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REVIEW ARTICLE

Review of strategies and factors to maximize cost-effectiveness of robotic hysterectomies and myomectomies in benign gynecological disease

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Abstract
Common benign gynecologic procedures include hysterectomies and myomectomies, with hysterectomy being the most common gynecologic procedure in the United States [1]. While historically performed via laparotomy, the field of gynecologic surgery was revolutionized with the advent of laparoscopic techniques, with the most recent advancement being the introduction of robotic-assisted surgery in 2005. Robotic surgery has all the benefits of laparoscopic surgery such as decreased blood loss, quicker return to activities, and shorter length of hospital stay. Additional robotic-specific advantages include but are not limited to improved ergonomics, 3D visualization, and intuitive surgical movements. Despite these advantages, one of the most commonly cited drawbacks of robotic surgery is the associated cost. While the initial cost to purchase the robotic console and its associated maintenance costs are relatively high, robotic surgery can be cost-effective when utilized correctly. This article reviews application strategies and factors that can offset traditional costs and maximize the benefits of robotic surgery.

Keywords Hysterectomy · Myomectomy · Cost of robotic surgery

Introduction

Hysterectomy for benign indications is the most common gynecologic procedure in the United States, with over 600,000 cases being performed annually [1]. Over an average lifetime, 43% of women will have undergone this procedure [2]. While the majority of cases are still performed through laparotomy, the introduction and popularization of minimally invasive methods have provided an alternative with multiple proven advantages [1, 3, 4]. Advancements in the field of minimally invasive surgery have led to the wide spread popularization of robotic surgery [5]. Robotic surgery is laparoscopic surgery; however, proponents of the robotic platform believe that this tool provides advantages unparalleled by traditional laparoscopic equipment [5]. Adopters of the robotic platform believe that this tool provides benefits over conventional laparoscopy for challenging cases including myomectomy, resection of endometriosis with significant adhesive disease, and operating on the morbidly obese patient [6].

The Food and Drug Administration approved the use of the Da Vinci® Robot (Intuitive Surgical Corporation. Sunnyvale, CA) for gynecologic indications in 2005. Robotic surgery provides all the advantages of laparoscopic surgery while offering additional benefits: improved ergonomics that mimic the natural hand movements of open surgery, an increased range of motion (up to 7° of freedom), and 3D visualization. These advantages can make even the most difficult cases feasible with robotic surgery. Since the introduction of the Da Vinci surgical system, its popularity has been widespread [7]. The dramatic increase in utilization of the robotic surgical system is not limited to gynecology, but has been seen in various other specialties including general surgery, colorectal surgery, otorhinolaryngology, and pediatric surgery [8–10]. However, gynecology and urology are two specialties that have helped to popularize the robotic surgical

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system by being early adopters, accounting for 86% of all robotic procedures performed in the USA [11].

One of the most common criticisms regarding robotic surgery for benign gynecologic indications is the associated cost. Annual hysterectomies contribute $5 billion to health care costs [12]. Endometriosis, a gynecologic condition affecting more than 5 million women in the United States, is estimated to incur $69.4 billion annually in direct and indirect costs [13]. These are only two examples of the way in which gynecologic conditions impact the annual cost of care delivered in a variety of settings. Studies have demonstrated that robotic surgery, on average, costs an additional $2000–$3000 compared to other modalities [14–16]. Costs have been consistently higher for all benign gynecologic surgery using the robotic platform. These studies, however, are imperfect and often do not consider costs outside of surgery alone. Ideal studies would not consider the cost of surgery in isolation, but would identify the total cost of care associated with different surgical modalities. Robotic surgery can be a cost-effective modality for surgery if utilized correctly. In this era of rising health care costs, it is imperative for individual practitioners to be cost-conscious. In this review paper, we will analyze the different costs associated with robotic hysterectomies and myomectomies, and discuss strategies that can be implemented to offset and minimize their cost.

Challenges of comparing cost

Comparing cost between modalities of surgery can be difficult as multiple confounders and different types of economic analyses are present in the literature. Some of the variables include direct healthcare costs, direct non-healthcare costs, indirect costs, actual charges, set charges, and inflation. The shortcomings of a majority of available data stem from heterogeneity of study designs and methodological flaws in the data analyses [13]. In a recent systematic review of all available literature from 2008 to 2016, the authors found that only a few studies had methodologically sound study design consistent with the Consolidated Heath Economic Evaluation Reporting Standards (CHEERS) statement [13]. Few available studies evaluate the societal burden of use of patient time, which includes lost productivity from work, transportation fees, and non-healthcare-associated costs [17, 18]. Often studies include the purchasing cost of the robotic surgical system and then fail to include out of hospital costs, which skew the cost analyses [13]. Including a fixed purchasing price of the robotic surgical system, often included in these cost comparison studies, will also skew data as an increase in robotic operations per year will actually decrease the overall cost per operation [19]. In the analysis by Lönnerfors et al., similar overall hospital costs were seen between traditional laparoscopy and robotic surgery ($7059 vs. $7016) when the robotic surgical system was considered a preexisting investment [20].

