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REVIEW

Economic evaluation of da Vinci-assisted robotic surgery: a systematic review

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Abstract

Background Health technology assessment (HTA) is frequently used when a new and expensive technology is being introduced into clinical practice. This certainly is the case with the da Vinci surgical robot, with costs ranging from $1 to $2.5 million for each unit. This systematic review documents major variability in the reported cost evaluation studies of da Vinci robot-assisted operations compared with those performed by the direct manual laparoscopic approach.

Methods Published studies in the English language related to the period 2000–2010 were searched using economic and clinical electronic databases.

Results All 11 reports included some form of cost analysis, which made it possible for the authors to extract information on certain specific economic outcomes: operating room time, hospital stay, and total costs. With the exception of two studies, the reported operating room time was higher with the robotic approach than with manual laparoscopic surgery, and the hospital stay was the same for the two techniques. Robotic surgery is significantly more expensive if the purchase and maintenance costs of the robot system are included in the total costs. Only 3 of the 11 publications included these costs.

Conclusions The disadvantage of robotic surgery is its higher costs related to purchase and maintenance of technology and its longer operating room time. However, emerging evidence shows that operating room time decreases with experience using the robot. From the HTA viewpoint, the result of this review is that the jury still is out on the HTA of da Vinci-assisted robotic surgery.

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Health technology assessment (HTA) is used to enable health care decisions through a multidisciplinary evaluation of the clinical, economic, organizational, ethical, and legal implications relative to the use and adoption of health care technologies [1–4]. The advantages and disadvantages of each technology are evaluated by HTA in terms of costs and benefits, with choice of available alternatives taken into consideration as well as economic evaluation of alternatives and their reported results.

The techniques of full economic evaluation are cost minimization analysis (CMA), cost-effectiveness analysis (CEA), cost-benefit analysis (CBA), and cost-utility analysis (CUA) [5]. The CMA technique compares costs among two or more alternatives with the same clinical effectiveness. With CEA, the costs of a health intervention are measured in monetary terms, whereas their effects are measured in "natural units" (e.g., number of lives saved, number of cases prevented or treated successfully). The CBA component allows evaluation of individual interventions and a comparative analysis of therapeutic interventions that have different objectives; the costs and consequences are valued in monetary terms. The CUA technique evaluates the costs of treatment in monetary terms, whereas the consequences of this treatment are expressed in nonmonetary units, representing the degree of utility associated with a different health status. The unit of measurement typically used to assess impact is years of survival, with the quality of life in terms of quality-adjusted life years (QALY) taken into account.

Frequently, HTA is used when a new and expensive technology is being introduced into clinical practice. This certainly is the case with the da Vinci surgical robot, which costs $1 to $2.5 million for each unit.

The robot was introduced into the United States in 1995, but its first clinical use dates back to 1997, and the first version became generally available for purchase in 1998. Currently, the United States has 1,400 installed robotic systems, and other countries have nearly 400. Since 2007 the number of operations performed worldwide with robotic assistance has tripled, increasing from 80,000 surgical procedures to 205,000 cases [6].

The main clinical specialties that have adopted use of the da Vinci robot are general surgery, thoracic and cardiac surgery, urology, gynecologic surgery, vascular surgery and otorhinolaryngology. The technical refinements by the company concerned (Intuitive Surgical) leading to the present four-arm, twin-console version has contributed to the steadily increased uptake of robotic surgery in recent years, although its use still is far from widespread. Thus, although the world market for use of the robot in 2000 was less than $5 billion, it was estimated to reach $25 billion by the end of 2010. An important downside of robotic surgery is its high costs compared with traditional surgery. However, the cost evaluation must not overlook the benefits that robotic surgery provides for both patients and the health care system.

This systematic review of the reported economic evaluation studies on the da Vinci approach aims to establish the relative costs between robotic and direct manual laparoscopic operations. The review, based on publications in the last decade, was designed in accordance with the recommendations of the Centre for Reviews and Dissemination [7] and the Cochrane Collaboration [8] and thus used an established rigorous and reproducible methodology. A protocol was developed to define the review question (i.e., the cost of da Vinci surgery versus direct manual laparoscopic surgery), the inclusion and exclusion criteria, data extraction, and the quality assessment of the selected studies. The quality of the publications was evaluated using the Evers checklist [9] (Table 1).

