Cost assessment of robotics in gynecologic surgery: A systematic review

Christos Iavazzo¹, Eleni K. Papadopoulou² and Ioannis D. Gkegkes³

¹Robotic Gynaecology and Gynaecological Oncology Department, Christie Hospital, Manchester, UK; and ²Department of Economics, Democritus University of Thrace, Komotini and ³First Department of Surgery, General Hospital of Attica ‘KAT’, Athens, Greece

Abstract

Aim: The application of robotics is an innovation in the field of gynecologic surgery. Our objective was to evaluate the currently available literature on the cost assessment of robotic surgery of various operations in the field of gynecologic surgery.

Material and Methods: PubMed and Scopus databases were systematically searched in order to retrieve the included studies in our review.

Results: We retrieved 23 studies on a variety of gynecologic operations. The mean cost for robotic, open and laparoscopic surgery ranged from 1731 to 48 769, 894 to 20 277 and 411 to 41 836 Euros, respectively. Operative charges, in hysterectomy, for robotic, open and laparoscopic technique ranged from 936 to 33 920, 684 to 25 616 and 858 to 25 578 Euros, respectively. In sacrocolpopexy, these costs ranged from 2067 to 7275, 2904 to 69 792 and 1482 to 2000 Euros, respectively. Non-operative charges ranged from 467 to 39 121 Euros. The mean total costs for myomectomy ranged from 27 342 to 42 497 and 13 709 to 20 277 Euros, respectively, for the robotic and open methods, while the mean total cost of the laparoscopic technique was 26 181 Euros. Conversions to laparotomy were present in 79/36 185 (0.2%) cases of laparoscopic surgery and in 21/3345 (0.62%) cases of robotic technique. Duration of robotic, open and laparoscopic surgery ranged from 50 to 445, 83.7 to 701 and 74 to 330 min, respectively.

Conclusion: Robotic surgery has the potential to become cost-effective in centers with many patients while industry competition could reduce the cost of the robotic instrumentation, making robotic technology more affordable and cost-effective.

Key words: cost, gynecology, health-care economics, outcome, robotics, training.

Introduction

During the last decade, robotically assisted surgery has made great progress and has become popular in various surgical fields, such as urology, general surgery, head/neck surgery, thoracic surgery and gynecology. Smaller incisions, shorter length of hospital stay, lower intraoperative blood loss and decreased postoperative pain are some of the major advantages of robotically assisted surgery over open surgical technique. In addition, robotic surgery may improve the surgical time compared with laparoscopy as it allows a 3-D view of the operating field, eliminating surgeon tremor, permitting more precise movements while the use of wristed instruments improves dexterity and facilitates easier suturing into the abdominal cavity. On the other hand, the lack of tactile feedback and the difficulty in operating in anatomically limited places,
such as the lower abdomen, due to instrument crowding, are some of the drawbacks of robotic surgery. Nevertheless, the elevated cost of acquisition as well as of maintenance of the robotic system (necessitating an annual service contract, 10% of the initial cost) represents the most important factor that causes drawbacks in the dissemination of robotically assisted surgery.3

The current cost of the da Vinci robotic equipment is relatively high and includes the acquisition, training and equipment-instrument cost. The initial capital for the acquisition of robotic devices can be amortized over a period of more than 7 years, which would amount to more than 1000 Euros per patient, if it is used for 300 or more procedures per year.2 If it were used for fewer patients, this would result in higher per-case charges. The robotic instruments have a limited number of uses (10 uses per instrument), and the charges per instrument are more than 1500 Euros.4 Nevertheless, the reimbursement to the hospital for utilization of the robot depends on the type of health insurance and on the health system.

The aim of the present study was to evaluate the currently available literature on the cost assessment of robotic gynecologic surgery.

Methods

Data sources

A systematic search was performed in PubMed (2 September 2013) and Scopus (2 September 2013) and the search strategy used included a combination of the keywords: robotic AND (gynecology OR endometrial OR cervical OR ovarian OR tubal OR sacrocolpopexy OR vaginal OR endometriosis OR fibroids OR myomectomy OR hysterectomy) AND (cost OR cost analysis). The references of the included articles were also hand searched.

Study selection criteria

The included studies reporting data on the cost assessment of robotic technology in gynecologic surgery were considered as admissible for this review. Abstracts, reviews, letters to the editor, short surveys, commentaries, editorials as well as studies published in languages other than English, German, French, Italian, Spanish, and Greek were not included in this review.