Another shortcoming of dated studies is the failure to consider how the learning curve for robotic surgery has changed over time. As surgeon comfort increases with the robotic platform, its use increases accordingly. Since 2008, about 80% of radical prostatectomies are being performed robotically, compared to a historically open procedure [21]. Several studies have shown that with greater expertise in the robotic surgical system there are shorter operating times, a shorter length of stay, and fewer readmissions [22–24]. A recent study analyzing robotic-assisted versus laparoscopic gastric bypass found that there were fewer complications associated with the robotic surgery group [25]. This same study found a lower rate of 90-day readmission rates for the robotic group compared to the laparoscopic group [25]. Data exist to show that the learning curve for robotic surgery directly impacts the cost associated with the procedure [26]. It is safe to assume that as surgeons become more comfortable, and thus more efficient, with the robotic surgical system the cost per procedure will decrease. There are already data to suggest that with high volume surgeons the robotic surgical system can be cost saving over traditional laparoscopy for large uteri [27]. It is undeniable that the robotic surgical system is here to stay and is gaining widespread traction. The estimated annual procedure volume has increased by a factor of 6 between the years 2008 and 2017 (136 000–877 000, respectively) [28]. Another inevitability is that the entry of competitors will introduce significant cost reductions from the price of the robotic surgical system being driven down [29]. Currently, one company has a stronghold on the robotic market; however, this is undeniably going to change.

Da Vinci® robotic cost components

Fixed costs

For robotic surgery, certain associated costs are unavoidable, such as the initial purchase of the Da Vinci® robotic console. In addition to this investment cost, the yearly maintenance costs need to be included in any analyses of robotic expense as well. The Da Vinci® robotic console, the only console currently available sold by Intuitive Surgical, Inc., can range from $1 to $2.3 million. Contrary to popular belief, this investment cost is not evenly distributed solely among robotic surgical cases performed at the purchasing entity (hospital, outpatient surgical center, etc.). The process of compensating the initial purchase cost is more complex and, as such, this result will vary between purchasing bodies. When the robot is a preexisting investment in an established entity, the cost difference between minimally invasive routes

do become more accurately comparable [30]. Annual robotic maintenance fees average between $100,000 and $180,000 and do not include the necessary, but disposable, ancillary equipment [14]. For institutions that perform a high volume of robotic procedures, the fixed costs become significantly less pronounced [16, 30].

Disposable costs

As previously mentioned, the initial investment in the robotic console does not include ancillary equipment. Table 1 shows a brief list of additional equipment that is available and may be required, for each individual case. Many of the exchangeable instruments, such as the robotic needle drivers or fenestrated graspers, have a lifespan of ten uses prior to requiring replacement. The hospital would have to invest in purchasing these instruments, ranging from $2000 to 3000, with their average cost per use incorporated into each individual case. Multiple studies have cited the disposable equipment as the driving force behind the high cost of robotic-assisted surgery [16, 31, 32]. Wright et al. compared variable costs (defined as disposable instruments and supplies) between traditional laparoscopic and robotic-assisted hysterectomies and found an additional average cost of $1207 for robotic cases.

Despite the unavoidable cost of purchasing disposable instruments to facilitate robotic surgery, the surgeon can still consciously reduce the cost per case with correct surgical preoperative planning. A study of robotic prostatectomies found that by excluding the use of energy sealing devices and minimizing redundant instrumentation, costs were reduced by as much as 40% per case [33]. Data exist to show that performing reduced-port robotic hysterectomy is feasible and has advantages including decreased docking time, reduced blood loss, and decreased length of hospital stay [34]. Reduced port robotic hysterectomy also translated into an approximate $1800 cost reduction per case ($6845 vs. $8709) [34]. Similarly, reduced port robotic hysterectomy and pelvic lymph node dissection for endometrial cancer translated into a statistically significant cost reduction per case when compared to conventional multiport robotic hysterectomy ($13,410 vs. $15,952; $p < 0.05$) [35]. Avoiding the redundancy of using multiple different instruments for a similar function in a single case can further decrease cost [33]. In addition, as multiple vendors eventually enter the market competition should drive down the price for robotic consoles and robotic equipment that Intuitive Surgical has currently set.

Table 1 Disposable equipment needed per case for robotic and laparoscopic cases

Shared between laparoscopy	Robotic specific
Foley catheter	Robotic custom pack
Veress needle	Instrument arm drapes
CO2 tubing	Camera arm drape
Suction irrigator	Camera drape
Uterine manipulator	Robotic needle driver
Laparoscopic ports	Robotic forceps
	Bipolar forceps
	Robotic fenestrated graspers
	Robotic ports

Modifying factors

Intraoperative and postoperative complications

Postoperative complications occur in up to 6–7% of patients undergoing surgery [32, 36]. Complications can include, but are not limited to, infections (urinary tract infections and superficial or deep wound infection), cardiovascular events (myocardial infarction, cardiac arrest, stroke), pulmonary events (pneumonia, pneumothorax, unplanned intubation), or thromboembolic events (deep venous thrombosis and pulmonary embolism). These complications have major financial consequences on the healthcare system. Any event complicating the surgery can increase the median cost of care per event by upwards of $11,626 [37]. These costs are largely driven by the increased need for resources, hospital charges, and increased length of hospital stay.

