Increasing Use of Minimally Invasive Hysterectomy

Effects on Cost and Complications

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Áhrif á kostnað og fylgikvilla

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Ágrip

MARKIÐ: Á þriggja ára rannsóknartímabili breyttist megin aðferð við legnámsaðgerðir úr opinni kviðarholsaðgerð í kviðsjáraðgerð. Markmið þessarar rannsóknar er að meta áhrif þessarar breytingar á útkomu sjúklinga og kostnað við legnámsaðgerðir framkvæmdar á Brigham and Women´s sjúkrahúsinu árið 2006 og bera saman við árið 2009.

EFNI OG AÐFERÐIR: Afturskyggn lýsandi rannsókn, 2133 konur (17-92 ára) sem gengust undir legnám árin 2006 og 2009. Aðgerðirnar voru framkvæmdar á þriðja stigs kennslusjúkrahúsi af fjölbreyttum hópi kvensjúkdómalækna. Upplýsingar um aðgerðakostnað fengust úr reikningsbókhaldi Brigham and Women's sjúkrahússins en aðrar upplýsingar fengust úr sjúkraskrám.

NIÐURSTÖÐUR: Heildarfjöldi legnámsaðgerða var svipaður bæði árin; 1054 aðgerðir 2006 og 1079 aðgerðir 2009, samtals 2133 aðgerðir á jafnmörgum konum. Hlutfall kviðarholsaðgerða og kviðsjáraðgerða breyttist marktæk; kviðarholsaðgerðum fækkaði úr 64.7% í 35.8%, $p<0.0001$ og kviðsjáraðgerðum fjölgaði úr 17.7% í 46% milli ára, $p=0.0001$. Hlutfall meiri háttar fylgikvilla í aðgerð (líffæraáverki og/eða blóðmissir ≥ 1 lítri) og minni háttar fylgikvilla eftir aðgerð lækkaði marktækt frá 2006 til 2009 (7.2% í 4%, $p=0.0012$ og 18% í 5.7%, $p<0.0001$). Kostnaður vegna aðgerða jókst marktækt frá 2006 til 2009 við allar aðgerðir nema þær sem nutu aðstoðar vélmenna.

ÁLYKTUN: Breytt nálgun við legnám, þar sem meirihluti aðgerða er framkvæmdur með hjálp kviðsjár í stað opinnar aðgerðar, hélst í hendur við marktækt lægri tíðni fylgikvilla.

SANNINDI: II-c.

Abstract

OBJECTIVE: In the three-year period under study, the main mode of access for hysterectomy changed from abdominal to laparoscopic. The objective is to evaluate the effects of this shift on perioperative outcomes and the cost of hysterectomies performed at Brigham and Women's Hospital in 2006 as compared to 2009.

METHODS: A retrospective analysis was performed on 2,133 women (aged 17 to 92) who underwent hysterectomy by any method in 2006 and 2009 at an urban academic tertiary care center performed by a diverse group of gynecologists. Operative cost data was gathered from the Brigham and Women's Hospital billing system and the remainder of data was extracted from the patients' medical records.

RESULTS: A total of 2,130 patients were included. The total number of hysterectomies performed at our institution remained stable (1,054 procedures in 2006 versus 1,079 in 2009) but the relative proportions of abdominal and laparoscopic cases changed markedly during this three-year period (64.7% to 35.8% for abdominal, $p<0.0001$ and 17.7% to 46% for laparoscopic cases, $p=0.0001$). The rate of intraoperative complications (organ injury and/or estimated blood loss ≥ 1000 ml) and minor postoperative complications decreased significantly between 2006 and 2009 (7.2% to 4%, $p=0.0012$ and 18% to 5.7%, $p<0.0001$, respectively). Operative costs increased significantly from 2006 to 2009 for all procedures apart from robotic hysterectomy.

CONCLUSION: A change in the mode of access from majority abdominal hysterectomy to majority minimally invasive hysterectomy was accompanied by a significant decrease in procedure-related complications.

LEVEL OF EVIDENCE: II-c.

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List of Abbreviations

AH	Abdominal Hysterectomy
VH	Vaginal Hysterectomy
LH	Laparoscopic Hysterectomy
MIGS	Minimally Invasive Gynecologic Surgery
RCT	Randomized Controlled Trial
RH	Robotically Assisted Laparoscopic Hysterectomy
LOS	Length of Stay
BMI	Body Mass Index
EBL	Estimated Blood Loss
OR time	Operation Room Time
OR	Odds Ratio
CI	Confidence Interval

1 Introduction

Hysterectomy is a surgical procedure in which a woman's uterus is removed from her body. First reports of hysterectomies are from ancient times: from Themison of Athens in 50 BC (1) and Soranus of Ephesus in 120 AD (2). Those procedures were performed because of severely prolapsed uteri and the surgery involved cutting both ureters and the bladder, leaving the women completely incontinent (3). The first successful planned vaginal hysterectomy (VH) was performed in 1813 by Conrad Langenbeck, a German anatomist and Surgeon General of the Hanoverian army (4). At that time, no anesthesia was available and Dr. Langenbeck did not have an assistant to help him perform the operation. Towards the end of the operation, Dr. Langenbeck encountered a massive hemorrhage so he called for an assistant. The only assistant available was a severely obese Surgeon Commander who suffered from gout. The Surgeon Commander was in such poor health that he did not manage to get up from his chair, so Dr. Langenbeck had no alternative but to control the bleeding on his own. At one point he had to use his teeth to tie suture! Despite considerable loss of blood, the patient survived. Unfortunately, no one believed that Dr. Langenbeck had performed the procedure, since there was no visible scar and the surgical specimen was lost on its way to the pathology department. The patient had dementia and did not give a reliable testimony, and the Surgeon Commander with the gout died shortly after the surgery was performed. Dr. Langenbeck was subject to ridicule and was mocked among his peers for 26 years until his patient died and an autopsy confirmed that the uterus had been removed (5).

The first attempted abdominal hysterectomy (AH), by Charles Clay of Manchester, England, in 1843, was unfortunately not successful. The procedure was performed without anesthesia and the patient was only given milk and brandy for pain management. The patient died shortly after the procedure due to great loss of blood. The first successful AH was performed 10 years later by Walter Burnham in Lowell, Massachusetts (6). The procedure was performed in the early days of anesthesia. The patient survived and Dr. Burnham performed another 15 hysterectomies in the next 13 years. Unfortunately only three of his patients survived; the others died because of sepsis, peritonitis or loss of blood. The peer review Mr. Burnham received was not flattering: "We consider extirpation of the uterus, not previously protruded or inverted, one of the most cruel and unfeasible operation that ever was projected or executed by the head or hand of man" (6). By 1880, abdominal hysterectomy had become more common but mortality remained high (70%); the majority of patients died because of a massive hemorrhage (5). Late 19th-century advances in surgical technique lowered mortality following hysterectomy and by 1910 the mortality rate after VH had gone down to 2.5%. Unfortunately, mortality following abdominal hysterectomy lagged behind. Finally, with the emergence of subtotal abdominal hysterectomy (a technique refined by Howard Kelly involving an approach little different from what is used today), the mortality rate following abdominal hysterectomy went down to 3.5% (7). With further advances in anti-coagulation therapy, antibiotics and intravenous therapy, together with safer anesthesia and blood transfusion, the mortality rate following both VH and total AH is now approximately 0.1% (7).

The increased safety of the procedure led to an increase in the number of operations performed. Now, hysterectomy is the most common major gynecologic surgical procedure, with more than 600,000 procedures performed in the United States every year (8). This corresponds to the removal of at least one uterus every minute of the year. In the U.S., 20% of women will have had a hysterectomy by the age of 40 (9), increasing to 33% by the age of 65 (10) and 43% by the age of 85 (11). The lifetime risk of women undergoing hysterectomy differs between countries. Hysterectomy is much more common in the United States, with a rate of 5.38 per 1000 women per year (12), than it is in Europe: 3.7 per 1000 in Italy and as few as 1.8 per 1000 in Norway (13). The rate differs also between different states of the United States; hysterectomy is more common on the West Coast than the East Coast (12).

1.1 Different Surgical Approaches

While the hysterectomy rate has remained stable in the U.S. at 5.38 per 1000 women per year for the past few decades, the distribution of surgical approaches has changed (12). Procedural approach is influenced by important factors including surgical indication, patients' characteristics, concomitant procedures, recovery and the experience of the surgeon (12). There are three main approaches to hysterectomy: the abdominal, laparoscopic and vaginal approach. The vaginal approach is the only approach exclusively performed by gynecologists. The most common and the most invasive approach is an AH (14). AH is considered the traditional mode of access and over the past decades it has been the most common mode (10,15,16). It can be performed as total (cervix removed) or subtotal (the cervix is left in place and only uterus removed). At first, AH was performed via vertical incision. The emergence of the Pfannenstiel incision in 1900 helped lower morbidity associated with abdominal laparotomy. The greater tensile strength of the Pfannenstiel incision wound is considered to decrease incidence of wound dehiscence and incisional hernia.

VH is performed via the vaginal top. VH is considered a minimally invasive procedure, resulting in less postoperative pain for the patient, a shorter hospital stay and a faster return to normal activities, as well as better cosmetic results. VH and laparoscopic hysterectomies (LH) are grouped together as minimally invasive procedures.