Definitions

Operative charges are defined as all the medical costs related with the operation itself (e.g. operating room, anesthesia, surgical supply). Non-operative charges are defined as all the costs not related with the operation itself but with the preoperative preparation and postoperative convalescence (e.g. postoperative medication, hospital stay, laboratory, radiology). Maintenance costs are included in the robot costs. Total costs are the sum of operative and non-operative charges. All costs are referred to hospital charges and estimated in Euros.

Results

In total, 141 and 108 studies were retrieved, respectively, from PubMed and Scopus among which 23 studies met the inclusion criteria of our systematic review.5–27 Only one additional study was included through hand-searching of references.28 The utilized search strategy is represented in Figure 1 (flow diagram).

The main characteristics of the included studies in our review (demographics, type of operation, number of patients, total costs, operative charges, non-operative charges, robot charges included in the total costs, professionals’ costs, surgical equipment costs, operating room costs, length of hospital stay, number of conversions to laparotomy, duration of the operation, blood loss) are presented in Tables 1 and 2.

Among the 24 studies, 15 referred to hysterectomy, three to myomectomy, four to sacrocolpopexy and two to tubal anastomosis. Two studies had four arms comparing robotic to open to laparoscopic to vaginal procedures; five studies had three arms comparing robotic to open to laparoscopic procedures; while 17 studies compared robotic with either an open or laparoscopic technique. Of the 23 studies listed, 14 had no surgical equipment or operating room costs. Of these 14, a further 11 had no operative charges or non-operative charges but only total costs. Among the 15 studies referring to the costs of hysterectomy, only three of them neglected to clarify whether the operation was combined with lymphadenectomy. A total of 4150 patients underwent the open method, 36 185 underwent the laparoscopic method and 3345 underwent the robotic method. The mean cost for robotic, open and laparoscopic methods ranged from 1731 to 48 769, 894 to 20 277 and 411 to 41 836 Euros, respectively. Operative charges ranged from 684 to 69 792 Euros. In hysterectomy, costs for robotic, open and laparoscopic procedures ranged from 936 to 33 920, 684 to 25 616 and 858 to 25 578 Euros, respectively. In sacrocolpopexy, costs ranged from 2067 to 7275, 2904 to...
69,792 and 1482 to 2000 Euros, respectively. The operative costs of myomectomies were not mentioned in any of the included studies. Non-operative charges ranged from 467 to 39,121 Euros. In hysterectomy, costs for robotic, open and laparoscopic procedures ranged from 492 to 39,121, 2260 to 41,062 and 467 to 29,874 Euros, respectively. In the included studies, the non-operative charges for myomectomy were not mentioned. In sacrocolpopexy, costs ranged from 331 to 3546, 1617 to 19,190 and 251 to 431 Euros, respectively. The mean total costs for myomectomy ranged from 27,342 to 42,497 and 13,709 to 20,277 Euros, respectively, for the robotic and open methods while the mean total cost of the laparoscopic technique was 26,181 Euros. Regarding tubal anastomosis, operative and non-operative charges were not mentioned while the mean total costs of the robotic and open methods were 10,452 and 8911, respectively. In 15 studies, the robotic costs were included in the estimation of operative charges. The professional cost ranged from 499 to 5178 Euros. Surgical equipment costs ranged from 25 to 5178 Euros. Operating room costs ranged from 48 to 28,762 Euros. Mean hospital stay (in days) for robotic, open and laparoscopic procedures ranged from 0.7 to 6, from 1 to 8.1 and from 0 to 42, respectively. Specifically, in hysterectomy, hospital stay for robotic, open and laparoscopic procedures ranged from 1 to 5.5, 2.7 to 8.1 and 1 to 4.6 days, respectively. In myomectomy, hospital stay ranged from 0.7 to 1.48, 2.3 to 3.62 and 1 to 3 days, respectively. In sacrocolpopexy, hospital stay ranged from 0 to 3, 1 to 25 and 0 to 42, respectively. Conversions to laparotomy were present in 79/36,185 (0.2%) cases of the laparoscopic procedure and in 21/3345 (0.62%) cases of the robotic technique. Duration of robotic, open and laparoscopic surgery ranged from 50 to 445, 83.7 to 701 and from 74 to 330 min, respectively. Blood loss in robotic, open and laparoscopic surgeries ranged from 20 to 2900, from 25 to 1300 and from 25 to 750 mL, respectively.