Complications associated more with laparotomy, compared to a minimally invasive procedure, include surgical site infection and hematomas, leading to increased rates of readmission. Surgical site infections can also result in a prolonged hospital stay, higher rates of reoperation, sepsis, and wound dehiscence, and can delay the patient's ability to return to work. Surgical site infections have been shown to lead to a doubling of the cost of care for a given procedure [38, 39]. Understanding the importance of minimizing complications in surgery is paramount and robotic hysterectomies have been shown to have the lowest incidence of wound infection when compared to other modalities [38].

As utilization increases for robotic surgery across multiple disciplines, there will certainly be more study and scrutiny of the differences in complication rates between the robotic platform and traditional laparoscopy [40]. For surgical oncology, surgeries largely performed via laparotomy, over a 5-year study period there was a fivefold increase in utilization of the robotic platform [40]. When traditional laparoscopic hysterectomy has been compared to robotic hysterectomy, many studies have shown comparable rates of intraoperative and/or postoperative complications [27, 41–43]. However, more recent data taking into account surgeon experience have shown that robotic-assisted surgeries may have less complications overall when compared to

all other modalities [44, 45]. A special concern often cited for laparoscopic or robotic surgery is the need for conversion to laparotomy. Even in complicated cases, with large uteri (500–1000 g), endometriosis, or large body mass index (BMI), robotic surgery was performed safely with no increase rates of complications, rates of blood transfusion, or conversions to laparotomy [46–48].

The dogma of minimizing complications to reduce costs holds true for hysterectomies and myomectomies regardless of modality. When laparoscopic and robotic hysterectomies are compared to open hysterectomies multiple studies have shown that there are fewer complications with the laparoscopic approach, either with or without the robotic console [49, 50]. One particular concern for laparoscopic hysterectomy was the cited increased incidence of urinary tract injuries compared to open or vaginal hysterectomy. However, more recently when the injuries are separated by type of injury (ureteral or bladder), there is no statistically significant difference between surgical modality. These dated findings may have been attributed to surgeon inexperience with laparoscopy, as subsequent studies have shown decreased rates of ureteral and bladder injury as familiarity with laparoscopy has increased [51, 52].

Given the inherent complexity of myomectomies unanticipated blood loss and blood transfusions are common concerns held surrounding these procedures. Two recent meta-analyses of robotic-assisted myomectomies found lower rates of estimated blood loss and decreased need for blood transfusions when compared to open myomectomies [4, 16]. There was also a higher incidence of intraoperative and postoperative complications associated with open myomectomies. When laparoscopic and robotic-assisted myomectomies were compared, there were no significant differences in estimated blood loss, need for blood transfusion, and overall complication rate between them.

Length of surgery

The length of surgery, or total operative time, has a positive correlation on the overall cost of any procedure. This can be attributed to operating room (OR) costs, physician and nursing fees, time spent in preoperative and postoperative areas, and anesthesia fees. Previously published works have found robotic surgery to be the longest of the different modalities, with an average increase of 26–72 min for hysterectomies [49]. In addition to the aforementioned influences, docking and undocking time, technical troubleshooting for robot specific issues (such as clashing arms), and less efficient electrosurgical vessel-sealing instruments can prolong robotic operative time [49]. Nash et al. found that longer operating times for robotic myomectomies were the driving force behind increased costs associated with robotic surgeries [45]. However, there are shortcomings to these studies. These critical studies highlighting the increased cost of robotics fail to account for where surgeons may be on the learning curve, what constitutes a high volume surgeon, and the operating room staff's comfort level with the robotic surgical system [51, 53, 54]. Overall operating time can be decreased with increased comfort with the robotic platform [55]. When the time for robotic set up has been taken into account, in addition to the actual operating time, which largely is dependent on the OR staff it significantly prolongs the total time of the procedure independent of surgeon experience [45]. Not enough emphasis has been placed on the impact the ancillary staff has on total operative times. Consistency breeds efficiency and it is safe to assume that efficiency reduces cost [27].

Due to the advantages of the robotic console cases selected for robotic surgery may be inherently more complicated, with patients having multiple previous abdominopelvic surgeries, higher BMIs, or large uteri. The few studies that have been able to minimize total operative time for robotic hysterectomies showed an improved cost profile when compared to other modalities of hysterectomy [27]. Thus, to assist in decreasing cost, efforts to have a dedicated OR staff to assist in robotic room setup and robotic instrument maintenance, thorough surgical planning, and increased operating efficiency should be kept in consideration when scheduling a robotic-assisted surgery.