Methods

Published studies in the English language were searched using the following electronic databases: PubMed; MEDLINE; the Cochrane Controlled Trials Register and Cochrane Systematic Reviews Database and Centre for Reviews and Dissemination (CRD), which includes the Database of Abstracts of Review of Effects (DARE); the NHS Economic Evaluation Database (NHS EED); and the HTA database. The search was performed for the period 2000–2010 using the search strategy outlined in Table 2.

The data from the selected publications were imported in RefWorks version 6.0, software for data management. The publications were assessed for inclusion by a three-step process:

1. Titles and abstracts of all identified studies were assessed by one reviewer and checked by a second reviewer.
2. Full texts of relevant articles then were obtained and inclusion criteria applied independently by two reviewers. Possible discords between reviewers were resolved by consensus.
3. Data were extracted by one reviewer and then checked by a second reviewer.

Inclusion criteria

In the study protocol, the reviewers selected publications from the mentioned databases as follows:

Studies All reports on economic evaluation: cost analysis, CMA, CEA, CUA, and CBA.
Patients Operations on adult patients only (age > 18 years).
Operations All interventions performed with the da Vinci robot compared with the direct manual laparoscopic approach.
Outcomes Cost of intervention, QALY, incremental cost-effectiveness ratio (ICER), hospital stay, operating time.

Exclusion criteria

The exclusion criteria ruled out studies not published in the English language and all publications before 1999. Conference proceedings, case reports, reviews, letters, and commentaries also were excluded.

Results

As of May 2010, 100 articles had been extracted by the search procedure. Exclusion of duplicates left 80 articles. This was further reduced to 65 articles. Scrutiny of the title resulted in further reduction to 35 publications. These were retrieved and assessed for eligibility. After reading of the full-text copies, only 11 publications were considered relevant to the review.

Two reviewers read and examined the full text of the 11 publications. None of the publications provided full economic evaluation (CMA, CEA, CUA, and CBA). Indeed, all simply reported on cost analysis.

Table 1 Quality assessment of economic evaluations

Evers checklist	Lotan [10]	Morino [11]	Heemskerk [12]	Morino [13]	El Nakadi [14]	Rawlings [15]	Heemskerk [16]	Breitenstein [17]	Park [18]	Sarlos [19]	Bolenz [20]
Is the study population clearly described?[a]	Theoretical Study	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
2. Are competing alternatives clearly described?	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
3.Is a well-defined research question posed in answerable form?	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
4. Is the economic study design appropriate to the stated objective?	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
5.Is the chosen time horizon appropriate to include relevant costs and consequences?	Not reported	✔	✔	✔	Not reported	✔	✔	✔	✔	✔	✔
6.Is the actual perspective chosen appropriate?	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified	✔
7.Are all important and relevant costs for each alternative identified?	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
8.Are all costs measured appropriately in physical units?	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
9. Are costs valued appropriately?	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
10. Are all important and relevant outcomes for each alternative identified?	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
11. Are all outcomes measured appropriately?	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
12. Are outcomes valued appropriately?	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
13. Is an incremental analysis of costs and outcomes of alternatives performed?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
14. Are all future costs and outcomes discounted appropriately?	×	×	×	×	✔	×	×	×	×	×	×
15. Are all important variables whose values are uncertain appropriately subjected to sensitivity analysis?	✔	×	×	×	×	×	×	×	×	×	×
16. Do the conclusions follow from the data reported?	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
17.Does the study discuss the generalizability of the results to other settings and patient/ client groups?	×	×	×	×	×	×	×	×	×	×	×
18.Does the article indicate that there is no potential conflict of interest of study researcher(s) and funder(s)?	×	×	×	×	×	×	×	×	×	✔	✔
19.Are ethical and distributional issues discussed appropriately?	×	✔	×	✔	✔	×	×	×	✔	✔	×