**Discussion**

In eras of economic recession, the strength of healthcare systems is tested. With the intention to maintain the basic structure and function of a healthcare system, the costs usually undergo substantial cuts. The adjustment of a healthcare system to new financial conditions necessitates also a cost-analysis of the various techniques and procedures, especially in surgical fields. Although cost studies are difficult to accomplish, it is imperative that physicians and society as a whole understand the impact of the cost of robotics. The comparison of innovative minimally invasive methods and standard surgical techniques therefore is essential. Furthermore, the operative costs among the different surgical approaches are influenced by the necessity of specialized equipment. In particular, robotically assisted surgery uses equipment of elevated cost due to the innovation of the technique and the high specialization of the equipment, which does not have a
### Table 1: Robotic surgery in gynecology: costs related to equipment and peri-operative outcomes, regarding hysterectomy†

<table>
<thead>
<tr>
<th>First author, year [ref]</th>
<th>Type of operation</th>
<th>Number of patients (%)</th>
<th>Total costs</th>
<th>Operative charges</th>
<th>Non-operative charges</th>
<th>Robot cost included (Y/N)</th>
<th>Professionals’ costs</th>
</tr>
</thead>
</table>
| Hysterec-  

omy  

Desile-  

tto,  

Gbaguidi,  

2013†† | LA  

Endometrium cancer group: 15/57 (26)  

Cervix cancer group: 12/57 (21) | Mean (±SD): 6666 (966)  

Mean (±SD): 783 (210) | Mean (±SD): 273 (73)  

Mean (±SD): 329 (54) | Mean (±SD): 403 (58)  

Mean (±SD): 345 (89) | Y | NR |
| RO  

Endometrium cancer group: 30/57 (53)  

Cervix cancer group: 10/57 (18) | Mean (±SD): 1086 (935), P < 0.001  

Mean (±SD): 1221 (252), P < 0.001 | Mean (±SD): 740 (173), P < 0.001  

Mean (±SD): 114 (5) (263) | Mean (±SD): 4384 (292.9) | Y | NR |
| Reynisson,  

2013†† | OP  

Mean: 9834 | NR | NR | Y | NR |
| RO  

Mean range: 642–1493 | Mean: 7803 (210) | Mean (±SD): 850 (141), P < 0.001 | Mean (±SD): 3362 (2287), P = 0.07 | Y | NR |
| Corcosno,  

2013 | OP  

Mean: 64607 (963) | Mean (±SD): 4943 (4478) | Mean (±SD): 2343 (341) | Mean (±SD): 3018.4 (504.5) | Y | NR |
| RO  

Mean: 5043 (2701) | Mean (±SD): 844 | NR | NR | NR | NR |
| Deniss,  

2012†† | OP  

Mean: 9556 | NR | NR | NR | NR |
| LA  

| RO  

In 2008: 13  

In 2009: 24  

In 2009: range: 783 | NR | NR | NR | NR |
| Lau  

2012†† | OP  

Mean: 7553 | NR | NR | Mean (±SD): 4036 (4284–5367) | Y | Mean (±SD): 504 (499–51)

| RO  

Mean: 5986, P < 0.001 | Mean (±SD): 7803 (966) | Mean: 9834 | Mean (±SD): 7803 (966) | Mean (±SD): 5986, P < 0.001 | Y | NR |
| Scribner,  

2012†† | LA  

Mean: 46763 | NR | NR | Mean (±SD): 4801 | NR |
| RO  

Mean: 64762 | Mean: 9556 | Mean: 844 | Mean: 6934 | Y | NR |
| Venkat,  

2012†† | LA  

Mean: 41830 | NR | NR | Mean (±SD): 25578 | NR |
| RO  

Mean: 47878, P < 0.01 | Mean: 9556 | Mean: 41830 | Mean: 25578 | NR | NR |
| Wright,  

2012†† | OP  

Mean: 7298 | NR | NR | Mean (±SD): 25578 | NR |
| RO  

Mean: 47878, P < 0.01 | Mean: 9556 | Mean: 25578 | Mean: 25578 | NR | NR |
| Jonasserdin,  

2011†† | OP††  

Mean (range): 4704 (12139–25812) | Mean (range): 25578 | Mean (±SD): 1666 (465) | Mean (±SD): 1666 (465) | Y | Mean (±SD): 3783 (1486) |
| LA††  

Mean (range): 846 (47) | Mean (range): 25578 | Mean (±SD): 1666 (465) | Mean (±SD): 1666 (465) | Y | NR |
| ROM††  

Mean (range): 110 (5) | Mean (range): 25578 | Mean (±SD): 1666 (465) | Mean (±SD): 1666 (465) | Y | NR |
| VA  