Many prior studies were completed at academic institutions where residents, and occasionally fellows, are incorporated into the surgical team. There is a varying degree of familiarity and skill with robotic surgery for trainees. Incorporating trainees into the robotic surgeries, while necessary, may lengthen operating time. However, having residents and fellows operate robotically can provide invaluable training to improve skills in the next generation of robotic surgery ultimately leading to decreased robotic costs.

Length of hospital stay/return to activity

There is a direct correlation between the length of hospital stay and associated cost. These costs are due to staff fees, room and board, pharmacy, laboratory tests, to name only a few. The length of stay varies between the modality of surgery. Multiple studies have shown that abdominal hysterectomy is associated with the longest stay, averaging 3–5 postoperative days [47, 56]. This is the driving force behind the cost of abdominal surgery [41, 57]. Length of stay for minimally invasive modalities is much shorter. When compared to one another, patients undergoing robotic hysterectomies, on average, are able to return home sooner than patients having laparoscopic hysterectomies. Robotic cases were also less likely to remain in the hospital beyond 2 days [14, 41, 56, 58]. Similar evidence from the colorectal literature has shown that robotic surgery for colorectal carcinoma

is associated with improved outcomes as well as short length of stay compared to traditional laparoscopy [59]. Some surgeons have also started discharging uncomplicated laparoscopic and robotic hysterectomies on the day of surgery, though robotic cases were more likely to be discharged home on the day of surgery [46]. A flaw in critical cost analyses is that using national databases to capture a large sample size studies fails to factor in same-day-discharges [51]. By not accounting for same-day-discharges, a sizeable proportion of robotic surgeries may be overlooked in cost analyses. The same has proven true for robotic myomectomies. When compared to open myomectomies, patients are discharged home from the hospital much sooner after undergoing a robotic procedure [60]. When compared there was no difference between laparoscopic and robotic myomectomies for length of stay, though both groups were unlikely to remain admitted for longer than 2 days [61].

In addition to decreasing the length of hospital stay to reduce cost, consideration must be given to the ability of a patient to return to work and minimize their loss of productivity. If there is a rapid return to productivity, the costs of equipment can be offset, or at least minimized [62]. However, there are minimal data analyzing this parameter specifically following robotic surgery. Sarlos et al. did show that there was a higher quality of life immediately following surgery and that the return to baseline is shorter by 2 days for robotic hysterectomies compared to laparoscopic [57]. Barnett et al. attempted to reconcile this issue using the "societal perspective model" to assess the cost differences between the modalities of surgery for endometrial cancer patients. In this model, costs associated with lost wages (at time of publication, the average weekly wage was $638 for women over the age of 16 in 2010) according to the Bureau of Labor and the average cost of caregivers for the duration of a patient's recovery were incorporated into the analysis [54]. Laparoscopy was the most cost-effective route of surgery, with a cost saving of $1347 compared to robotic surgery, and $2719 compared to open hysterectomies. In a separate contradictory analysis by Jonsdottir et al., robotic surgery was found to have the lowest indirect cost to society when accounting for the patient's ability to return to productivity when compared to laparoscopic, abdominal, and vaginal hysterectomies [18].

Surgeon experience

The correlation between surgeon volume and patient outcomes has been established as a positive one. Postoperative outcomes for patients undergoing hysterectomy by any modality have been more favorable when performed by a "high volume surgeon," compared to a lower volume surgeon. Economically, Wallenstein et al. estimated that if 15% of the annual 550,000 hysterectomies performed laparoscopically were done with a high volume surgeon or in a high volume surgery center (instead of low volume surgeon or surgery center), potential savings to the healthcare system can reach $71–$80 million [63]. Surgeon comfort with the different routes of surgery can also influence the hysterectomy modality offered to a patient. High volume minimally invasive surgeons are more likely to offer and proceed with a minimally invasive route for hysterectomy as opposed to an open hysterectomy, compared to lower volume surgeons. These minimally invasive procedures have been consistently shown to be more cost-effective than open surgeries [62].

Boyd et al. noted that in all hysterectomies performed in New York State from 2001 to 2006 patient outcomes were associated with surgeon volume. Patients under the care of a high volume surgeon (surgeons performing more than 10 cases per year in this study) had better postoperative outcomes when compared to patients under the care of a lower volume surgeon [31]. The same finding is reflected in studies that analyzed laparoscopic hysterectomies and abdominal hysterectomies separately and their association between surgical experience and short-term complication rates [63, 64]. Lowering the postoperative complication rate will serve to drive down the associated operative costs.