[a] Evers checklist assessment for the methodologic quality of the economic evaluation of the studies included in review. This checklist is specific for full economic evaluation studies but also can be used for the cost analysis studies. Some specific questions (e.g., question 13 on the incremental analysis, which refers specifically to cost-effectiveness analysis) are not strictly applicable to the cost analysis. Hence, for this item, we have responded N/A (not applicable). Because the economic studies on robotic surgery report only very preliminary results, they require further research before their findings are generalized to other settings/patient groups (question 17)

N/A not applicable; ✔ Yes; × No

Table 2 The search strategy

Databases	Keywords
PubMed MEDLINE	(open and robotic and laparoscopic surgery) AND (cost OR economic) AND (English[lang] AND ("2000/01/01 "[PDat]:"2010/05/12"[PDat]))
Cochrane controlled trials register and cochrane systematic reviews	MeSH descriptor Surgery, Computer-Assisted explode all trees with qualifier: "EC in Cochrane Central Register of Controlled Trials"
Centre for reviews and dissemination	Robotic surgery and cost

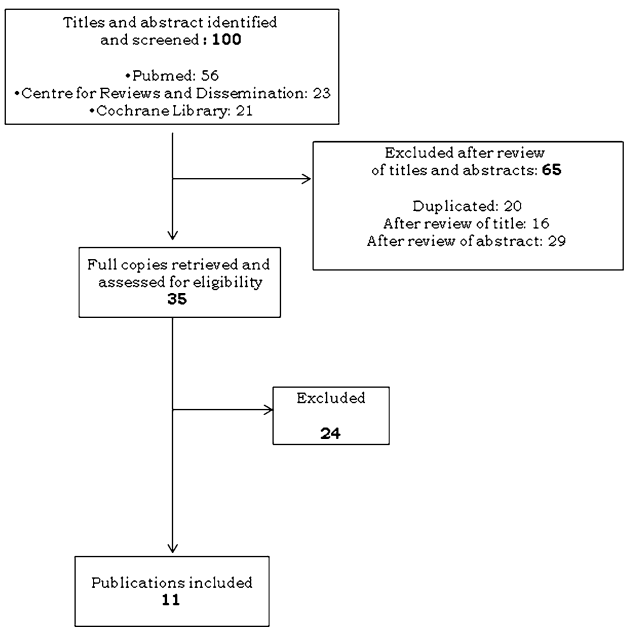

Fig. 1 Review steps

The review (Fig. 1) was based on four studies from the United States [10, 15, 18, 20] and seven studies from European countries: two Italian studies [11, 13], two Dutch studies [12, 16], two Swiss studies [17, 19], and one Belgian study [14]. These studies covered a range of operations, with two studies on prostatectomy [10, 20], two on Nissen fundoplication [13, 14], and two on cholecystectomy [12, 17]. Other publications concerned adrenalectomy [11], colectomy [15], rectopexy [16], pulmonary lobectomy [18], and hysterectomy [19]. The full details of the articles in tabular form used for the review can be obtained by request from the corresponding author.

Cost analysis of laparoscopic robotic surgery versus manual laparoscopic surgery

Lotan et al. [10] reported on a study comparing costs between laparoscopic prostatectomy and robot-assisted prostatectomy. The model used included cost of hospitalization and professional fees provided by the billing office. Costs related to laparoscopic instrumentation were based on equipment used at the county hospital and at the University of Texas Southwestern Medical Center, whereas the costs for the robot devices were based on equipment used at the Mayo Clinic.

The cost model covered two scenarios. In the first scenario, the robot costs included purchase and maintenance of the robot. In the second scenario, the authors assumed that the robot was donated and thus considered maintenance cost only. These authors performed one-way sensitivity analysis to estimate the effect that different numbers of cases per year had on costs. The overall costs in this study were $6,041 for direct manual laparoscopic surgery and $7,280 for robotic surgery if the purchase cost was included or $6,709 if the purchase cost was omitted. The costs related to the surgeon's professional fees were the same for both techniques.