Mean (range): 7722, P < 0.001 | Mean (range): 25578 | Mean (±SD): 1666 (465) | Mean (±SD): 1666 (465) | Y | NR |
| LA††  

Mean (range): 846 (47) | Mean (range): 25578 | Mean (±SD): 1666 (465) | Mean (±SD): 1666 (465) | Y | NR |
| VA††  

Mean (range): 7722, P < 0.001 | Mean (range): 25578 | Mean (±SD): 1666 (465) | Mean (±SD): 1666 (465) | Y | NR |
| Landeen,  

2011†† | OP††  

Mean (±SD): 3194 (947) | Mean (±SD): 7803 (966) | Mean (±SD): 7803 (966) | Mean (±SD): 2658 (1814–3503) | Y | NR |
| RO††  

Mean (±SD): 6934 | Mean (±SD): 7803 (966) | Mean (±SD): 7803 (966) | Mean (±SD): 2658 (1814–3503) | Y | NR |
| Shah,  

2011†† | OP  

Mean: 5986 | NR | NR | Mean: 4801 | NR |
| LA  

Mean: 25578 | Mean: 5986 | Mean: 5986 | Mean: 5986 | NR | NR |
| ROM††  

Mean: 3392, P < 0.01 | Mean: 5986 | Mean: 5986 | Mean: 5986 | NR | NR |
| Holte,  

2010† | LA  

Median: 2740 | Median: 1595 | Median: 2598 | Median: 2598 | NR | NR |
| RO  

Median: 390 (43) | Median: 2598 | Median: 2598 | Median: 2598 | NR | NR |
| Pacic,  

2010† | LA††  

Mean (±SD): 25798 (36188) | Mean (±SD): 25798 (36188) | Mean (±SD): 25798 (36188) | Mean (±SD): 2010 (2512), P < 0.01 | Y | NR |
| Rom††  

Mean: 992 | Mean: 25798 (36188) | Mean (±SD): 25798 (36188) | Mean (±SD): 2010 (2512), P < 0.01 | Y | NR |
| Ball,  

2010† | LA  

| RO  

| LA  

Mean: 6238 | Mean: 484 (25) | Mean: 484 (25) | Mean: 484 (25) | NR | NR | Mean (range): 1770 (1134–2280), P > 0.05 |
<table>
<thead>
<tr>
<th>First author, year</th>
<th>Surgical equipment costs</th>
<th>Operating room costs</th>
<th>Length of hospital stay (days)</th>
<th>Conversion to laparotomy (%)</th>
<th>Duration of surgery (min)</th>
<th>Blood loss (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desille-Gbaguidi, 2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>148 (308)</td>
<td>Mean</td>
<td>148 (308)</td>
<td>Mean</td>
<td>5.27 (1.2)</td>
<td>Mean (SD): 259 (101)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>5.37 (1.2)</td>
<td>Mean (SD): 477 (477)</td>
</tr>
<tr>
<td>Mean</td>
<td>423 (312)</td>
<td>Mean</td>
<td>423 (312)</td>
<td>Mean</td>
<td>461 (1.35)</td>
<td>Mean (SD): 269 (74)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>3.09 (0.3)</td>
<td>Mean (SD): 391 (94)</td>
</tr>
<tr>
<td>Mean</td>
<td>288 (79)</td>
<td>Mean</td>
<td>288 (79)</td>
<td>Mean</td>
<td>4.70 (1.33)</td>
<td>Mean (SD): 291 (94)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>—</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>7.84 (8.3)</td>
<td>Mean (SD): 218.2 (54.3)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>3.71 (4.2)</td>
<td>Mean (SD): 189.2 (35.4)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>0.08</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
<tr>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>213.5 (90.5)</td>
<td>Mean</td>
<td>&lt; 0.01</td>
<td>Mean (SD): 213.5 (90.5)</td>
</tr>
</tbody>
</table>

†All costs are estimated in Euros. ‡Adjusted for the following: type of hysterectomy, robotic vs non-robotic; age; race; insurance type; marital status; year; indication for surgery; complex surgery; comorbidity condition; census region; surgical specialty; location; hospital type, bed count. §Mean = (range). ††Expressed in hours. Hysterectomy was defined as: combination of hysterectomy, robotic vs non-robotic; age; race; insurance type; marital status; year; indication for surgery; complex surgery; comorbidity condition; census region; surgical specialty; location; hospital type, bed count; all patients. Refined - Diagnosis Related Group severity index. VARI Expressed in hours. In this study, it was not clearly stated if hysterectomy was compared with common hysterectomy. CI, confidence interval; IQR, interquartile range; LA, laparoscopic; N, No; NR, not referred; OP, open; RO, robotic; SD, standard deviation; VA, vaginal; Y, Yes.
Table 2. Robotic surgery in gynecology: costs related to equipment and peri-operative outcomes, regarding myomectomy, sacrocolpopexy and tubal anastomosis.