Length of surgery is also directly influenced by surgeon volume. Tunitsky et al. showed that in the hands of a "high volume surgeon," or a practitioner that has performed at least 29 cases, there was a significant decrease in operating time, decreased in length of hospital stay, and decreased rates of conversion to laparotomy for laparoscopic hysterectomies [64]. In addition, a bulk of the available studies were performed in the early stages of robotic implementation: a time when surgeons were likely still in the early stages of their learning curve and may have been more comfortable with traditional laparoscopy. Examining robotic surgery across all specialties Barbash et al. states that a minimum of 150–200 cases are needed to master robotic surgery [30]. Lenihan et al. determined that a minimum of 50 cases is needed to develop competence in laparoscopic hysterectomy [65]. Specifically for robotic hysterectomy, Geller et al. showed improvements in operating time after 20 cases, while Woelk et al. states a minimum of 91 cases needed to demonstrate proficiency (based on the rate of intraoperative complications) [66, 67]. Much of the available literature assessing the effectiveness of robotic hysterectomy was conducted in an era when surgical experience was not a variable included in the analysis, or is downplayed. The minimization of surgeon volume and how this impacts cost is highly significant, especially when comparing surgical modalities [5]. There is evidence that expert surgeon skills are not stagnant, but do continue to improve with higher case volume [68]. In a study of robotic prostatectomies "super experts" (defined as surgeons with between 2100 and 3500 case history) outperformed "experts" (defined as surgeons with between 100 and

750 case history) in four cardinal steps of a robotic-assisted radical prostatectomy ($p < .05$) [68]. This study highlights the importance that volume does matter and surgeons continue to improve as their case volume grows.

As surgeon experience has become incorporated into the analyses, multiple studies have shown an improved profile for robotic hysterectomies [16, 30, 56, 66]. Robotic hysterectomy has the lowest rate of intraoperative and postoperative complications compared to all other routes of hysterectomy, when performed by "high volume surgeons" (defined by having performed at least 60 cases within the study period in their respective modality [55]. This finding was also demonstrated by Lönnerfors et al., where robotic surgery not only had improved complication rates, but also was the faster modality compared to traditional laparoscopic hysterectomy [20]. The total cost of robotic surgery also becomes comparable between laparoscopic and robotic hysterectomies when the analyses set the robotic console as a preexisting instrument of the entity, thus disregarding purchasing cost ($7059 vs $7016). However, the most cost-efficient modality reported by Lönnefors et al. remained vaginal hysterectomy ($4579), a modality that was not consistently compared against robotic hysterectomies [20]. One study did show that robotic surgery can be significantly more cost-effective than laparoscopy. In the hands of high volume surgeons with more than 200-case experience, robotic hysterectomies performed in women with uteri > 750 g can save an average of $1859 per case. For enlarged uteri (defined as > 1000 g), robotic surgery can decrease cost by $4509 when compared with laparoscopic hysterectomy [27].

Conclusions

Robotic surgery is an innovative technology that is surely advancement in the right direction. Three-dimensional visualization as well as expanded articulation and ergonomics are only the beginning of what is to come. Robotic opponents often site cost as the insurmountable drawback from the robotic surgical system. Competition will enter the market, which will certainly drive down cost. We must remember that cost analyses are extremely challenging to perform well and are fraught with bias. Certain costs are unavoidable, such as the acquisition cost and maintenance fees of the robotic platform. However, cost comparisons constantly leave out the original acquisition cost and maintenance fees associated with traditional laparoscopic equipment. A fair cost analysis must account for the expense associated with the conventional laparoscopic equipment being compared to the robotic equipment [5]. With increasing surgical experience using the robotic console the length of surgery and surgical complications will decrease accordingly. The reduced incidence of complications in robotic surgery and shorter length of hospital stay will also help minimize overall costs and greatly offset fixed costs associated with the robot. Having dedicated operating room staff proficient in preparing the robotic console for surgery and room turnover is yet another means to cut down on overall cost associated with the device. It is easy to forget that only 30 years ago traditional laparoscopy was considered a gimmick that had no place in the operating room.

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Compliance with ethical standards

Conflict of interest Catherine Wu, Jordan Klebanoff, and Paul Tyan report no conflict of interest. Gaby Moawad is a speaker and consultant for Intuitive Surgical.