LH is an abdominal procedure performed through one to four small incisions on the abdomen. The surgeon inserts ports or trocars through the incision and into the abdomen. Various long-armed instruments, used to perform the surgery, can be inserted through the trocars. LH uses laparoscopic techniques in varying degrees in performing a hysterectomy. These include: laparoscopic assisted vaginal hysterectomy, total laparoscopic hysterectomy, laparoscopic supra-cervical hysterectomy and robotic assisted laparoscopic hysterectomy. Laparoscopic approaches allow visualization of the pelvis and freeing adhesions, among other laparoscopic therapies (17). LH provides better quality of life postoperatively, when compared to the traditional mode of access, AH (18) and is one of the main reasons why many women and surgeons choose this approach. One of the major drawbacks of LH is that it requires an advanced level of skill, and the available surgical training is often inadequate.

The concept of robotic surgery was introduced by the U.S. Army (The da Vinci ® System) as an attempt to allow telesurgery for injured soldiers near the battlefield. It was first incorporated into

urologic procedures in 2001 and then into thoracoscopically-assisted cardiotomy in 2002 (19). Robotic surgery involves a laparoscopic procedure with robotic assistance. The da Vinci ® Robotic Surgical System was FDA-approved for use in gynecologic surgery in 2005. Many surgeons have embraced the da Vinci® technology over conventional laparoscopy because of the technological advantages of wristed instrumentation, high definition three-dimensional optics for the surgeon, ergonomics and autonomy of camera control. Furthermore, many surgeons with limited advanced laparoscopic skills have successfully converted their practice from primary laparotomy to minimally invasive surgery, using the da Vinci® System. Finally, it is less dependent on pneumoperitoneum and therefore it is ideal for use on obese patients who do not tolerate the high intra-abdominal pressure needed during laparoscopic procedures. But the robot also has shortcomings. It does not provide a tactile feedback, so surgeons have to rely on visual clues and the cost is greater than that of other hysterectomy procedures. Currently, robotic-assisted laparoscopy in gynecologic surgery is in the developmental and early adoption phase, but more gynecologists are likely to train and adopt this technology in the next few years (19).

1.2 What is the Appropriate Mode of Access?

The risks and benefits of each approach have been compared through randomized, retrospective and prospective cohort studies. However, there is insufficient data from well-designed randomized controlled trials upon which to base recommendations (17), and subsequently no consensus has arisen regarding the optimal procedure for any given gynecological condition (17,20,21). Many authors (22-26) have come to the conclusion that VH should be the first option for hysterectomy for benign disease (20), based on low incidence of complications and also on cost-effectiveness. LH should be considered when the vaginal approach is not feasible (17). The minimally invasive procedures have shown clear advantages over AH in terms of less intraoperative blood loss, shorter hospital stay, quicker return to normal activities, and fewer wound and abdominal wall infections (17). The authors of a retrospective analysis of 15,404 women undergoing hysterectomy in 2005-2006 concluded that minimally invasive procedures were not only better for patients, with less surgical pain, fewer complications and faster recovery to full activity, but also with lower cost (14). They also conclude that clinical and economic outcomes should encourage clinicians to consider greater use of minimally invasive hysterectomy procedures in patients who have no contraindications for laparoscopic or vaginal approach to hysterectomy. Moreover, when considering contraindications, higher volume surgeons mention fewer contraindications to minimally invasive procedures than lower volume surgeons (27). Despite this evidence, only one in three hysterectomies in the United States is currently performed as a minimally invasive procedure (16).

1.3 Quality of Life following Gynecologic Surgery

Major indications for hysterectomies have not changed much since the emergence of the procedures but the surgical technique has changed and is still changing. Hysterectomy is in 90% of cases performed for benign indications, the most frequent being uterine leiomyomas (30-35%) followed by bleeding, pain and prolapse. Since the procedures are mainly performed for benign indications, quality of life following surgery is a major concern. According to the Maryland Women´s Health study, a

prospective interview study of 1,299 women prior to and up to two years following hysterectomy, the quality of life improved dramatically for the majority of women following a hysterectomy of any kind (28).

1.4 Alternatives to Hysterectomy

The rate of hysterectomy appears to be decreasing. Possible reasons for this decrease include higher incidences of less invasive therapies for management of conditions previously treated by hysterectomy (16). These alternatives can be attempted prior to proceeding with hysterectomy. Appropriate alternatives are largely dependent on indication. If a woman suffers from excessive uterine bleeding, simply inserting a hormonal intra-uterine device (IUD) can significantly decrease her bleeding. Bleeding problems have been treated with dilatation and curettage, where the endometrium is scraped out, and simultaneously, intra-uterine polyps can be removed. Hysteroscopy can also be used to remove polyps and/or submucosal fibroids. Performing advanced hysteroscopy requires significant surgical skills and not all gynecologists offer the option. If excessive bleeding is believed to be because of fibroids, uterine fibroid embolization or a myomectomy may be a good option (29). Myomectomy can be performed via abdominal or laparoscopic route with or without robotic assistance. Another alternative in treating an excessive bleeding is a uterine artery embolization, a procedure performed by interventional radiologist, or a uterine artery occlusion, performed by placing clips on the uterine vessels. Recently a less invasive therapy has shown promise as a medical treatment for fibroids and bleeding. A selective progesterone receptor modulator, Asoprisnil, 25 mg, decreased fibroids volume and suppressed bleeding in 83% of users in a randomized controlled trial (RCT) (30). Hysterectomy is a permanent solution to many of these benign and common problems, e.g. fibroids and bleeding. Unfortunately, the alternative procedures are only successful 85-90% of the time and sometimes women are not willing to accept a 10-15% chance of unsuccessful treatment and therefore choose to proceed with hysterectomy as the first intervention.

1.5 Risks Associated with Gynecologic Surgery

Once the decision has been made to proceed with a hysterectomy, the surgeon and the patient have to decide which mode of access should be chosen. As is stated above, there is no current consensus regarding the optimal procedure for any given gynecological condition (17,20,21), so a decision has to be made in which the benefits outweigh the risks. Hysterectomy constitutes major surgery and all surgery carries a risk of complications. Serious adverse outcomes are rare, but common complications like major bleedings and infections, as well as postoperative pain and nausea, need to be discussed with every patient. Risk factors for postoperative nausea can be divided into patient factors and surgical factors. Gynecologic and urologic procedures carry a high risk of postoperative pain and nausea. Generally, patient factors for pain and postoperative nausea are: being a pubescent or post-pubescent female, prior history of postoperative nausea or motion sickness, being a non-smoker and postoperative opioid use (31). It is clear that many hysterectomy patients have a high risk of postoperative nausea and vomiting. Therefore gynecologic surgeons performing hysterectomies should use a prophylactic regimen for their patients, for better control of postoperative nausea and pain, so increasing their patients' postoperative quality of life.

1.6 The Future

The emergence of LH resulted in a need to determine the appropriate role for each surgical approach. The minimally invasive procedures (VH and LH) have shown clear advantages over AH (14,17), but still the majority (c. 60%), of hysterectomies in the United States are performed via laparotomy (10,12,15,16). This discordance between evidence and practice is believed to be fueled by a combination of factors, including technical difficulties and inadequate training, lack of peer support and equipment (27), misconceptions about safety, cost and technical feasibility (14) and possibly because of higher reimbursement for AH (32) than minimally invasive gynecology surgery (MIGS) procedures.

When gynecologists´ attitudes and hysterectomy practices are explored, an interesting discrepancy emerges. The vast majority of gynecologists (95%) chose a minimally invasive approach for themselves or their spouse when asked about their preferred mode of access, with roughly 40% choosing the laparoscopic route. Yet the majority of operations are performed via the abdominal route. Also, 78.8% of the gynecologists who answered the survey said they believed that the ideal goal should be a minimally invasive procedure, and participants expressed a strong desire to increase the number of minimally invasive hysterectomies in their practice (27).

Health-care costs have been rising in recent decades and are likely to continue to rise in the future. Attuning the importance of cost control with an increasing emphasis on patients' satisfaction and clinical excellence has proved challenging. Less surgical pain, shorter hospital stay and lower morbidity all contribute to higher patient satisfaction ratings for minimally invasive procedures (14). While the procedure itself may be more costly, the shortened hospital stay typical of minimally invasive procedures may result in their greater overall cost-effectiveness (33).

2 Objectives

We were interested in evaluating the effects of changing the main mode of access for hysterectomy from abdominal to laparoscopic at a major teaching hospital. Therefore, the objective of this study was to compare the operative cost and perioperative outcomes of hysterectomies performed at Brigham and Women's Hospital in 2006 and 2009. This study provides an up-to-date review of utilization patterns and outcomes associated with various surgical approaches to hysterectomies at a major teaching hospital in the northeastern U.S.A.

3 Materials and Methods

All hysterectomies performed at Brigham and Women's Hospital in 2006 and 2009 were identified via a review of operation room case records. All surgical operations that included a hysterectomy in these years were included, excepting one that was a component of a gender reassignment procedure in 2009. The operations were performed by a diverse group of gynecologists at Brigham and Women's Hospital, an academic tertiary care center in the northeastern United States. The majority of the surgeons practice as general obstetricians/gynecologists; however, the group also included specialized gynecologic oncologists, urogynecologists and specialists in minimally invasive gynecologic surgery. Moreover, the hospital comprises an active teaching environment with approximately 40 residents and 20 fellows in training each year in the Department of Obstetrics and Gynecology. The AH group included all AH, subtotal and total, while the VH group consisted of all VH. The LH group represented all LHs: subtotal and total LH, in addition to laparoscopically assisted vaginal hysterectomy (LAVH). The robotic hysterectomy (RH) group contained all laparoscopic procedures that were performed with robotic assistance.

Information was abstracted regarding medical record number, age, length of hospital stay, procedure type, operative room time (as listed in the operation report system and defined as time in and time out of the operation room) and operative cost. Other data were gathered from the patients' electronic medical records. The individually-gathered information obtained from the charts included body mass index (BMI; calculated as weight (kg/height $(m)^2$), preoperative and postoperative findings and diagnoses, procedures performed, pathology reports, estimated blood loss (EBL) as noted by the circulating theater nurse, indication for surgery, prior abdominal surgeries, uterine weight, postoperative complications, and postoperative admission related to the surgery. Operative reports were further reviewed to collect information regarding intraoperative complications and conversions to laparotomy.