With the robotic approach, the higher cost was due to equipment ($1,705). For the manual laparoscopic surgery, this cost was $533. The operating time was shorter with robotic prostatectomy: 140 min vs 200 min for the laparoscopic approach. There was no significant difference in the length of hospital stay between laparoscopic prostatectomy (1.3 days) and robot-assisted prostatectomy (1.2 days). In this study, the model assumed the cost of the da Vinci robot to be $1.2 million plus an annual maintenance fee of $100,000.

Morino et al. [11] reported the results of a small prospective randomized controlled trial (RCT) designed to compare direct manual laparoscopic and robot-assisted adrenalectomy. The outcomes of this small RCT were length of hospital stay and total operative time. The RCT findings showed that the total operative time was significantly longer in the robotic arm due to the lack of robotic instruments specifically designed for laparoscopic surgery and to longer robot setup time. The authors acknowledged that the robot setup time would decrease with increased experience. The difference in costs for adrenalectomy between the robotic ($3,466) and laparoscopic ($2,737) procedures did not include the initial purchase cost of the da Vinci system. The increased expense was mainly due to the use of semidisposable robotic instruments and the longer operative time. The authors argued that although no economic benefit could be demonstrated for the robot-assisted approach, the multidisciplinary use of the system (e.g., in urology and cardiac, general laparoscopic, and thoracic surgery) would result in a faster, more cost-effective realization of return on the initial investment.

Heemskerk et al. [12] compared robotic laparoscopic cholecystectomies (LC) ($n = 12$) with direct manual laparoscopic operations ($n = 12$) performed during the same period in the same hospital. These authors considered that robotic laparoscopic surgery with four robotic arms provided potential cost advantages over conventional LC despite the longer operating room time because the use of the fourth robotic arm allowed the performance of the operation with one less assistant, thereby decreasing salary costs. Consequently, the salary costs for the manual and robot-assisted LCs were equivalent (€273.74 vs €274.57) despite a significantly longer overall operating room time for the robotic group. The costs for the hospital stay and accessory tests were comparable between the two groups. The extra material costs of the da Vinci Surgical System instruments (€889.18) resulted in a significantly higher total cost (€3,329.07) than for direct manual LC (€2,148.45), with a difference of €1,180.62.

Morino et al. [13] reported on a trial of Nissen fundoplication. Patients with gastroesophageal reflux disease were randomized to either robot-assisted surgery or laparoscopic surgery (25 patients each). The authors evaluated the cost of the operating room, surgical tools, and hospital stay. The cost of the robot was not included. Operating time showed a significant difference: 131.3 min for the robot-assisted surgery versus 91.1 min for the manual laparoscopic intervention. The length of hospital stay was similar: 3.0 days for the robotic surgery versus 2.9 days for the direct manual laparoscopic approach. The total cost for the robotic surgery was €3,157 compared with €1,527 for the manual laparoscopic surgery. With the robotic approach, 46.1% of the total cost was due to the need for limited-use/disposable instruments. With laparoscopic surgery, most of the cost resulted from the hospital stay (57% of the total cost), whereas the cost for the disposable instruments was only 6.5% of the total cost. These authors attribute the longer operating time to the robot setup time and difficulties achieving good port positioning for the robot.

Nakadi et al. [14] carried out a small prospective randomized trial comparing da Vinci robotic surgery and direct manual laparoscopic Nissen fundoplication in a randomized cohort of 20 patients with gastroesophageal reflux disease. In this study, 11 patients were assigned to the manual laparoscopic group and 9 to the robotic intervention. These authors studied direct in-hospital medical costs only, which included hospital stay costs, surgery costs, and pharmacy costs. The material investments were discounted using the net present value method, which considers the marginal cost of capital to be 5% per year and the paying-off period to be 5 years. The total direct medical costs were €5,907 for the manual laparoscopic approach and €27,561 for the robotic approach, which included the initial investment (€15,175) and the cost of maintenance (€6,271). When the instrumentation costs were considered in relation to the real operating room occupation time, the cost for the manual laparoscopic surgery was €5,167 compared with €6,973 for the robotic surgery. In both groups, the length of stay was similar for the manual laparoscopic and robotic surgery (4.1 vs 4.4 days). The robotic surgery incurred a longer operating time (137 min) than the manual laparoscopic approach (96 min).