References

1. Jm Wu, Wechter ME, Geller EJ, Nguyen TV, Visco AG (2003) Hysterectomy rates in the United States. Obstet Gynecol 110(5):1091–1095
2. Merrill RM (2001) Prevalence corrected hysterectomy rates and probabilities in Utah. Ann Epidemiol 11:127–135
3. AAGL Advancing Minimally Invasive Gynecology Worldwide (2011) AAGL position statement: route of hysterectomy to treat benign uterine disease. J Minim Invasive Gynecol 18(1):1–3
4. Iavazzo C, Mamais I, Gkegkes ID (2016) Robotic assisted vs laparoscopic and/or open myomectomy: systematic review and meta-analysis of the clinical evidence. Arch Gynecol Obstet 294:5–17
5. Advincula AP, Wang K (2009) Evolving role and current state of robotics in minimally invasive gynecologic surgery. J Minim Invasive Gynecol 16(3):291–301
6. Sinha R, Sanjay M, Rupa B, Kumari S (2015) Robotic surgery in gynecology. J Minim Access Surg Jan-Mar 11(1):50–59
7. Papalekas E, Fisher J (2018) Trends in route of hysterectomy after the implementation of a comprehensive robotic training program. Minim Invasive Surg 2018:7362489. https://doi.org/10.1155/2018/7362489
8. Molina DC, Lambreton F, Majul RA (2018) Trends in robotic pancreaticoduodenectomy and distal pancreatectomy. J Laparoendosc Adv Surg Tech A 29(2):147–151. https://doi.org/10.1089/lap.2018.0421
9. Cave J, Clarke S (2018) Paediatric robotic surgery. Ann R Coll Surg Engl 100(Suppl 7):4–13
10. Garas G, Tolley N (2018) Robotics in otorhinolaryngology-head and neck surgery. Ann R Coll Surg Engl 100(Suppl 7):34–41
11. Alemzadeh H, Raman J, Levenson N, Kalbarczyk Z, Iyer RK (2016) Adverse events in robotic surgery: a retrospective study of 14 years of FDA data. PLoS One 11(4):e0151470. https://doi.org/10.1371/journal.pone.0151470
12. Agency for Healthcare Research and Quality. Health Services research on hysterectomy and alternatives. https://archive.ahrq.gov/research/hysterec.htm. Accessed 10 Sep 2017
13. Korsholm M, Sorensen J, Mogensen O, Wu C, Karlsen K, Jensen PT (2018) A systematic review about costing methodology in robotic surgery: evidence for low quality in most of the studies. Health Econ Rev 8(1):21. https://doi.org/10.1186/s13561-018-0207-5