Complications were defined as intraoperative complications (EBL ≥ 1000 ml, organ injury or major anesthesia problem), major postoperative complications (ileus, pulmonary embolism, re-operation, or readmission) and minor postoperative complications (deep vein thrombosis; chest, urinary or wound infection and/or fever ≥ 38°C) (18,34). Suspected urinary tract infection was considered a confirmed infection if the physician charted the diagnosis or the patient received antibiotics for this condition.

Operative costs per hysterectomy were determined from the perspective of the hospital. Operative costs, as obtained from hospital accounting ledgers, include direct (equipment cost and operative room time) and indirect (day surgery, ambulatory procedure room, nursing, recovery room, non-nursing) costs. Equipment cost was based on the actual price paid by the hospital for the equipment that was utilized. Costs associated with operative time (including staffing costs) are determined by an institutional time-based linear formula for operating room rent. All cost values were adjusted for inflation and reported as 2009 real U.S. dollars. Inflation adjustments were made using the All Items Consumer Price Index (35) which demonstrated that inflation from 2006 to 2009 was 6.4%. Accordingly, we multiplied the actual cost data from 2006 with 1.064 in order to obtain the cost in 2009 real U.S. dollars.

The study was reviewed and approved by the Partners' Internal Review Board. Statistical descriptions and analyses were performed using SAS software (SAS Institute Inc., Cary, NC, USA; Version 9.0). Associations were tested using $\chi 2$ and Fisher exact tests for categorical variables and two-sided t-tests for continuous variables. A multivariate linear and logistic regression analysis was also performed for the major perioperative outcomes under study as predicted by the year of surgery, adjusted for the demographic parameters and the mode of access involved therein. A p value of <0.05 was considered significant for all variables.

4 Results

A total of 2,133 patients were included in this retrospective cohort study comparing mode of hysterectomy access in the years 2006 and 2009. Although the total number of hysterectomies performed at our institution remained stable (1,054 procedures in 2006 versus 1,079 in 2009), the relative proportions of abdominal and laparoscopic cases changed markedly during this three-year period. As can be seen in Table 1 and Figure 1, the percentage of cases performed abdominally demonstrated a significant decrease from 64.7% in 2006 to 35.8% in 2009 (p=0.0001). The proportion completed vaginally did not change significantly, but the percentage of laparoscopic cases increased dramatically from 17.7% in 2006 to 46% in 2009 (p=0.0001). The great majority of hysterectomies were total hysterectomies including removal of the cervix (78% and 80% in 2006 and 2009, respectively), demonstrating no significant change in distribution of total and subtotal hysterectomies over the time period.

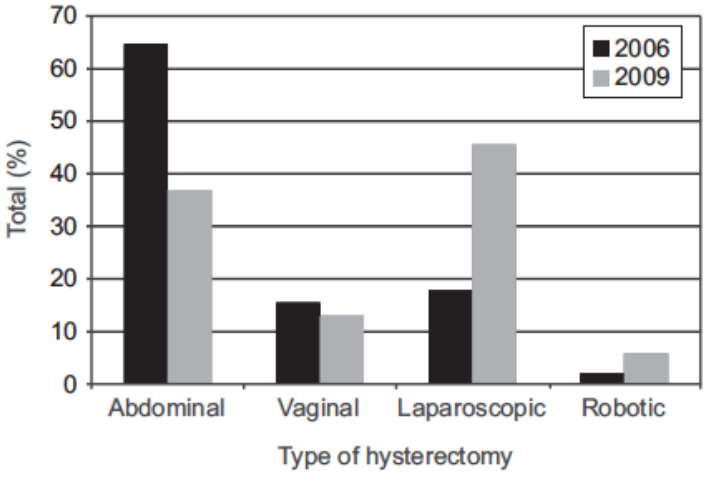


Figure 1. Mode of Access for Hysterectomy in 2006 compared to 2009
Figure adopted from (35) **(See Appendix)**

Table 1. Mode of Access for Hysterectomy in 2006 compared with 2009

	2006 n=1054	2009 n=1079	p-value
Abdominal	682 (64.7)	386 (35.8)	<0.0001
Vaginal	163 (15.5)	134 (12.4)	0.0812
Laparoscopic	187 (17.7)	496 (46)	0.0001
Robotic	22 (2.1)	63 (5.8)	0.0001
Total hysterectomy	818 (78)	868 (80)	0.2418
Subtotal hysterectomy	193 (18)	190 (18)	0.9187
Radical hysterectomy	43 (4)	21 (2)	0.0038

Data is presented as number and (%).

The baseline demographics of the patients undergoing hysterectomy (Table 2) did not differ significantly between 2006 and 2009 apart from an increase of mean BMI (28.6 ± 8.0 versus 30.1 ±8.3 respectively, p=0.0012) and mean age at time of operation (52 ±11.8 years versus 53 ± 11.7 years, p=0.048). The indications for surgery did not vary significantly between the two years; the most common indications for hysterectomy in both time periods were symptomatic leiomyomata, abnormal uterine bleeding and malignancy (data not shown in tables). The percentage of cases performed for malignancy was stable at 38-40% over the study period.

Table 2. Patient Demographics and Operative Findings

	2006 n=1054	2009 n=1079	p-value
BMI (kg/m^2) †	28.6±8.0 (16.8-65.6)	30.1±8.3 (16.2-69.4)	0.0012
Age (years) †	52±11.8 (17-92)	53±11.7 (18-91)	0.0480
Previous laparoscopy ‡	206 (21.0)	223 (23.1)	0.2615
Previous laparotomy ‡	381 (38.9)	384 (40.7)	0.4193
Findings ‡			
Fibroids	431 (40.9)	624 (58.2)	<0.0001
Endometriosis	87 (8.3)	63 (5.9)	0.0290
Adhesions	261 (24.9)	259 (24.1)	0.70
Malignancy	409 (38.3)	430 (40.1)	0.5490

‡ Number and (%) or † mean ± SD and (range).
BMI=Body Mass Index.
Significance is a two sided t- test.

Table 3 illustrates the perioperative outcomes and complications for all hysterectomies performed in 2006 and 2009. The uterine weight in grams did not differ significantly between the two years (p=0.2158); nor did total operative time (p=0.6779). There was a marked difference, however, with regard to decreased EBL (330±490 ml in 2006 versus 205±293 ml in 2009, p=<0.0001) and length of stay (3.2±3.1 days versus 2.1±1.9 days, p=<0.0001). Additionally, a regression analysis performed on conversion risk showed the odds of converting from laparoscopic to laparotomy were four times greater in 2006 than in 2009 (OR 4.022, 95% CI 2.234, 7.239). We did not discriminate between conversions performed because of technical feasibility versus major hemorrhage or other intraoperative event. Although the risk of visceral, neurologic or vascular injury did not differ significantly over the study period, the risk of EBL>1000 ml in 2009 was almost half the risk in 2006 (p=0.0013). Intraoperative complications not otherwise delineated in Table 3 include a splenic laceration that occurred in 2009. The risk of major postoperative complications did not differ significantly over the study period (p=0.08) but there was a significant decreased in incidence of minor postoperative complications in 2009 (from 18% in 2006 to 5.7% in 2009, p=<0.0001). Interestingly, these statistical associations remained unchanged on performing a multivariate regression analysis, as can seen from table 4 (35).

Major postoperative complications not listed specifically in Table 3 for 2006 include one case each of laryngeal spasm requiring Intensive Care Unit admission, persistent tachycardia attributed to residual pneumoperitoneum and suspected cerebrovascular accident.

Table 3. Perioperative Outcomes and Complications in 2006 versus 2009

	2006 n=1054	2009 n=1079	p-value
Uterine weight (grams) †	248.5±352 (2-4260)	270±429 (21-5500)	0.2158
Conversion to laparotomy‡	32 (8.94)	24 (3.46)	0.0002
EBL (ml) †	330±490 (10-6000)	205±293 (10-4600)	<0.0001
LOS (days) †	3.2±3.1 (0-32)	2.1±1.9 (0-21)	<0.0001
OR time (minutes) †	191±71 (57-540)	192±64 (63-496)	0.6779
Major intraop. complications‡	76 (7.22)	43 (3.99)	0.0012
EBL >1000 ml	60 (6.10)	32 (3.10)	0.0013
Bladder and ureter injury	14 (1.33)	6 (0.56)	0.0646
Bowel injury	1 (0.09)	2 (0.19)	1.00
Nerve injury	5 (0.47)	1 (0.09)	0.1205
Vessel injury	0 (0)	1 (0.09)	1.00
Major postop. complications‡	77 (7.31)	59 (5.47)	0.08
Readmission	44 (4.19)	45 (4.19)	0.9995
Reoperation	20 (1.90)	18 (1.67)	0.6823
Ileus	25 (2.38)	12 (1.11)	0.0255
PE	8 (0.76)	5 (0.46)	0.4176
Minor postop. complications‡	189 (17.98)	61 (5.66)	<0.0001
DVT	4 (0.38)	0 (0.0)	0.0596
Infection	67 (6.37)	50 (4.64)	0.0788

‡ Number and (%) or † mean ± SD and (range).
Infection=urinary-, wound-, chest infection or fever.
EBL= Estimated Blood Loss, LOS= Length of Stay, OR time= Operative Room Time, PE=Pulmonal Embolia, DVT=Deep Vein Thrombosis.
Some patients developed more than one major intraoperative or postoperative complication but they were only counted once.
Significance is a two sided t- test.