<table>
<thead>
<tr>
<th>First author, year [ref]</th>
<th>Type of operation</th>
<th>Number of patients (%)</th>
<th>Total costs</th>
<th>Operative charges</th>
<th>Non-operative charges</th>
<th>Robot cost included (Y/N)</th>
<th>Professionals’ costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Myomectomy</strong>*&lt;sup&gt;‡&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nash, 2012&lt;sup&gt;17&lt;/sup&gt;</td>
<td>OP 106/133 (79.7)</td>
<td>Mean (±SD): 20 277 (5941)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td>RO 27/133 (20.3)</td>
<td>Mean (±SD): 36 029 (8258)</td>
<td>P &lt; 0.0001</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Nezhat, 2009&lt;sup&gt;18&lt;/sup&gt;</td>
<td>LA 35/50 (70)</td>
<td>Mean: 26 181</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>Y</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td>RO 15/50 (30)</td>
<td>Mean: 42 497</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>Y</td>
<td>NR</td>
</tr>
<tr>
<td>Advincula, 2007&lt;sup&gt;19&lt;/sup&gt;</td>
<td>OP 29/58 (50)</td>
<td>Mean (±SD): 13 709 (6075)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>Y</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td>RO 29/58 (50)</td>
<td>Mean (±SD): 27 342 (5270)</td>
<td>P &lt; 0.0001</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td><strong>Sacrocolpopexy</strong>*&lt;sup&gt;‡&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elliott, 2012&lt;sup&gt;20&lt;/sup&gt;</td>
<td>OP 19/39 (52.2)</td>
<td>Mean: 8960</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td>RO 40/39 (67.6)</td>
<td>Mean: 7723</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Hoyte, 2012&lt;sup&gt;21&lt;/sup&gt;</td>
<td>OP 91/164 (55.9)</td>
<td>Median (range): 5105 (5045-8894)</td>
<td>Median (range): 2570 (2044-1792)</td>
<td>Median (range): 2475 (1670-1910)</td>
<td>P &lt; 0.0001</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td>RO 73/164 (45.6)</td>
<td>Median (range): 5090 (2775-6798), P &lt; 0.0001</td>
<td>Median (range): 5038 (2349-7275), P &lt; 0.0001</td>
<td>Median (range): 2381 (653-3546), P &lt; 0.0001</td>
<td>NR</td>
<td>NR</td>
<td></td>
</tr>
<tr>
<td><strong>Tubal anastomosis</strong>*&lt;sup&gt;‡&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patel, 2008&lt;sup&gt;24&lt;/sup&gt;</td>
<td>LA 10/28 (35.7)</td>
<td>Mean: 891</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>Y</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td>RO 18/28 (63.1)</td>
<td>Mean: 10 452</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>Y</td>
<td>NR</td>
</tr>
<tr>
<td>Rodgers, 2007&lt;sup&gt;25&lt;/sup&gt;</td>
<td>OP 41/67 (61.2)</td>
<td>1446 greater for robotic; 95%CI (843-1375), P &lt; 0.0001</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td>RO 26/67 (38.8)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>First author, year [ref]</th>
<th>Surgical equipment costs</th>
<th>Operating room costs</th>
<th>Length of hospital stay (days)</th>
<th>Conversion to laparotomy (%)</th>
<th>Duration of surgery (min)</th>
<th>Blood loss (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Myomectomy</strong>*&lt;sup&gt;‡&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nash, 2012&lt;sup&gt;17&lt;/sup&gt;</td>
<td>Mean (±SD): 3.292 (3.427)</td>
<td>Mean (±SD): 8.066</td>