Rawlings et al. [15] compared costs between the da Vinci robotic system and manual laparoscopic surgery for colonic resections. The robotic and laparoscopic groups were similar in gender, age, body mass index (BMI), and indication for surgery. For the analysis, the cohort of patients was divided into right and sigmoid colectomies. The average total case time for right colectomy in the robotic group (218.9 min) was 49.7 min longer than in the laparoscopic group (169.2 min), and this difference was significant ($P = 0.002$). Two factors contributed to the longer average case time in the robotic group: the port setup time and the variation in anastomotic technique. The total operating room (OR) and OR room personnel cost, OR supply cost, and OR time cost were significantly higher for the robotic cases than for the laparoscopic cases. The OR personnel cost was higher for the robotic cases because two circulating nurses instead of one were assigned to the room. The total hospital cost for the robotic group was 14.6% higher than for the laparoscopic group, but this difference was not significant. Thus, although the longer case time with the robot has an impact on the operating room cost, the increase is not large enough to increase the overall hospital cost significantly. For sigmoid colectomy, the difference in total case time between the two groups was not significant. The difference in the total OR cost (higher in the robot group by 21.8%) also was not significant, although the OR time was longer for the robotic group. However, the OR personnel and the OR supply cost were significantly higher for the robotic group. The reasons for these higher costs for robotic sigmoid colectomy were the same as observed with robotic right colectomy. Both operations required more time with the robot, but the difference was statistically significant only for the right colectomy. Although, the total hospital costs were higher for both right and sigmoid colectomy in the robotic cases compared with manual laparoscopy, the difference was not significant.

In a prospective study, Heemskerk et al. [16] compared 14 cases of robot-assisted laparoscopic rectopexy with 19 cases managed by the direct manual laparoscopic approach. The primary end points of the study were procedure time, hospital stay, and costs. The study used costs for hospital admission and treatment, material costs during surgery, and salary costs. The secondary end points were morbidity and mortality. Robot-assisted laparoscopic rectopexy resulted in increased operating time (39 min) and higher costs than manual direct laparoscopic rectopexy (€3,672.84 vs. €3,115.55). The authors concluded that part of the increase in time was due to tasks involved in changing robotic instruments and to their limited experience with robotic surgery.

Breitenstein et al. [17] reported on a prospective case-matched controlled study designed to evaluate the potential benefits of robot-assisted cholecystectomy versus the laparoscopic approach. The study cohort consisted of 50 consecutive patients submitted for robot-assisted cholecystectomy, who were individually matched with 50 consecutive patients undergoing the same procedure laparoscopically. The cost analysis included costs generated in the operating room and in the ward. The operating room costs included surgery, anesthesia, consumables, and amortization. The cost for the robot was $1,275,000 plus an annual maintenance cost of $127,500. The amortization of the robot per case was $1,275 (amortization of 5 years and 300 cases for year). For the ward, lump sums were calculated for preoperative, operative, and postoperative days. Other costs included were those for preoperative radiographs and electrocardiograms. The total hospital costs were calculated prospectively based on actual cost. The total cost of robot-assisted operations was $7,985.40 compared with $6,255.30 for direct manual LC (cost difference, $1,730.10). The operating time (skin to skin) (54.6 min for robotic vs 50.2 min for laparoscopic LC) and hospital stay (4.58 days for robotic vs 4.84 days for laparoscopic LC) were similar in the two groups. The higher costs for the robotic approach resulted predominantly from consumables ($1,126.1) and amortization ($1,275.0).