14. Pasic RP, Rizzo JA, Fang H, Ross S, Moore M, Gunnarsson C (2010) Comparing robot-assisted with conventional laparoscopic hysterectomy: impact on cost and clinical outcomes. J Minim Invasive Gynecol 17(6):730–738
15. Wright KN, Jonsdottir GM, Jorgensen S, Shah N, Einarsson JI (2012) Costs and outcomes of abdominal, vaginal, laparoscopic, and robotic hysterectomies. JSLS 16(4):519–524
16. Advincula AP, Xu X, Goudeau S, Ransom SB (2007) Robot assisted laparoscopic myomectomy versus abdominal myomectomy: a comparison of short term surgical outcomes and immediate costs. J Minim Invasive Gynecol 14(6):698–705
17. Shah NT, Wright KN, Jonsdottir GM, Jorgensen S, Einarsson JI, Muto MG (2011) The feasibility of societal cost equivalence between robotic hysterectomy and alternate hysterectomy methods for endometrial cancer. Obstet Gynecol Int. https://doi.org/10.1155/2011/570464
18. Jonsdottir GM, Jorgensen S, Cohen S, Wright KN, Shah NT, Chavan N, Einarsson JI (2011) Increasing minimally invasive hysterectomy: effect on cost and complications. Obstet Gynecol 117(5):1142–1149
19. Iavazzo C, Papadopoulou EK, Gkegkes ID (2014) Cost assessment of robotics in gynecologic surgery: a systematic review. J Obstet Gynecol Reprod Biol 40(11):2125–2134
20. Lönnerfors C, Reynisson P, Persson J (2015) A randomized trial comparing vaginal and laparoscopic hysterectomy vs robotic-assisted hysterectomy. J Minim Invasive Gynecol 22(1):78–86
21. Jacobs EF, Boris R, Masterson TA (2013) Advances in robotic-assisted radical prostatectomy over time. Prostate Cancer 2013:902686
22. Bogani G, Multinu F, Dowdy SC, Cliby WA, Wilson TO, Gostout BS et al (2016) Inorporating robotic-assisted surgery for endometrial cancer staging: analysis of morbidity and costs. Gynecol Oncol 141(2):218–224
23. Wright JD, Burke WM, Wilde ET, Lewin SN, Charles AS, Kim JH et al (2012) Comparative effectiveness of robotic versus laparoscopic hysterectomy for endometrial cancer. J Clin Oncol 30(8):783–791
24. Turunen H, Pakarinen P, Sjöberg J, Loukovaara M (2013) Laparoscopic vs robotic-assisted surgery for endometrial carcinoma in a centre with long laparoscopic experience. J Obstet Gynaecol 33(7):720–724
25. Cahais J, Lupinacci RM, Oberlin O, Goasguen N, Zuber K, Valverde A (2018) Less morbiditiy with robotic-assisted gastric bypass surgery than with laparoscopic surgery? Obes Surg 29(2):519–525. https://doi.org/10.1007/s11695-018-3545-9
26. Laursen KR, Hyldgard VB, Jensen PT, Sogaard R (2018) Health care cost consequences of using robotic technology for hysterectomy: a register-based study of consecutive patients during 2006–2013. J Robot Surg 12(2):283–294
27. Moawad GN, Abi Khalil ED, Tyan P, Shu MK, Samuel D, Amdur R, Scheib SA, Marfori CQ (2018) Comparison of cost and operative outcomes of robotic hysterectomy compared to laparoscopic hysterectomy across different uterine weights. J Robotic Surg 11(4):433–439. https://doi.org/10.1007/s11701-017-0674-4
28. Childers CP, Maggard-Gibbons M (2018) Estimation of the acquisition and operating costs for robotic surgery. JAMA 320(8):835–836
29. Knight J, Escobar PF (2014) Cost and robotic surgery in gynecology. J Obstet Gynaecol Res 40(1):12–17
30. Barbash GI, Glied SA (2010) New technology and health care costs—the case of robotic assisted surgery. N Engl J Med 363(8):701–704
31. Boyd LR, Novetsky AP, Curtin JP (2010) Effect of surgical volume on route of hysterectomy and short term morbidity. Obstet Gynecol 116(4):909–915
32. Brummer TH, Seppälä TT, Härkki PS (2008) National learning curve for laparoscopic hysterectomy and trends in hysterectomy in Finland 2000–2005. Hum Reprod 23(4):840–845
33. Delto JC, Wayne G, Yanes R, Nieder AM, Bhandari A (2015) Reducing robotic prostatectomy costs by minimzing instrumentation. J Endourol 29(5):556–560
34. Bogliolo S, Ferrero S, Cassani C, Musacchi V, Zanellini F, Dominoni B et al (2016) Single-site versus multiport robotic hysrerectomy in benign gynecologic disease: a retrospective evaluation of surgical outcomes and cost analysis. J Minim Invasive Gynecol 23(4):603–609
35. Moukarzel LA, Sinno AK, Fader AN, Tanner EJ (2017) Comparing single-site and multiport robotic hysterectomy with sentinel lymph node mapping for endometrial cancer: surgical outcomes and cost analysis. J Minim Invasive Gynecol 24(6):977–983
36. Johnson N, Barlow D, Lethaby A, Tavender E, Curr L, Garry R (2005) Methods of hysterectomy: systematic review and meta-analysis of randomized controlled trials. BMJ 330(7506):1478
37. Donnez O, Jaboul P, Squifflet J, Donnez J (2008) A series of 3190 laparoscopic hysterectomies for benign disease from 1990 to 2006: evaluation of complications compared with vaginal and abdominal procedures. BJOG 116(4):492–500
38. Swenson CW, Kamdar NS, Harris JA, Uppal S, Campbell DA, Morgan DM (2016) Comparison of robotic and other minimally invasive routes of hysterectomy for benign indications. Am J Obstet Gynecol 215(5):650
39. Rosero EB, Kho KA, Joshi GP, Giesecke M, Schaffer JI (2013) Comparison of robotic and laparoscopic hysterectomy for benign gynecologic disease. Obstet Gynecol 122(4):778–786
40. Stewart CL, Ituarte PHG, Melstrom KA, Warner SG, Melstrom LG, Kai LL et al (2018) Robotic surgery trends in general surgical oncology from the national inpatient sample. Surg Endosc. https://doi.org/10.1007/s/00464-018-6554-9
41. Pellegrino A, Gianluca RD, Fachechi G, Corso S, Pirovano C, Trio C, Villa M, Turoli D, Youssef A (2017) Cost analysis of minimally invasive hysterectomy vs open approach performed by a single surgeon in an Italian center. J Robot Surg 11(2):115–121
42. Boggess JF, Gehrig PA, Cantrell L, Shafer A, Mendivil A, Rossi E, Hanna R (2009) Perioperative outcomes of robotically assisted hysterectomy for benign cases with complex pathology. Obstet Gynecol 114(3):585–593
43. Silasi DA, Gallo T, Silasi M, Menderes G, Azodi M (2013) Robotic versus abdominal hysterectomy for very large uteri. JSLS 17(3):400–406
44. Dimick JB, Chen SL, Taheri PA, Henderson WG, Khuri SF, Campbell DA (2004) Hospital costs associated with surgical complications: a report from the private sector national surgical quality improvement program. J Am Coll Surg 199(4):531–537
45. Nash K, Feinglass J, Zei C, Lu G, Mengesha B, Lewicky-Gaupp C, Lin A (2012) Robotic assisted laparoscopic myomectomy versus abdominal myomectomy: a comparative analysis of surgical outcomes and costs. Arch Gynecol Obstet 285:435–440
46. Paraiso MF, Ridgeway B, Park AJ, Jelovsek JE, Barber MD, Falcone T, Einarsson JI (2013) A randomized trial comparing conventional and robotically assisted total laparoscopic hysterectomy. Am J Obstet Gynecol 208(5):368e1–368e7
47. Bell MC, Torgerson J, Seshadri-Kreaden U, Wierda Suttle A, Hunt S (2008) Comparison of outcomes and cost for endometrial cancer staging via traditional laparotomy, standard laparoscopy, and robotic techniques. Gynecol Onc 111(3):407–411
48. Lau S, Vaknin Z, Ramam-Kumar A, Halliday D, Frano E, Gotlieb W (2012) Outcomes and cost comparisons after introducing a robotics program for endometrial cancer surgery. Obstet Gynecol 119(4):717–724
49. Mahdi H, Goodrich S, Lockhart D, DeBernardo R, Moslemi-Kebria M (2014) Predictors of surgical site infection in women