<td>NR</td>
<td>—</td>
<td>Mean (±SD): 114.54 (39.06)</td>
<td>Median: 150</td>
</tr>
<tr>
<td></td>
<td>Mean (±SD): 28.782 (7834)</td>
<td>Mean (±SD): 8.91</td>
<td>P &lt; 0.0001</td>
<td>NR</td>
<td>Mean (±SD): 226.41 (88.31)</td>
<td>Median: 150</td>
</tr>
<tr>
<td>Nezhat, 2009&lt;sup&gt;18&lt;/sup&gt;</td>
<td>Mean (range): 0.15 (0.23)</td>
<td>Mean (range): 0.35</td>
<td>NR</td>
<td>0.03</td>
<td>Mean (range): 203.95 (33.0)</td>
<td>Mean (range): 420 (100–750)</td>
</tr>
<tr>
<td></td>
<td>Mean (range): 1.4 (1.15)</td>
<td>Mean (range): 0.12</td>
<td>0.01</td>
<td>Mean (range): 234 (140–448)</td>
<td>Mean (range): 370 (150–500), P = 2</td>
<td>NR</td>
</tr>
<tr>
<td>Advincula, 2007&lt;sup&gt;19&lt;/sup&gt;</td>
<td>Mean (±SD): 3.62 (1.5)</td>
<td>Mean (±SD): 1.50</td>
<td>NR</td>
<td>0.003</td>
<td>Mean (±SD): 154.41 (43.34)</td>
<td>Mean (±SD): 364.66 (473.28)</td>
</tr>
<tr>
<td></td>
<td>Mean (±SD): 148 (9.9), P &lt; 0.0001</td>
<td>Mean (±SD): 228 (150–439)</td>
<td>P &lt; 0.0001</td>
<td>2/29869</td>
<td>Mean (±SD): 231.38 (38.30)</td>
<td>Mean (±SD): 195.69 (228.55)</td>
</tr>
<tr>
<td><strong>Sacrocolpopexy</strong>*&lt;sup&gt;‡&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elliott, 2012&lt;sup&gt;20&lt;/sup&gt;</td>
<td>Mean (range): 3.3 (1.1–11)</td>
<td>Mean (range): 1 (0.2–2), P &lt; 0.0001</td>
<td>NR</td>
<td>—</td>
<td>Mean (±SD): 221 (101–401)</td>
<td>Mean (±SD): 224 (75–400)</td>
</tr>
<tr>
<td></td>
<td>Mean (range): 22.5 (150–439), P &lt; 0.0001</td>
<td>Mean (range): 63 (25–250), P &lt; 0.0001</td>
<td>NR</td>
<td>—</td>
<td>Mean (±SD): 226 (150–439), P &lt; 0.0001</td>
<td>Mean (±SD): 224 (75–400)</td>
</tr>
<tr>
<td></td>
<td>Mean (range): 1410 (138–3014), P = 0.001</td>
<td>Mean (range): 1555 (909–2171), P &lt; 0.0001</td>
<td>Mean (range): 2 (1–5), P &lt; 0.0001</td>
<td>—</td>
<td>Mean (range): 212 (119–380), P = 0.001</td>
<td>Mean (range): 50 (25–250), P &lt; 0.0001</td>
</tr>
<tr>
<td>Parauso, 2012&lt;sup&gt;22&lt;/sup&gt;</td>
<td>Mean (±SD): 34 (11.3)</td>
<td>Mean (±SD): 43 (77)</td>
<td>Mean (±SD): 1 (0–42)</td>
<td>—</td>
<td>Mean (±SD): 365 (50), P &lt; 0.0001</td>
<td>Mean (±SD): 85 (46)</td>
</tr>
<tr>
<td></td>
<td>Mean (±SD): 1 (1–3), P = 0.48</td>
<td>Mean (±SD): 1 (1–3), P = 0.48</td>
<td>Mean (±SD): 206 (42), P &lt; 0.0001</td>
<td>—</td>
<td>Mean (±SD): 281 (58), P &lt; 0.0001</td>
<td>Mean (±SD): 86 (42), P = 0.85</td>
</tr>
<tr>
<td><strong>Tubal anastomosis</strong>*&lt;sup&gt;‡&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patel, 2008&lt;sup&gt;23&lt;/sup&gt;</td>
<td>Mean (±SD): 34.7%</td>
<td>Mean (±SD): 46</td>
<td>Mean (±SD): 500</td>
<td>—</td>
<td>Mean (±SD): 155.5 (120–385)</td>
<td>Mean (±SD): 201 (140–263)</td>
</tr>
<tr>
<td></td>
<td>Mean (±SD): 142 (85–3499)</td>
<td>Mean (±SD): 99 (72–1599), 0/60</td>
<td>Median (±SD): 181 (154–202), P &lt; 0.0001</td>
<td>—</td>
<td>Median (±SD): 229 (205–252), P &lt; 0.0001</td>
<td>Median (±SD): 19 (19–72), P &lt; 0.0001</td>
</tr>
<tr>
<td>Rodgers, 2007&lt;sup&gt;25&lt;/sup&gt;</td>
<td>Mean (±SD): 142 (85–3499)</td>
<td>Mean (±SD): 99 (72–1599), 0/60</td>
<td>Median (±SD): 181 (154–202), P &lt; 0.0001</td>
<td>—</td>
<td>Median (±SD): 229 (205–252), P &lt; 0.0001</td>
<td>Median (±SD): 19 (19–72), P &lt; 0.0001</td>
</tr>
</tbody>
</table>