Park and Flores [18] compared costs between robotic and video-assisted thoracic surgery (VATS). The study took into consideration real cost data, which included all indirect costs, direct costs, and surgeon's fees. The comparison between subsets of patients undergoing lobectomy by VATS and those undergoing robot-assisted VATS showed increased costs with the use of robotic technology, primarily during the first hospital day. The reason for the increased robotic costs were the additional disposable costs of the robotic instruments and drapes. However, this cost difference was influenced by the small number of robotic cases compared with the standard VATS cases. The operating room time was similar: 3.45 h for VATS and 3.37 h for robotic surgery.

Sarlos et al. [19] compared robot-assisted total hysterectomy with direct manual laparoscopic total hysterectomy using perioperative outcomes and costs as end points. The study was a prospective matched case-control investigation using data from 40 consecutive robot-assisted cases individually matched with retrospective data for laparoscopic cases according to age, BMI, and uterine weight. The study also reported on the surgeons' subjective impressions of robotic surgery obtained by a self-administered questionnaire. The study included data on costs generated in the operating room, namely, the personnel costs for the surgeons, the anesthetist, and the nurses calculated as costs per minute with different factors based on the salaries for each specialty. The costs for the purchase of all devices and sterilization only for reusable instruments also were included. The study showed that robot-assisted total hysterectomy was safe and that the learning curve was quite rapid if the surgeon was experienced in conventional laparoscopic surgery. The postoperative outcome was similar to that for direct manual laparoscopic hysterectomy, but the operating times were significantly longer in robotic group. The costs for robotic surgery (€4,066.84) were higher than for conventional laparoscopy (€2,150.76). Most of the extra cost was due to material costs.

Bolenz et al. [20] reported on a cost comparison between robotic and laparoscopic prostatectomy for prostate cancer. The study included 643 consecutive patients undergoing this procedure: 262 patients with the robot and 220 with manual laparoscopic surgery. The authors evaluated direct costs only and did not include the purchase and maintenance of the da Vinci system. The total direct costs were higher with the robotic approach ($6,752) than with laparoscopic surgery ($5,687). The two approaches differed in terms of operating room costs ($2,798 for robotic vs $2,453 for laparoscopic surgery) and surgical supply costs ($2,015 for robotic vs $725 for laparoscopic surgery). The hospital length of stay was similar for the two approaches (1.56 for robotic vs 1.76 for laparoscopic surgery). These authors concluded that had they included indirect costs, the robotic and laparoscopic surgeries would have emerged more effective from a societal perspective than from a hospital perspective.

To facilitate a comparison of the cost analysis of the studies included in the review, costs were converted to euros (estimate as of 20 April 2011). Costs in national currencies were inflated to 2011 values, and currencies different from the euro were converted to euros (Table 3). The Consumer Price Index (http://www.bls.gov/bls/inflation.htm) and the Gross Domestic Product Deflator Index for Euro area (http://www.imf.org) were used respectively for inflating U.S. dollars and euro to 2011 values. Currency conversions from U.S. dollars to euros ($1 = €0.70) were calculated as of 21 April 2011 (http://www.oanda.com/lang/it).

Discussion

It should be stressed that none of the publications included data on cost effectiveness, cost-benefit analysis, or cost-utility analysis, precluding the full economic evaluation required by HTA. Instead, these studies of variable design and nature reported a simple cost analysis, which varied in detail, rendering comparative analysis between robotic and manual laparoscopic surgical approaches difficult. This review had thus to extract information from prospective nonrandomized, retrospective case-matched controlled studies and small prospective randomized trials. However, some form of cost analysis was reported, and this made it possible for the authors to extract information on certain specific economic outcomes, but a full HTA currently is not possible.