undergoing hysterectomy for benign gynecologic disease: a multicenter analysis using the national surgical quality improvement program data. J Minim Invasive Gynecol 21(5):901–909
50. De Lissovoy G, Fraeman K, Hutchins V, Murphy D, Song D, Vaughn B (2009) Surgical site infection: incidence and impact on hospital utilization and treatment costs. Am J Infect Control 37(5):387–397
51. Wright JD, Ananth CV, Lewin SN, Burke WM, Lu YS, Neugut AI, Herzog TJ, Hershman DL (2013) Robotically assisted vs laparoscopic hysterectomy among women with benign gynecologic disease. JAMA 309(7):689–698
52. Albright BB, Witte T, Tofte AN, Chou J, Black JD, Desai VB, Erekson EA (2016) Robotic versus laparoscopic hysterectomy for benign disease: a systematic review and meta-analysis of randomized trials. J Minim Invasive Gynecol 23(1):18–27
53. Nezhat C, Lavie O, Hsu S, Watson J, Barnett O, Lemyre M (2009) Robotic assisted laparoscopic myomectomy compared with standard laparoscopic myomectomy—a retrospective matched control study. Fertil Steril 91(2):556–559
54. Barnett JC, Judd JP, Wu JM, Scales CD, Myers ER, Havrilesky LJ (2010) Cost comparison among robotic, laparoscopic, and open hysterectomy for endometrial cancer. Obstet Gynecol 116(3):685–693
55. Lim PC, Crane JT, English EH, Farnam RW, Garza DM, Winter ML, Rozeboom JL (2016) Multicenter analysis comparing robotic, open, laparoscopic, and vaginal hysterectomies performed by high-volume surgeons for benign indications. Int J Gynaecol Obstet 133(3):359–364
56. Khan NA, Quan H, Bugar JM, Lemaire JB, Brant R, Ghali WA (2006) Association of postoperative complications with hospital costs and length of stay in a tertiary care center. J Gen Intern Med 21(2):177–180
57. Sarlos D, Kots L, Stevanovic N, von Felten S, Schar G (2012) Robotic compared with conventional laparoscopic hysterectomy: a randomized controlled trial. Obstet Gynecol 120(3):604–611
58. Aarts JWM, Nieboer TE, Johnson N et al (2015) Surgical approach to hysterectomy for benign gynaecological disease. Cochrane Database Syst Rev. https://doi.org/10.1002/14651858.CD003677.pub5.
59. Zhu XL, Yan PJ, Yao L, Liu R, Wu DW, Du BB et al (2018) Comparison of short-term outcomes between robotic- assisted and laparoscopic surgery in colorectal cancer. Surg Innov 7:1553350618797822
60. Barakat EE, Bediwy M, Zimberg S, Nutter B, Nosseir M, Falcone T (2011) Robotic assisted, laparoscopic, and abdominal myomectomy: a comparison of surgical outcomes. Obstet Gynecol 117(2):256–266
61. Behera MA, Likes CE III, Judd JP, Barnett JC, Havrilesky LU, Wu JM (2012) Cost analysis of abdominal, laparoscopic, robotic assisted myomectomies. J Minim Invasive Gynecol 19(1):52–57
62. Hanstede MM, Wise LA, Strewart EA, Feldman S (2009) The relation of annual surgeon case volume to clinical outcomes and resource utilization in abdominal hysterectomy. J Repod Med 54(4):193–202
63. Wallenstein MR, Ananth CV, Kim JH, Burke WM, Hershman DL, Sharyn N, Neugut AI, Lu YS, Herzog TJ, Wright JD (2012) Effect of surgical volume on outcomes for laparoscopic hysterectomy for benign indications. Obstet Gynecol 119(4):709–716
64. Tunitsky E, Citil A, Ayaz R, Esin S, Knee A, Harmanli O (2010) Does surgical volume influence short-term outcomes of laparoscopic hysterectomy? Am J Obstet Gynecol 203(1):24.e1–24.e6
65. Lenihan JP Jr, Kovanda C, Seshadri-Kreaden U (2008) What is the learning curve for robotic assisted gynecologic surgery? J Minim Invasive Gynecol 15:589–594
66. Geller EJ, Lin FC, Matthews CA (2013) Analysis of robotic performance times to improve operative efficiency. J Minim Invasive Gyencol 20(1):43–48
67. Woelk JL, Casiano ER, Weaver AL, Gostout BS, Trabuco EC, Gebhart JB (2013) The learning curve of robotic hysterectomy. Obstet Gynecol 121:87–95
68. Hung AJ, Oh PJ, Ghodoussipour S, Lane C, Jarc A, Gill IS (2018) Expert versus super experts: differences in automated performance metrics and clinical outcomes for robot-assisted radical prostatectomy. BJU Int. https://doi.org/10.1111/bju.14599