Table 4. Multivariate Regression Analysis for Perioperative Outcomes under Study

Table adopted from (36) **(see Appendix)**

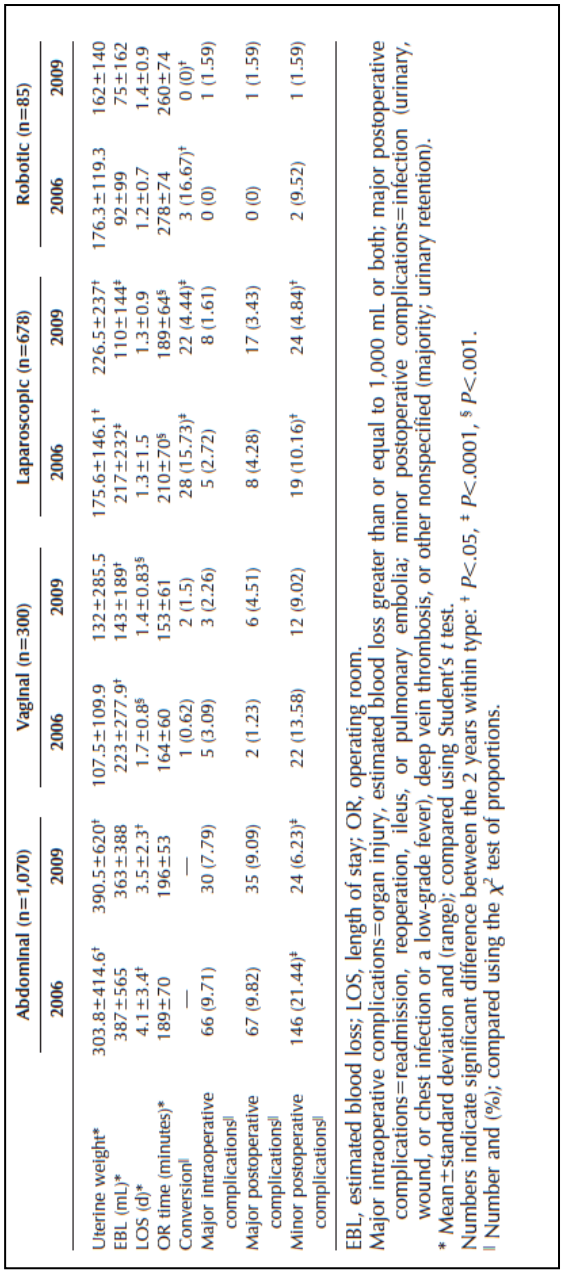
	EBL*			Length of Stay (d)*			Major Intraoperative Complications†			Major Postoperative Complications†			Minor Postoperative Complications†		
	Coefficient	SE of Coefficient	*P*	Coefficient	SE of Coefficient	*P*	OR	SE	*P*	OR	SE	*P*	OR	SE	*P*
Intercept	128.523	87.309	.141	0.163	0.554	.768	—	—	—	—	—	—	—	—	—
Age (y)	−1.488	0.975	.127	0.029	0.006	.000	1.013	0.011	.230	1.021	0.010	.028	1.011	0.008	.162
BMI (kg/m^2)	1.753	1.402	.211	0.0006	0.009	.939	0.992	0.015	.602	1.003	0.014	.807	1.015	0.011	.170
Prior laparotomy (yes or no)	45.361	22.982	.049	0.451	0.152	.003	1.573	0.392	.069	1.377	0.315	.162	1.432	0.268	.054
Prior laparoscopy (yes or no)	−70.604	27.861	.011	−0.268	0.184	.146	0.751	0.259	.407	0.778	0.247	.429	0.814	0.198	.398
Abdominal approach (yes or no)	303.550	52.289	.000	2.361	0.324	.000	5.723	5.865	.089	8.158	8.358	.040	2.812	1.722	.091
Vaginal approach (yes or no)	141.508	60.747	.020	−0.017	0.381	.965	1.302	1.532	.823	2.910	3.258	.340	2.536	1.677	.159
Laparoscopic approach (yes or no)	72.503	53.641	.177	0.045	0.335	.893	1.363	1.475	.775	3.076	3.231	.285	1.691	1.078	.410
Year of surgery (2006–2009)	−59.250	23.698	.013‡	−0.584	0.155	<.001‡	0.611	0.159	.059‡	1.068	0.252	.780	0.272	0.057	<.001‡

EBL, estimated blood loss; SE, standard error; OR, odds ratio; BMI, body mass index.
* Results of multivariate linear regression.
† Results of multivariate logistic regression.
‡ Indicates statistical significance at $P \leq .05$.

Table 5 (35) demonstrates perioperative outcomes and complications as analyzed by type of hysterectomy. A significant decrease in EBL was particularly prominent in the VH and LH groups ($p<0.05$ and <0.0001, respectively). While the length of hospital stay remained stable for LH and RH groups (1.2-1.4 days), the mean stay decreased by 0.5 days for AH ($p<0.05$). The only group that demonstrated a significant decrease in operative time in this subgroup analysis was the LH (210±70 mins in 2006 vs. 189±64 mins in 2009, $p<0.001$). Incidence of minor postoperative complications decreased significantly from 2006 to 2009 for both AH and LH, from 21.4% to 6.2% and 10.2% to 4.8%, respectively.

Table 5. Perioperative Outcomes and Complications by Type of Hysterecomy. 2006 compared to 2009

Table adopted from (36) **(see Appendix)**



	Abdominal (n=1,070)		Vaginal (n=300)		Laparoscopic (n=678)		Robotic (n=85)	
	2006	2009	2006	2009	2006	2009	2006	2009
Uterine weight*	303.8±414.6†	390.5±620†	107.5±109.9	132±285.5	175.6±146.1†	226.5±237†	176.3±119.3	162±140
EBL (mL)*	387±565	363±388	223±277.9†	143±189†	217±232‡	110±144‡	92±99	75±162
LOS (d)*	4.1±3.4‡	3.5±2.3†	1.7±0.8§	1.4±0.83§	1.3±1.5	1.3±0.9	1.2±0.7	1.4±0.9
OR time (minutes)*	189±70	196±53	164±60	153±61	210±70§	189±64§	278±74	260±74
Conversion‖	—	—	1 (0.62)	2 (1.5)	28 (15.73)‡	22 (4.44)‡	3 (16.67)†	0 (0)†
Major intraoperative complications‖	66 (9.71)	30 (7.79)	5 (3.09)	3 (2.26)	5 (2.72)	8 (1.61)	0 (0)	1 (1.59)
Major postoperative complications‖	67 (9.82)	35 (9.09)	2 (1.23)	6 (4.51)	8 (4.28)	17 (3.43)	0 (0)	1 (1.59)
Minor postoperative complications‖	146 (21.44)‡	24 (6.23)‡	22 (13.58)	12 (9.02)	19 (10.16)†	24 (4.84)†	2 (9.52)	1 (1.59)

EBL, estimated blood loss; LOS, length of stay; OR, operating room.
Major intraoperative complications=organ injury, estimated blood loss greater than or equal to 1,000 mL or both; major postoperative complications=readmission, reoperation, ileus, or pulmonary embolia; minor postoperative complications=infection (urinary, wound, or chest infection or a low-grade fever), deep vein thrombosis, or other nonspecified (majority; urinary retention).
* Mean±standard deviation and (range); compared using Student's *t* test.
Numbers indicate significant difference between the 2 years within type: † $P<.05$, ‡ $P<.0001$, § $P<.001$.
‖ Number and (%); compared using the χ^2 test of proportions.

As can be seen in Table 6, the operative cost rose by a significant margin (p<0.0001). When analyzed by type of hysterectomy, the operative cost by type increased significantly for AH (p<0.0001), VH (p=0.0003) and LH (p<0.0001) from 2006 to 2009. The operative cost increase was greatest for the LH type, an increase of 33.1%.

Table 6. Operative Cost, Percentages in Difference and Significance

	n	2006[§]	2009[§]	% Diff.*	p-value
Operative Cost					
Composite Cost	1079	5.103 ± 2.183	6.897 ±2.471	35.2%	<0.0001
Abdominal hysterectomy	386	4.986 ± 1.959	6.214 ± 2030	24.6%	<0.0001
Vaginal hysterectomy	134	3.957 ± 1.227	4.210 ± 1.249	6.4%	0.0003
Laparoscopic hysterectomy	496	5.793 ± 2.234	7.710 ± 1.965	33.1%	<0.0001
Robotic hysterectomy	63	11.324-1.716	10.528 ± 2.968	-7%	0.0837

% difference is calculated as follows: 2009-2006 cost/ 2006 cost.
Significance is a two sided t- test.
[§]Cost is presented in 2009 real dollars.

*Difference in cost in percentages.

5 Discussion

A dramatic shift in mode of access for hysterectomy occurred at Brigham and Women's Hospital between the 2006 and 2009, and was accompanied by improved perioperative outcomes. In response to national practice changes and increasing patient awareness of minimally invasive options for therapy, the Minimally Invasive Gynecologic Surgery (MIGS) Division at Brigham and Women's Hospital was opened in 2006. The inception of the MIGS program at our institution brought an increased consciousness of alternative routes for performing hysterectomy, specifically laparoscopic and robotic surgery. The MIGS faculty increased resident and fellow education with new techniques to approach both routine and complex cases, while also encouraging faculty colleagues in application of these skills in their practice by acting as a surgical mentor when needed. Although the Gynecologic Oncologists at our institution were already incorporating minimally invasive techniques in their practices, this new collaboration fostered their further utilization in everyday practice.