*Displayed in cost units. ‡All costs are estimated in Euros. §Expressed in hours. †Expressed in minutes. CI, confidence interval; IQR, interquartile range; LA, laparoscopic; N, No; NR, not reviewed; OP, open; RO, robotic; SD, standard deviation; Y, Yes.
multimode utility; for example, the instruments of standard laparoscopy cannot be used in robotically assisted surgery.4 The acquisition cost of the only available system on the market is over 1 million Euros while the maintenance costs per year are almost 150 000 Euros. In order to amortize the costs of robotic equipment, the health-care structures can rely on an elevated number of cases undergoing surgery, as Van Dam et al. proved.3 Moreover, the lack of market competition is a major factor that keeps the costs of robot-related instrumentation high (Table 3). In the early 1980s, the first robot surgical systems were developed.29 The Zeus device (Computer Motion) – a competitor of the da Vinci surgical system (Intuitive Surgical) – was used in the first application of robots in gynecologic surgery.30 Computer Motion, which had been present in the robotic surgical systems market earlier than Intuitive Surgical, sued Intuitive Surgical for patent infringement. The dispute between the two companies resulted in the 2003 merger and the da Vinci system’s ultimate market domination.31

Variation in operating time is also an important factor that may influence the total surgical costs. The need for reduced operating time becomes more obvious in private health structures. Operating time charges are generally calculated in intervals of 15–30 min. During the robotic approach, the setup of the equipment is considerably longer compared to the laparoscopic or open surgery procedure but of course this can be improved when a well-trained surgical team is implicated in the setup.32 Moreover, the operative time depends on the experience of both the operator and the surgical team. The learning curve may present great variation being subject to the surgeon’s capability.1 Also, the costs related to the learning curve are considered as elevated or more often as an additional cost due to the fact that surgeons have already gone through a training program for open and laparoscopic operations.33 It should also be mentioned that in order to reduce the costs related to the learning curve, a high caseload and virtual reality simulators are necessary.33,34

Minimally invasive surgery has been shown to have benefits over laparotomy for the treatment of patients with a variety of gynecologic pathologies.35,36 A smaller incision diminishes postoperative pain, shortens recovery time, reduces hemorrhaging, generates a better cosmetic result and poses fewer complications. These are some of the principal advantages of minimally invasive surgery over the open surgical method. Especially, robotic procedures can minimize the cost of operating on elderly or morbidly obese patients with comorbidities, as they minimize the hospital stay in these patients. On the contrary, lack of depth perception, absence of direct tactile sensation by the surgeon and limited range of motion at the surgical site are some of the major limitations of minimally invasive surgery.37 In the field of gynecologic surgery, as far as the overall costs of the open and laparoscopic approaches, there is no statistically significant difference.38

The duration of hospital stay also has a substantial impact on the overall charge of hospitalization. Minimally invasive surgical techniques (both robotic and laparoscopic approaches) generally require a shorter hospital stay than the open methods.3 For this reason, the obtained cost savings due to the decreased number of hospital days can compensate the increased operative expenses of the minimally invasive techniques. For example, patients treated robotically or laparoscopically have a mean hospitalization of 1–2 days while those treated with open surgery often stay for more than 4 days.1,18 In the study by Tan-Kim et al., even though the maximum hospital stay was 42 days, the median duration was 1 day.23 Moreover, the costs of hospitalization are also in correlation with the type of health-care structure, the health system and the type of health insurance.3,38 Cost data in this field are difficult to analyze as they differ between countries as well as the private and public sectors. Different opinions are raised regarding the comparison of robotic procedures to laparoscopy, there are studies that claim that the reduced hospital stay after robotic surgery in comparison with laparoscopy may present a financial advantage over the standard laparoscopic procedures.39 Other studies showed closely similar advantages between these two minimally invasive techniques.40 At the moment, it seems that laparoscopy is a more economic minimally invasive method compared to robotic procedures. One of the main future goals is to clarify

Table 3 Factors that could increase the cost of robotically assisted surgery

- Manufacturer’s monopoly
- High cost of robotic-related equipment
- Robotic instruments have a limited number of uses
- The charges for robotic surgery are not always reimbursable
- If the robot is not used for multipurpose utilities
- Longer setup of the robotic equipment in comparison with open or laparoscopic approach
- Lack of specialized robotically assisted surgical units
how robotic procedures could become a superior method compared to laparoscopy regarding cost.

