)
Bowel obstruction	8	(0.2)	10	(0.3)	0.64		2	(0.1)	1	(0.1)
Ileus	31	(0.8)	27	(0.7)	0.60		6	(0.3)	7	(0.4)
Medical complications	102	(2.7)	122	(3.2)	0.17	1.21 (0.92–1.59)	26	(1.4)	23	(1.2)
Venous thromboembolism	49	(1.3)	57	(1.5)	0.43		16	(0.9)	13	(0.7)
Myocardial infarction	9	(0.2)	6	(0.2)	0.44		1	(0.1)	3	(0.2)
Cardiopulmonary arrest	1	(0.03)	2	(0.05)	0.56		0	-	0	-
Respiratory failure	23	(0.6)	26	(0.7)	0.67		5	(0.3)	6	(0.3)
Renal failure	11	(0.3)	29	(0.8)	0.004		1	(0.1)	2	(0.1)
Stroke	1	(0.03)	1	(0.03)	0.99		0	-	0	-
Bacteremia/sepsis	7	(0.2)	5	(0.1)	0.56		1	(0.1)	0	-
Shock	12	(0.3)	11	(0.3)	0.83		2	(0.1)	2	(0.1)
Pneumonia	10	(0.3)	3	(0.1)	0.05		1	(0.1)	1	(0.1)
Utilization										
Transfusion	47	(1.2)	30	(0.8)	0.05	0.64 (0.40–1.01)	17	(0.9)	17	(0.9)
Reoperation	11	(0.3)	10	(0.3)	0.83	0.91(0.39–2.14)	9	(0.5)	4	(0.2)

	Oophorectomy				P-value	PS Matched OR or difference Laparoscopic vs. Robotic	Cystectomy			
	Laparoscopic		Robotic				Laparoscopic		Robotic	
	n	(%)	n	(%)			n	(%)	n	(%)
Readmission	3	(0.1)	0	-	0.08		2	(0.1)	0	-
Total cost ^I	\$4922 (\$3724–\$6803)		\$7426 (\$5123–\$10,791)		<0.001	\$2504 (\$2356–\$2652)	\$4133 (\$3090–\$5868)		\$7444 (\$5356–\$10,672)	
Fixed cost	\$2120 (\$1417–\$3139)		\$3173 (\$1901–\$5346)		<0.001	\$1053 (\$964–\$1141)	\$1807 (\$1118–\$2687)		\$3186 (\$2001–\$5304)	
Variable cost	\$2614 (\$1962–\$3618)		\$3913 (\$2816–\$5446)		<0.001	\$1299 (\$1222–\$1376)	\$2236 (\$1649–\$3131)		\$4133 (\$3025–\$5436)	
Procedural costing hospitals										
Total cost	\$4737 (\$3603–\$6561)		\$7801 (\$5532–\$11,274)		<0.001	\$3064 (\$2889–\$3240)	\$3913 (\$2921–\$5513)		\$7551 (\$5364–\$10,781)	
Fixed cost	\$2036 (\$1334–\$3002)		\$3435 (\$2088–\$5700)		<0.001	\$1400 (\$1280–\$1519)	\$1712 (\$1034–\$2475)		\$3264 (\$2056–\$5462)	
Variable cost	\$2527 (\$1910–\$3549)		\$4055 (\$2945–\$5588)		<0.001	\$1529 (\$1429–\$1628)	\$2142 (\$1606–\$3006)		\$4132 (\$3007–\$5450)	
Non-routine discharge	13 (0.5)		10 (0.3)		0.47	0.70 (0.27–1.84)	2 (0.2)		1 (0.1)	
Death	0 -		3 (0.1)		0.10	-	1 (0.1)		0 -	

OR=Odds ratio

Data represent propensity score-matched cohorts.

^I P<0.05