When the data for mode of access in hysterectomy is examined, some interesting trends can be seen. The 2006 proportions of hysterectomy performed via each route were similar to what has been reported in previously published data from similar time periods, with approximately 65% of hysterectomies being performed abdominally (12,37). Interestingly, vaginal hysterectomy appears to be a much less common approach at our institution than the nationwide percentage of 20.3% (12). Potential explanations for this discrepancy may be that, as a referral center, our institution often sees more advanced pathology that may not be as amenable to vaginal approach, such as large uterus, adnexal mass, history of endometriosis or previous pelvic surgery. Additionally, the majority (approximately 55%) of hysterectomies were performed by the Gynecologic Oncology service or the MIGS service at our institution; these surgeons specialize in techniques other than vaginal hysterectomy. The proportion of laparoscopic hysterectomies increased by over 30% during the course of our study. Overall, the robotic hysterectomy was the least common approach though the rate nearly tripled over the three-year period of our study, demonstrating rapid integration of this latest addition to the surgeon's armamentarium. It is also worth noting that the vast majority of robotic cases were oncology cases, often radical hysterectomies. The relatively high number of total hysterectomies (~80%) may reflect the volume of cases performed for malignancy as well as advanced endometriosis.

The patient groups analyzed in our study (2006 versus 2009) can be considered comparable in terms of demographic baseline data. Regarding operative outcomes, overall EBL decreased significantly between the two years along with the changing mode of access. When broken down by type of hysterectomy, the figures reveal a significant decrease in EBL specifically for the LH group, which may point to better outcomes as surgeons gain experience with this technique. Uterine weights were similar between 2006 and 2009 overall, but increased over time in both the abdominal and laparoscopic groups. This may reflect a shift over time in patient selection for each procedure, with abdominal hysterectomy being reserved for the largest uteri in some cases, along with increasing comfort with laparoscopic approach to larger uteri. There was also a significant decrease in length of stay between 2006 to 2009, again reflecting the trends in mode of access with quicker recovery in the minimally invasive groups. The decreased length of stay among the AH and VH groups may reflect

changing trends in postoperative management with an increasing emphasis on faster return to daily activities. Operative time for LH decreased significantly between the two years, again suggesting increasing comfort level and expertise with these procedures. Minimizing operative time should continue to be an important objective in gynecologic surgery, as decreased anesthesia time has demonstrated patient benefits including lower infection rates (38).

Both intraoperative and minor postoperative complications decreased significantly over the three-year period spanned by the study. The incidence of visceral, vascular and neurologic injury remained low in both years examined, but a noteworthy decrease in major blood loss (>1000 ml) was observed. As the laparoscopic approach became more popular, it is possible that many surgeons achieved sufficient experience to overcome initial learning-curve difficulties and therefore achieve lower complication rates. It is possible that such an “experience effect” over time could have potentially confounded the difference in complication rates and indirectly, therefore, in the cost calculation under study. However, despite the retrospective nature of the study given the timeframe concerned, we do believe that the difference seen here represents a significant trend attributable to an alteration in the mode of access for hysterectomies. No intraoperative or major postoperative complications were observed in 2006 related to robotic surgery. Possible explanations for this may be that only experienced surgeons began utilizing robotic surgery at our institution in the first few years following its FDA approval. Alternatively, the surgeons may have selected less complex cases to perform with robotic assistance while they were familiarizing themselves with the new technology.

The drivers of hospital costs are notoriously complex and challenging to discern. Previous work examining the cost of hysterectomy at our institution (personal communication, Wright KN, 2010) has demonstrated that operative time predicts operative cost more than any other factor. A strong association was also demonstrated between operative cost, length of stay and total mean cost per hysterectomy, calculated as direct cost (labor, supplies and fixed equipment) and indirect cost (cost of depreciation per square foot of unit). Based on this understanding, it is surprising to note significant increases in operative cost for all methods (except RH) despite decreased operative time and complication rates.

This result counters the intuition that introducing newer, higher-technology modes of access comes at significant cost to the hospital due to initial costs and the need for increased equipment, operative time and other resources. It is possible that higher upfront resource costs may be balanced by shorter length of stay, and a shift from AH to LH could also increase the communal cost-effectiveness of hysterectomy by recovering labor production. As a straightforward calculation, we can estimate the average indirect cost to society per hysterectomy using the cost of lost labor production as a proxy. The indirect cost to society can be determined using median gender-specific weekly salaries for full-time workers aged 19 and older in 2009 (gathered from the National Bureau of Labor Statistics, median weekly earnings $657) (39), multiplied by the average number of days until return to work (as reported in the literature for each mode of hysterectomy) and add that to the total hospital cost. A literature search revealed that mean time until return to work in the United States is quoted as 38-41 days after AH, 29-35 days after VH (40-43) and 19-24 days after LH (43,44). To our knowledge, no data exists approximating return to work times after RH; the assumption was made that this could be

considered equivalent to return to work time for LH as experienced nationwide. But as is said above, drivers of cost are complex and this simple calculation can only been seen as an indicator of a possible cost item in the equation.

The operative cost of RH decreased significantly, possibly due to improved efficiency as our surgeons and ancillary staff gained familiarity with this mode of access, which is often thought to be the most costly mode from the hospital perspective. The more robust cost analysis of the 2009 data (personal communication, Wright KN 2011), demonstrated that the total mean cost was highest for RH but the societal cost (indirect cost to society determined using the cost of labor production as a proxy) was highest for AH and least for VH. Minimally invasive hysterectomy is therefore a cost-effective and safe alternative to abdominal hysterectomy. While it is instructive to have an overview of the costs to our hospital of changing the mode of access for hysterectomy, we were limited by a lack of information on the individual drivers of cost for each method. Further investigation of the cost-effectiveness of each mode of hysterectomy is needed.

5.1 Current Guidelines

The main purpose of this study was to compare outcomes between types of hysterectomy; this issue is worth discussing in reference to current practice guidelines. The 2009 ACOG guidelines, in concordance with the most recent Cochrane review, state that vaginal hysterectomy should be considered the surgery of choice, if feasible, because of lower morbidity and increased cost-effectiveness as compared with other modes of access (17,20,40). Specifically, the Cochrane review points to increased urinary tract injury and longer operative time as potential drawbacks of laparoscopic hysterectomy (17). This data, however, is pooled from randomized trials completed from 1992-2004 and may not reflect more current realities. Our data suggest that with dedication to the implementation of minimally invasive techniques, goals such as decreased complications, decreased operative time, decreased conversion rate and decreased EBL can be realized. Although vaginal hysterectomy may be viewed by some as the ultimate minimally invasive approach, not all cases can be safely completed via the vaginal route. Even in situations where VH is possible, we may be underestimating the relative benefits of LH as this approach continues to be refined. In addition to lower complication rates, patient-specific outcomes such as pain must also be considered. There is some evidence that LH may be associated with less postoperative pain when compared to VH (45,46). Further well-designed trials should be performed to elucidate further the relative benefits of LH versus VH in the light of these findings.

A recent American Association of Gynecologic Laparoscopists (AAGL) position statement concludes that continued efforts should be taken to facilitate minimally invasive approaches; furthermore the cost-effectiveness of VH and LH mandate that they should be considered procedures of choice (47).

5.2 Weaknesses and Strengths of this Study

Although this study represents a large patient database, it is limited by its retrospective nature, with its inherent selection bias. The data collection itself is subject to measurement bias as a result of inaccurate coding of procedures or errors in data gathering, although the data set was gathered from one source with only two individuals involved in its creation, which may increase accuracy. Although we did consider the inclusion of parity and the racial and ethnic distribution among the demographic characteristics in Table 2, we were limited by the non-availability, inconsistency, or both of these data over the study period. In this case we have not attempted to identify any potential confounding variables or effect modifiers that may exist, such as surgeons' learning curves, changing protocols, or variations in surgical experience. The variety in surgical procedures, and of indications (benign compared with malignant), adds to heterogeneity of results, though this may also limit our final interpretation by diluting an effect that took place in only one subgroup. The major strength of this study is the volume of cases analyzed along with our outcomes of interest. All conclusions on cost outcomes were drawn from actual hospital billing data, which allows a realistic perspective on the findings. The diversity of cases and surgeons, together with the involvement of trainees, lends generalizability to our results.

6 Conclusion

In conclusion, we found that the main mode of access for hysterectomy exhibited a drastic shift over the years 2006 to 2009 from majority abdominal to majority laparoscopic approach. This change brought about improved perioperative outcomes including decreased blood loss, risk of conversion, intraoperative complications, minor postoperative complications, and shorter hospital stay, but the operative cost increased from 2006 to 2009. Our data suggests that implementation of minimally invasive techniques, goals such as low complication rate, shorter operative time, lower conversion rate, and less estimated blood loss can be realized. The creation of a minimally invasive gynecologic surgery service at Brigham and Women's Hospital has benefitted not only trainees and the hospital, but first and foremost: our patients.

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Appendix

Increasing Minimally Invasive Hysterectomy

Effect on Cost and Complications

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OBJECTIVE: In a 3-year period, the main mode of access for hysterectomy at Brigham and Women's Hospital changed from abdominal to laparoscopic. We estimated potential effects of this shift on perioperative outcomes and costs.

METHODS: We compared the perioperative outcomes and the cost of care for all hysterectomies performed in 2006 and 2009 at an urban academic tertiary care center using the χ^2 test or Fisher's exact test for categorical variables and two-sided Student's *t* test for continuous variables. A multivariate regression analysis was also performed for the major perioperative outcomes across the study groups. Cost data were gathered from the hospital's billing system; the remainder of data was extracted from patients' medical records.