As shown in our data analysis presented in Table 1 – the majority of which referred to hysterectomy – the robotic procedure is more expensive than laparoscopy, which in turn is more expensive than open surgery. Although, the cost of buying the robot, professional cost, surgical equipment cost and operating room cost varies in the different studies, we believe that it could be minimized if we also analyze the minimal hospital stay, the quicker return to normal activities of the patient as well as his/her family members, the minimal conversion rates to laparotomy and the minimal blood loss. Moreover, the improvement in training of all the personnel will minimize the surgical time and so the cost analysis is definitely in favor of minimally invasive techniques.

In future, robotics could be established as a common tool in everyday surgery. In order to achieve this, operative costs and unnecessary charges should be reduced. It is fundamental to create specialized robotic units operating on a large number of patients per year to minimize the number of instruments used per operation (with a maximum of four instead of five), to decrease the operating time per procedure (by improving the training of dedicated robotic surgeons) and to opt for the early discharge of patients when possible. Furthermore, the creation of competition in the market is essential in order to reduce the price of the robotic system and equipment, which would make robotically assisted surgery more accessible. Another suggestion to reduce the cost is the multi-use of the robot by multi-specialties, good research of the market area covered, good training of all the team implicated, and – although it is difficult in periods of economic recession – the system could be bought by charities or research funding.

Several limitations and weaknesses should be taken into consideration in the interpretation of the results of this study. First of all, the limited number of the included studies and of the number of the total patients included in these studies indicates the novelty of the method. Factors such as the study design, the robotic use, the surgical volume, the surgeon’s experience and the diverse suppliers among different institutions and different countries, render the comparison between robotic and the other techniques difficult. The multiple variables that factor into the ‘cost’ calculation are based on different countries, private versus public sector, and practice patterns related to hospital length of stay. As surgeons have just started to report their experiences as proficient robotic surgeons compared to all of the ‘initial experience with robot’ papers, the operative times numbers are going to be dramatically different and of course that is going to affect the cost. Based on insurance reimbursement, costs cannot be correlated to charges. Certainly, it would be more effective if ultimate costs were analyzed; however, it is extremely difficult to analyze direct and indirect costs. For this reason, one could argue that a cost-effectiveness model, including a specific cut-off point at which volume justifies investment and docking speed leads to equivalent costs with laparoscopy, could offer more information in the hospital systems across the world.

From our literature search, robotic procedures cost more than laparoscopic and open procedures; however, it seems that when the initial cost for robotic acquisition is ignored, then robotic procedures are the most cost-effective approach. It has already been shown that the cost-effectiveness could be explained by three different models: the societal perspective model, the hospital perspective plus robot costs and the model with exclusion of robotic acquisition cost. In general, we conclude that the cost of robotic procedures could be lowered by counting the lost wages and the caregiver costs, as well as by decreasing the cost of disposable equipment, operating room supplies, docking time, theatre time and recovery time. However, due to the heterogeneity of the studies and the lack of all the above information in several studies, safe conclusions could not be reported in our opinion by cost-effectiveness models that include studies from the initial phase of robotic use in gynecology, as well as newer studies, including operations performed by most well-trained surgical teams. Furthermore, there are not yet studies that present long-term outcomes in order to have a real cost-effective analysis, including quality-adjusted life-years gained. In addition, in the retrieved studies, there is no clarification between the clinical outcomes among experienced surgeons and trainees. Costs of readmission are difficult to assess and insert into our analysis. Last but not least, the cost is different in diverse types of operations as well as the cost of surgical time, while in order to maintain uniformity in the charges due to different currencies, all costs were converted into Euros. As far as our search strategy, which was previously defined, it could be considered limited due to the exclusion of abstracts, reviews, short surveys, commentaries and editorials.
Conclusion
The application of robotics in the field of gynecologic surgery is an innovation that has had an important impact on the surgical treatment of several pathologies. Nonetheless, of the elevated costs of the acquisition and maintenance of robotic equipment, robotically assisted surgery has the potential to become cost-effective in centers with many patients. In order to maximize the utilization of this surgical modality, it should be applied not only on clinical cases but also for resident surgical training. Technological advancement and, above all, industry competition could reduce the cost of the robotic instrumentation, making the robotic technology more affordable and cost-effective.

Disclosure
The authors declare that there are no conflicts of interest.

References