The main economic outcomes reported by the studies included operating room time, hospital stay, and total costs. The main results of the comparison between different types of surgical intervention are shown in Table 3. Within the

Table 3 Cost analysis of surgery of the included studies

Author (year of publication)	Country	Type of surgical operation	Results (euro, 2011)
Lotan et al. (2004) [10]	USA	Prostatectomy	Overall costs Robotic: €5,675 (no purchase) Laparoscopic: €5,110
Morino et al. (2004) [11]	Italy	Adrenalectomy	Total costs Robotic: €3,417 Laparoscopic: €2,698
Heemskerk et al. (2006) [12]	The Netherlands	Cholecystectomy	Total costs Robotic: €3,837 Laparoscopic: €2,477
Morino et al. (2006) [13]	Italy	Nissen fundoplication	Total costs Robotic: €3,693 Laparoscopic: €1,760
El Nakadi et al. (2006) [14]	Belgium	Nissen fundoplication	Total costs Robotic: €30,002 Laparoscopic: €6,430
Rawlings et al. (2007) [15]	USA	Right and sigmoid colectomy	Right colectomy Total hospital costs Robotic: €7,211 Laparoscopic: €6,290 Sigmoid colectomy Total hospital costs Robotic: €9,627 Laparoscopic: €8,835
Heemskerk et al. (2007) [16]	The Netherlands	Rectopexy	Total costs Robotic: €3,818 Laparoscopic: €3,239
Breitenstein et al. (2008)[17]	Switzerland	Cholecystectomy	Total costs Robotic: €7,252 Laparoscopic: €5,680
Park & Flores (2008) [18]	USA	Pulmonary lobectomy	Total costs Robotic: €3,214 VATS: €298
Sarlos et al. (2010) [19]	Switzerland	Hysterectomy	Total costs surgery Robot: €4,227 Laparoscopic: €2,236
Bolenz et al. (2010) [20]	USA	Prostatectomy	Direct costs Robotic: €4,955 Laparoscopic: €4,174

VATS video-assisted thoracic surgery

clear limitations of the reported studies included in the review, it appears that the total cost for robotic surgery currently is higher than for the manual laparoscopic approach.

Operating room time appears to be longer with the robotic approach than with the manual laparoscopic approach, except in the reports by Lotan et al. [10] (respectively 140 vs. 200 min) and Park and Flores [18] (respectively 217 vs. 225 min). One report [20] did not specify operating room time but rather operating room costs. However, these authors reported higher operating room costs with robotic surgery.

Robotic surgery definitely is more expensive if the purchase and maintenance of the robot system are included in the total costs. The purchase and maintenance costs were included in only 3 of the 11 publications [10, 14, 17]. Lotan et al. [10] reported on two economic scenarios. The first scenario included the robot's purchase and maintenance costs, and the second scenario included maintenance only. Nakadi et al. [14] included in the total costs the investment and maintenance of the robot system. Breitenstein et al. [17] reported the amortization for the robotic system per case as $1,275 based on an amortization period of 5 years and 300 cases per year. The higher costs of robotic surgery are mainly due to the high purchase and maintenance costs for the robot and to a lesser extent to the longer operating room time. However, emerging evidence shows that operating room time decreases with experience in use of the robot.

To date, two aspects have been overlooked that have a bearing on the existing debate. The first aspect concerns the facilitation of complex and advanced operations by the Da Vinci robot. The second aspect is the changed role of the assisting surgeon during the performance of robot-assisted laparoscopic surgery. There is emerging evidence from established centers that robotic surgery facilitates the performance of certain advanced operations, especially those that involve procedures in confined places and those requiring complex intracorporeal hand suturing [21–28]. Additionally, it appears that the acquisition of laparoscopic operating skills may be enhanced in trainees by practice with the robot where this training facility is available [29]. If these reported benefits of robotic surgery, especially the facilitated execution of complex interventions with improved task quality and patient outcome, are confirmed by prospective studies, then the high initial investment in the robotic technology may be more than justified.

The second consideration that we have observed in the ongoing programmi di ricerca scientifica di rilevante interesse nazionale (PRIN) study of robotic surgery in Italy is the significantly changed role of the assisting surgeon during the performance of robot-assisted laparoscopic surgery. In manual laparoscopic surgery, the assistant either holds the camera or at best provides retraction for the operating surgeon, whereas during robotic surgery, the assistant is removed from the surgeon, stands in the sterile field, and performs certain key component steps of the operation while trying to negotiate between the robotic arms.

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