RESULTS: This retrospective study included 2,133 patients. The total number of hysterectomies performed remained stable (1,054 procedures in 2006 compared with 1,079 in 2009) but the relative proportions of abdominal and laparoscopic cases changed markedly during the 3-year period (64.7% to 35.8% for abdominal, $P<.001$; and 17.7% to 46% for laparoscopic cases, $P<.001$). The overall rate of intraoperative complications and minor postoperative complications decreased significantly (7.2% to 4%, $P<.002$; and 18% to 5.7%, $P<.001$, respectively). Operative costs increased significantly for all procedures aside from robotic hysterectomy, although no significant change was noted in total mean costs.

CONCLUSION: A change from majority abdominal hysterectomy to minimally invasive hysterectomy was accompanied by a significant decrease in procedure-related complications without an increase in total mean costs.

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LEVEL OF EVIDENCE: II

Because hysterectomy is the most common major gynecologic surgical procedure in the United States,[1] it has been estimated that 20% of U.S. women will have a hysterectomy by the age of 40 years,[2] increasing to 43% by the age of 85 years.[3] Since the introduction of laparoscopic hysterectomy in 1989,[4] it has become increasingly widespread as a result of lower morbidity and shortened recovery time as compared with abdominal hysterectomy.[5–7] The emergence of laparoscopic hysterectomy as a viable surgical option resulted in the need to determine the appropriate role for each operative approach. Vaginal hysterectomy and laparoscopic hysterectomy have shown clear advantages over abdominal hysterectomy regarding decreased blood loss, shorter hospital stay, quicker return to normal activities, and fewer complications.[5,7] These issues contribute to higher patient satisfaction ratings for minimally invasive procedures.[5] In addition to these clinical interests, there is widespread concern that healthcare costs in the United States are rising at an unsustainable rate. As a result, it is important that therapeutic decisions are not only safe and effective, but cost-effective as well. In practice, although the laparoscopic or robotic procedures may be more costly, the shortened hospital stays typically associated with these cases may result in greater overall cost-effectiveness.[8]

In light of these issues, we were interested in estimating the repercussions of a change in mode of access for hysterectomy (from the majority of abdominal to the majority of laparoscopic) that occurred at our institution over a 3-year period. Main outcome measures include incidence of perioperative complications, total mean costs, and operative costs of hysterectomies

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performed at Brigham and Women's Hospital in 2006 compared with 2009. This study provides an up-to-date review of use patterns and outcomes associated with various surgical approaches to hysterectomies as experienced at a major teaching hospital.

MATERIALS AND METHODS

All hysterectomies performed at Brigham and Women's Hospital in 2006 and 2009 were identified through review of operation room case records. All surgical operations that included a hysterectomy in these years were included, except one that was a component of a gender reassignment procedure in 2009. The operations were performed by a diverse group of gynecologists at Brigham and Women's Hospital, an academic tertiary care center in the northeastern United States. The majority of the surgeons practice as general obstetrician and gynecologists; however, the providers also include specialized gynecologic oncologists, urogynecologists, and specialists in minimally invasive gynecologic surgery. Moreover, the hospital comprises an active teaching environment with approximately 40 residents and 20 fellows in training each year within the Department of Obstetrics and Gynecology. The abdominal hysterectomy group includes all abdominal hysterectomies, subtotal and total, whereas the vaginal hysterectomy group consists of all vaginal hysterectomies. The laparoscopic hysterectomy group represents all laparoscopic hysterectomies: subtotal and total laparoscopic hysterectomies as well as laparoscopically assisted vaginal hysterectomies. The robotic hysterectomy group contains all laparoscopic procedures that were performed with robotic assistance.

Information was abstracted regarding medical record number, age, length of stay, procedure type, operative time (as listed in the operation report system and defined as time in and time out of the operating room), operative cost, and total mean cost. Other data were gathered from the patients' electronic medical records. The individually gathered information obtained from the charts included body mass index (calculated as weight (kg)/[height (m)]^2), preoperative and postoperative findings and diagnoses, procedures performed, pathology reports, estimated blood loss as noted by the circulating nurse, indication for surgery, prior abdominal surgeries, uterine weight, postoperative complications, and postoperative admission (planned compared with unplanned). Operative reports were further reviewed to glean information regarding intraoperative complications and conversions to laparotomy.

Complications were defined as intraoperative complications (estimated blood loss greater than or equal to 1,000 mL, organ injury, or major anesthesia problem), major postoperative complications (ileus, pulmonary embolism, reoperation, or readmission), and minor postoperative complications (deep vein thrombosis; chest, urinary, or wound infection, low-grade fever, or both).[9,10] These data were recorded along with other events such as postoperative urinary retention. Suspected urinary tract infection was considered a confirmed infection if the physician charted the diagnosis or the patient received antibiotics for this condition.

Both operative costs and total mean costs per hysterectomy were determined from the perspective of the hospital. Operative costs, as obtained from hospital accounting ledgers, include direct (equipment cost and operative time) and indirect (day surgery, ambulatory procedure room, nursing, recovery room, nonnursing) costs. Equipment cost was based on the actual price paid by the hospital for the equipment that was used. Costs associated with operative time (including staffing costs) are determined by an institutional time-based linear formula for operating room rent. Total mean costs include direct (labor, supplies, fixed equipment) and indirect cost (cost of depreciation per square foot of unit) related to the encounter. All cost values were adjusted for inflation and reported as 2009 real U.S. dollars. Inflation adjustments were made using the All Items Consumer Price Index,[11] which demonstrated that inflation from 2006 to 2009 was 6.4%. Accordingly, we multiplied the actual cost data from 2006 with 1.064 to get the cost in 2009 real U.S. dollars. As an important note, although we expect hospital costs to vary by institution, for the purposes of this study, we are interested in only the inflation-adjusted relative cost difference between 2006 and 2009 as perceived by the hospital rather than the absolute dollar and cents costs. The absolute costs we report are based on institutional formulas that take into account the specific prices and purchasing requirements of our market.

As a straightforward calculation, we estimated the average indirect cost to society per hysterectomy using the cost of lost labor production as a proxy. The indirect cost to society was determined using median gender-specific weekly salaries for full-time workers 19 years and older in 2009 (gathered from the National Bureau of Labor Statistics, median weekly earnings $657[12]) multiplied by the average number of days until return to work (as reported in the literature for each mode of hysterectomy) and added to the total mean cost for each procedure type in the year 2009. A literature search revealed that mean time until return to work in the United States is quoted as 38–41 days after abdominal hysterectomy, 29–35 days after vaginal hysterectomy,[13–16] and 19–24 days after lapa-

roscopic hysterectomy (Einarsson JI, Suzuki Y, Vellinga T, Jonsdottir GM, Magnusson MK, Yoshida H. Post-operative quality of life prospective comparison in patients having total laparoscopic hysterectomy versus laparoscopic supracervical hysterectomy. In press.).[15] To our knowledge, no data exist approximating return to work times after robotic hysterectomy; the assumption was made that this could be considered equivalent to return to work time for laparoscopic hysterectomy as experienced nationwide.

The study was reviewed and approved by the Partners Internal Review Board. Statistical descriptions and analyses were performed using SAS 9.0 software. Associations were tested using χ^2 and Fisher's exact tests for categorical variables and two-sided Student's *t* tests for continuous variables. A multivariate linear and logistic regression analysis was also performed for the major perioperative outcomes under study as predicted by the year of the surgery while adjusting for the demographic parameters and the mode of access involved therein. $P<.05$ was considered significant for all variables.

RESULTS

A total of 2,133 patients was included in this retrospective cohort study comparing mode of hysterectomy access in the years 2006 and 2009. Although the total number of hysterectomies performed at our institution remained stable (1,054 procedures in 2006 compared with 1,079 in 2009), the relative proportions of abdominal and laparoscopic cases changed during this 3-year period. As seen in Figure 1, the percentage of cases performed abdominally demonstrated a significant decrease from 64.7% in 2006 to 35.8% in 2009 ($P<.001$). The proportion completed vaginally did not change significantly; however, the percentage of laparoscopic cases increased from 17.7% in 2006 to 46% in 2009 ($P<.001$). The great majority of hysterectomies were total hysterectomies, including removal of the cervix (78% and 80% in 2006 and 2009, respectively), demonstrating no significant change ($P=.012$) in distribution of total and subtotal hysterectomies over the time period.

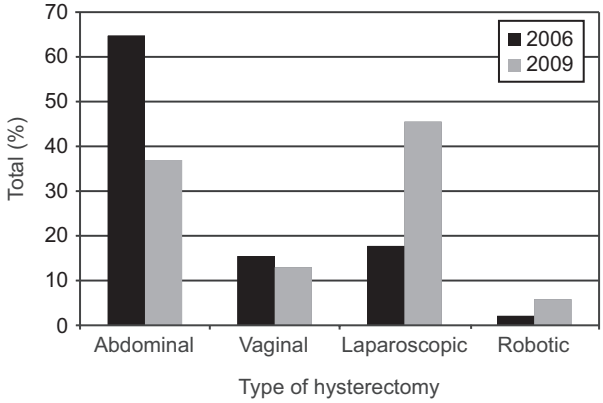

Fig. 1. Mode of access for hysterectomy in 2006 compared with 2009.

Jonsdottir. Changing the Mode of Access for Hysterectomy. Obstet Gynecol 2011.

The baseline demographics of the patients undergoing hysterectomy (Table 1) did not differ significantly between 2006 and 2009 aside from an increase of mean body mass index (28.6±8.0 compared with 30.1±8.3, respectively; $P<.002$) and mean age at the time of operation (52±11.8 years compared with 53±11.7 years; $P=.048$). The indications for surgery did not vary significantly between the 2 years; the most common indications for hysterectomy in both time periods were symptomatic leiomyomata, abnormal uterine bleeding, and malignancy (data not shown in tables). The percentage of cases performed for malignancy was stable at 38–40% over the study period.

Table 1 also illustrates the perioperative outcomes and complications for all hysterectomies performed in 2006 and 2009. The uterine weight in grams did not differ significantly between the 2 years ($P<.216$) nor did total operative time ($P<.678$). There was a marked difference, however, with regard to decreased estimated blood loss (330±490 mL in 2006 compared with 205±293 mL in 2009; $P<.001$) and length of stay (3.2±3.1 days compared with 2.1±1.9 days, $P<.001$). Additionally, a univariate regression analysis performed on conversion risk showed the odds of converting from laparoscopic to laparotomy were four times higher in 2006 than in 2009 (odds ratio, 4.022; 95% confidence interval, 2.234–7.239). We did not discriminate between conversions performed because of technical feasibility compared with major hemorrhage or other intraoperative event. Although the risk of visceral, neurologic, or vascular injury did not differ significantly over the study period, the risk of estimated blood loss greater than 1,000 mL in 2009 was almost half the risk in 2006 ($P<.002$). Intraoperative complications not otherwise delineated in Table 1 include a splenic laceration that occurred in 2009. Major postoperative complications not listed specifically in Table 1 for 2006 include laryngeal spasm requiring intensive care unit admission, persistent tachycardia attributed to residual pneumoperitoneum, and suspected cerebrovascular accident. Although the risk of major postoperative complications did not differ significantly over the study period ($P=.08$), the decreased incidence of minor postoperative complications in 2009 (from 18% in 2006 to 5.7% in 2009, $P<.001$) can be ascribed to the decreased occurrence of urinary retention. Interestingly, these statistical associa-

Table 1. Patient Demographics, Operative Findings, Perioperative Outcomes, and Complications in 2006 Compared With 2009

	2006 (n=1,054)	2009 (n=1,079)	*P*
BMI (kg/m^2)*	28.64±8.02 (16.8–65.6)	30.14±8.34 (16.2–69.38)	<.002
Age (y)*	52±11.8 (17–92)	53±11.7 (18–91)	.048
Previous laparoscopy†	206 (21.02)	223 (23.13)	<.262
Previous laparotomy†	381 (38.92)	384 (40.72)	<.42
Findings†			
Leiomyomas	431 (40.93)	624 (58.21)	<.001
Endometriosis	87 (8.26)	63 (5.85)	.029
Adhesions	261 (24.86)	259 (24.14)	.70
Oncology	409 (38.3)	430 (40.07)	.549
Uterine weight (grams)*	248.5±352 (2–4,260)	270±429 (21–5,500)	<.216
Conversion to laparotomy†	32 (8.94)	24 (3.46)	<.001
EBL (mL)*	330±490 (10–6,000)	205±293 (10–4,600)	<.001
LOS (d)*	3.17±3.09 (0–32)	2.12±1.86 (0–21)	<.001
OR time (min)*	191±71 (57–540)	192±64 (63–496)	<.678
Cases with major intraoperative complications†	76 (7.22)	43 (3.99)	<.002
EBL greater than 1,000 mL	60 (6.10)	32 (3.10)	<.002
Bladder and ureter injury	14 (1.33)	6 (0.56)	<.065
Bowel injury	1 (0.09)	2 (0.19)	>.99
Nerve injury	5 (0.47)	1 (0.09)	<.121
Vessel injury	0 (0)	1 (0.09)	>.99
Cases with major postoperative complications‡	77 (7.31)	59 (5.47)	.08
Readmission	44 (4.19)	45 (4.19)	<.1
Reoperation	20 (1.90)	18 (1.67)	<.683
Ileus	25 (2.38)	12 (1.11)	<.026
PE	8 (0.76)	5 (0.46)	<.418
Cases with minor postoperative complications†	189 (17.98)	61 (5.66)	<.001
DVT	4 (0.38)	0 (0.0)	<.06
Infection‡	67 (6.37)	50 (4.64)	<.079

BMI, body mass index; EBL, estimated blood loss; LOS, length of stay; OR, operating room; PE, pulmonary emboli; DVT, deep vein thrombosis.

* Mean±standard deviation and (range); compared using Student's *t* test.

† Number and (%); compared using the chi-square test of proportions or the Fisher's exact test as required.

‡ Infection=urinary, wound, or chest infection or low-grade fever.

tions remained unchanged on performing a multivariate regression analysis, as can be seen from Table 2.

Table 3 demonstrates perioperative outcomes and complications as analyzed by type of hysterectomy. A significant decrease in estimated blood loss was particularly prominent in the vaginal and laparoscopic hysterectomy groups ($P<.05$ and $<.001$, respectively). Whereas the length of hospital stay remained stable for laparoscopic and robotic hysterectomy groups (1.2–1.4 days), the mean stay decreased by 0.5 days for abdominal hysterectomy ($P<.05$). The only group that demonstrated a significant decrease in operative time in this subgroup analysis was the laparoscopic hysterectomy (210±70 minutes in 2006 compared with 189±64 minutes in 2009; $P<.001$). Incidence of minor postoperative complications decreased significantly from 2006 to 2009 for both abdominal and laparoscopic hysterectomy, from 21.4% to 6.2% and 10.2% to 4.8%, respectively.

As seen in Table 4, total mean cost per hysterectomy by year (including all modes of access) did not change significantly but operative cost rose by a significant margin ($P=.142$ and $P<.001$, respectively). When analyzed by type of hysterectomy, total mean cost increased significantly for vaginal and laparoscopic hysterectomy ($P<.001$) but decreased for robotic hysterectomy ($P<.001$). Similarly, operative cost by type increased significantly for abdominal hysterectomy ($P<.001$), vaginal hysterectomy ($P<.001$), and laparoscopic hysterectomy ($P<.001$) from 2006 to 2009. Our estimates for the indirect cost to the society for each method in 2009 real U.S. dollars were as follows: for abdominal hysterectomy, the cost was $17,671–18,065; for vaginal hysterectomy, $15,631–16,419; for laparoscopic hysterectomy, $14,826–15,483; and for robotic hysterectomy, $13,501–14,158.

DISCUSSION

A shift in mode of access for hysterectomy occurred at Brigham and Women's Hospital between years 2006 and 2009. In addition to national practice changes and

Table 2. Multivariate Regression Analysis for Perioperative Outcomes Under Study

	EBL*			Length of Stay (d)*			Major Intraoperative Complications†			Major Postoperative Complications†			Minor Postoperative Complications†		
	Coefficient	SE of Coefficient	*P*	Coefficient	SE of Coefficient	*P*	OR	SE	*P*	OR	SE	*P*	OR	SE	*P*
Intercept	128.523	87.309	.141	0.163	0.554	.768	—	—	—	—	—	—	—	—	—
Age (y)	−1.488	0.975	.127	0.029	0.006	.000	1.013	0.011	.230	1.021	0.010	.028	1.011	0.008	.162
BMI (kg/m^2)	1.753	1.402	.211	0.0006	0.009	.939	0.992	0.015	.602	1.003	0.014	.807	1.015	0.011	.170
Prior laparotomy (yes or no)	45.361	22.982	.049	0.451	0.152	.003	1.573	0.392	.069	1.377	0.315	.162	1.432	0.268	.054
Prior laparoscopy (yes or no)	−70.604	27.861	.011	−0.268	0.184	.146	0.751	0.259	.407	0.778	0.247	.429	0.814	0.198	.398
Abdominal approach (yes or no)	303.550	52.289	.000	2.361	0.324	.000	5.723	5.865	.089	8.158	8.358	.040	2.812	1.722	.091
Vaginal approach (yes or no)	141.508	60.747	.020	−0.017	0.381	.965	1.302	1.532	.823	2.910	3.258	.340	2.536	1.677	.159
Laparoscopic approach (yes or no)	72.503	53.641	.177	0.045	0.335	.893	1.363	1.475	.775	3.076	3.231	.285	1.691	1.078	.410
Year of surgery (2006–2009)	−59.250	23.698	.013‡	−0.584	0.155	<.001‡	0.611	0.159	.059‡	1.068	0.252	.780	0.272	0.057	<.001‡

EBL, estimated blood loss; SE, standard error; OR, odds ratio; BMI, body mass index.
* Results of multivariate linear regression.
† Results of multivariate logistic regression.
‡ Indicates statistical significance at $P \leq .05$.

increasing patient awareness of minimally invasive options for therapy, the Minimally Invasive Gynecologic Surgery Division at Brigham and Women's Hospital opened in 2006. The inception of the minimally invasive gynecologic surgery program at our institution brought an increased consciousness for alternate routes of performing hysterectomy, specifically laparoscopic and robotic surgery. The minimally invasive gynecologic surgery faculty increased resident and fellow education with new techniques to approach both routine and complex cases while also encouraging faculty colleagues in application of these skills to their practice by acting as a surgical mentor when needed. Although the gynecologic oncologists at our institution were already incorporating minimally invasive techniques in their practices, this new collaboration fostered further use into everyday practice.

When examining the data for mode of access of hysterectomy, some interesting trends can be seen. The 2006 proportions of hysterectomy performed

Table 3. Perioperative Outcomes and Complications for 2006 Compared With 2009 by Type of Hysterectomy

	Abdominal (n=1,070)		Vaginal (n=300)		Laparoscopic (n=678)		Robotic (n=85)	
	2006	2009	2006	2009	2006	2009	2006	2009
Uterine weight*	303.8±414.6†	390.5±620†	107.5±109.9	132±285.5	175.6±146.1†	226.5±237†	176.3±119.3	162±140
EBL (mL)*	387±565	363±388	223±277.9†	143±189†	217±232‡	110±144‡	92±99	75±162
LOS (d)*	4.1±3.4†	3.5±2.3†	1.7±0.8§	1.4±0.83§	1.3±1.5	1.3±0.9	1.2±0.7	1.4±0.9
OR time (minutes)*	189±70	196±53	164±60	153±61	210±70§	189±64§	278±74	260±74
Conversion‖	—	—	1 (0.62)	2 (1.5)	28 (15.73)‡	22 (4.44)‡	3 (16.67)†	0 (0)†
Major intraoperative complications‖	66 (9.71)	30 (7.79)	5 (3.09)	3 (2.26)	5 (2.72)	8 (1.61)	0 (0)	1 (1.59)
Major postoperative complications‖	67 (9.82)	35 (9.09)	2 (1.23)	6 (4.51)	8 (4.28)	17 (3.43)	0 (0)	1 (1.59)
Minor postoperative complications‖	146 (21.44)‡	24 (6.23)‡	22 (13.58)	12 (9.02)	19 (10.16)†	24 (4.84)†	2 (9.52)	1 (1.59)

EBL, estimated blood loss; LOS, length of stay; OR, operating room.
Major intraoperative complications=organ injury, estimated blood loss greater than or equal to 1,000 mL or both; major postoperative complications=readmission, reoperation, ileus, or pulmonary embolia; minor postoperative complications=infection (urinary, wound, or chest infection or a low-grade fever), deep vein thrombosis, or other nonspecified (majority; urinary retention).
* Mean±standard deviation and (range); compared using Student's *t* test.
Numbers indicate significant difference between the 2 years within type: † $P<.05$, ‡ $P<.0001$, § $P<.001$.
‖ Number and (%); compared using the χ^2 test of proportions.

Table 4. Total Hospital Cost and Operation Cost, Percentages in Difference, and Significance*

	n	2006†	2009†	Percent Difference	*P*
Total mean cost					
Composite cost	1,054	11.812±8.510	12.296±6.606	4.1	.142
Abdominal hysterectomy	682	13.347±9.855	12.678±7.471	−5	<.147
Vaginal hysterectomy	163	7.693±2.378	11.820±6.000	53.7	<.001
Laparoscopic hysterectomy	187	9.288±4.050	12.329±6.317	32.7	<.001
Robotic hysterectomy	22	16.004±2.397	11.004±4.208	−31.2	<.001
Operative cost					
Composite cost	1,079	5.103±2.183	6.897±2.471	35.2	<.001
Abdominal hysterectomy	386	4.986±1.959	6.214±2.030	24.6	<.001
Vaginal hysterectomy	134	3.957±1.227	4.210±1.249	6.4	<.002
Laparoscopic hysterectomy	496	5.793±2.234	7.710±1.965	33.1	<.001
Robotic hysterectomy	63	11.324±1.716	10.528±2.968	−7	<.084

* Percent difference is calculated as: 2009–2006 cost/2006 cost.
† Cost is presented in 2009 real dollars.

through each route are similar to what is reported in previously published data from similar time periods, approximately 65% of hysterectomies being performed abdominally.[17,18] Interestingly, vaginal hysterectomy appears to be a much less common approach at our institution than the nationwide percentage of 20.3%.[18] Potential explanations for this discrepancy may be that, as a referral center, our institution often sees more advanced pathology that may not be as amenable to vaginal approach (large uterus, adnexal mass, history of endometriosis, previous pelvic surgery). Additionally, the majority (approximately 55%) of hysterectomies was performed by the gynecologic oncology service or the minimally invasive gynecologic surgery service at our institution; these surgeons specialize in techniques aside from vaginal hysterectomy. The proportion of laparoscopic hysterectomies increased over 30% during the course of our study. Overall, the robotic hysterectomy was the least common approach, although the rate nearly tripled over the 3-year period of our study, demonstrating rapid integration of this latest addition to the surgeon's armamentarium. It is also worth noting that the vast majority of robotic cases were oncology cases, often radical hysterectomies. The relatively high number of total hysterectomies (approximately 80%) may reflect the volume of cases performed for malignancy as well as advanced endometriosis.

The patient groups analyzed in our study (2006 compared with 2009) can be considered comparable in terms of demographic baseline data. Regarding operative outcomes, overall estimated blood loss decreased significantly between the 2 years along with the changing mode of access. When broken down by type of hysterectomy, one can see a significant decrease in estimated blood loss specifically for the laparoscopic hysterectomy group, which may point to better outcomes as surgeons gain experience with this technique. The uterine weights were similar between 2006 and 2009 overall but increased over time in both the abdominal and laparoscopic groups. This may reflect a shift over time in patient selection for each procedure with abdominal hysterectomy being reserved for the largest uteri in some cases along with increasing comfort with a laparoscopic approach to larger uteri. There was also a significant decrease in length of stay from 2006 to 2009, again reflecting the trends in mode of access with quicker recovery in the minimally invasive groups. The decreased length of stay demonstrated by abdominal and vaginal hysterectomy groups may reflect changing trends in postoperative management. Operative time for laparoscopic hysterectomy decreased significantly between the 2 years, again suggesting increasing comfort level and expertise with these procedures.

Both intraoperative and minor postoperative complications decreased significantly over the 3 years of the study. The incidence of visceral, vascular, and neurologic injury remained low over both periods; however, a noteworthy decrease in major blood loss (more than 1,000 mL) was observed. As the laparoscopic approach became more popular, it is possible that many surgeons achieved sufficient experience to overcome the initial learning curve and therefore achieve lower complication rates. It is possible that such an "experience effect" over time could have potentially confounded the differences in complication rates and indirectly, therefore, in the cost calculations under study. However, despite the retrospective nature of the study given the timeframe concerned, we do believe that the differences seen here represent a significant trend attributable to an

alteration in the mode of access for hysterectomies. No intraoperative or major postoperative complications were observed in 2006 related to robotic surgery. Possible explanations for this may be that only experienced surgeons began using robotic surgery at our institution in the first few years after its Food and Drug Administration approval. Alternately, the surgeons may have selected less complex cases to perform with robotic assistance while they were familiarizing themselves with the new technology.

It is notable that from the perspective of our hospital, the total mean costs per hysterectomy did not increase despite a major shift in mode of access. This result counters the intuition that introducing newer, higher-technology modes of access comes at significant cost to the hospital as a result of initial costs and the need for increased equipment, operative time, and other resources. Our data support the fact that the higher upfront resource costs may be balanced by the shorter length of stay. As our societal cost estimation suggests, a shift from abdominal hysterectomy to laparoscopic or robotic hysterectomy is likely to increase the communal cost-effectiveness of hysterectomy by recovering labor production.

The drivers of hospital costs are notoriously complex and challenging to discern. Previous work examining the cost of hysterectomy at our institution (Wright KN, Jonsdottir GM, Jorgensen S, Shah N, Einarsson JI. A comparison of abdominal, vaginal, laparoscopic, and robotic hysterectomies: surgical outcomes and operative cost in a single institution. In press.) has demonstrated that operative time predicts operative cost more than any other factor. A strong association was also demonstrated among operative cost, length of stay, and total mean cost per hysterectomy. Based on this understanding, it is surprising to note significant increases in operative cost for all methods (except robotic hysterectomy) despite decreased operative time and complication rates. Total mean costs per hysterectomy rose by significant margins over the study period for laparoscopic and vaginal hysterectomy, which may be partially explained by the increase in operative costs. Conversely, both the operative cost and total mean cost of robotic hysterectomy decreased significantly, potentially as a result of improved efficiency as our surgeons and ancillary staff gained familiarity with this mode of access. Although robotic hysterectomy is often thought to be the most costly mode from the hospital perspective, our calculated cost to society was lowest for robotic hysterectomy, ranging from $13,501 to $14,158. Although it is instructive to have an overview of the costs to our hospital of changing the mode of access for hysterectomy, we were limited by a lack of information on the individual drivers of cost for each method.

Although this study represents a large patient database, it is limited by its retrospective nature with inherent selection bias. The data collection itself is subject to measurement bias as a result of inaccurate coding of procedures or errors in data gathering, although the data set was gathered from one source with only two individuals involved in its creation, which may increase accuracy. Although we did consider the inclusion of parity and the racial and ethnic distributions among the demographic characteristics in Table 2, we were limited by the nonavailability, inconsistency, or both of these data over the study period. In this case, we have not attempted to identify any potential confounding variables or effect modifiers that may exist such as surgeons' learning curves, changing protocols, or variations in surgical experience. The variety in surgical procedures as well as indication (benign compared with malignant) adds to heterogeneity of results, although this may also limit our final interpretation by diluting an effect that took place in only one subgroup. The major strength of this study is the volume of cases analyzed along with our outcomes of interest. All conclusions on cost outcomes were drawn from actual hospital billing data, which allows a realistic perspective of the findings. The diversity of cases and surgeons, along with involvement of trainees, lends generalizability to our results.

In conclusion, we found that main mode of access for hysterectomy exhibited a drastic shift over the years 2006 to 2009 from majority abdominal to majority laparoscopic. This change brought about improved perioperative outcomes, including decreased blood loss, risk of conversion, intraoperative complications, minor postoperative complications, and length of hospital stay. Although the operative cost increased in 2009, the total mean cost was not significantly affected. It is worth discussing issues surrounding outcomes by mode of hysterectomy in light of current practice guidelines. The 2009 Cochrane Review on the topic points to increased urinary tract injury and longer operative time as potential drawbacks of laparoscopic hysterectomy.[19] Our data suggest that with dedication to the implementation of minimally invasive techniques, goals such as decreased complications, decreased operative time, decreased conversion rate, and decreased estimated blood loss can be realized. The creation of a minimally invasive gynecologic surgery service at Brigham and Women's Hospital has benefitted not

only trainees and the hospital, but first and foremost our patients.

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