22 Cost and Outcomes in Robotic-Assisted Laparoscopic Surgery

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Abstract

The modern era of advanced laparoscopic surgery is the direct result of the disruptive work of Prof. Dr. Erich Mühe with laparoscopic cholecystectomy in 1985 (Reynolds Jr, JSLS 5(1):89–94, 2001). Since his original work in the field of minimally invasive surgery has incorporated diverse and aggressive refinements of instrumentation and techniques for many operative indications (Reynolds Jr, JSLS 5(1):89–94, 2001). These efforts at reducing surgical stress while improving cosmesis have included reductions in port size/number, altered extraction sites, attempts at hand assistance, and ultimately single port access (Bucher et al., Br J Surg 98(12):1695–1702, 2011). The ultimate goal of all these innovations is to provide our patients with high quality surgical care while maintaining high value.

Keywords

Cost • Robotic surgery • Laparoscopic surgery • Outcomes • Colorectal surgery

The modern era of advanced laparoscopic surgery is the direct result of the disruptive work of Prof. Dr. Erich Mühe with laparoscopic cholecystectomy in 1985 [1]. Since his original work in the field of minimally invasive surgery has incorporated diverse and aggressive refinements of instrumentation and techniques for many operative indications [1]. These efforts at reducing surgical stress while improving cosmesis have included reductions in port size/number, altered extraction sites, attempts at hand assistance, and ultimately single port access [2]. The ultimate goal of all these innovations is to provide our patients with high quality surgical care while maintaining high value.

Robotic-assisted laparoscopic surgery has been the most recent attempt to further refine minimally invasive procedures. The device features EndoWrist instruments, providing seven

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degrees of freedom for instrument movement and tremor filtering. It allows surgeons to be in a seated posture for long operation tolerance and permits three-dimensional imaging, real-time radiographic correlation, and easy suture maneuvering [3, 4]. Hyung suggested that the application of robotic technology for general surgery is technically feasible and safe, improves dexterity, allows for better visualization, and attains a high level of precision [5]. However, the widespread adoption is limited by the absence of tactile sensation and the extremely high cost for acquisition and utilization of the technology [5]. The recent appearance in the market of three-dimensional laparoscopic cameras at substantially lower costs further erodes the potential benefits of the robotic platform.

Robotic-assisted laparoscopic surgery has been adopted to perform many general surgical procedures including cholecystectomy, Nissen fundoplication, Heller myotomy, and Roux-en-Y gastric bypass. More recently, colorectal procedures [5, 6] are being incorporated into an ever-growing number of robotic-assisted indications. The da Vinci robot is postulated to provide improved visualization due to incorporation of the three-dimensional viewing system, mitigate surgeon tremor and improve ergonomics [7]. The available data from robotic-assisted laparoscopic procedures, confirms that the majority of patient outcome benefits associated with laparoscopic surgery are maintained, albeit consistently at higher costs.

Robotic-assisted procedures have been widely adopted in urology and increasingly in gynecologic surgery, due to the shorter learning curve for advanced suturing compared to conventional laparoscopy. This is especially true in confined spaces due to the added articulation and the three-dimensional visualization. One of the limitations of conventional laparoscopic surgery results from working with long instruments through a fixed entry point on the surface of the body while watching a screen. This leads to reduced tactile feedback, diminished fine motor control, tremor amplification, and difficult hand–eye coordination [8]. There have been only limited assessments of the recently available three-dimensional laparoscopes; however, the improved visualization contributes significantly to suturing skills compared to traditional two-dimensional optics.

Although both laparoscopic prostatectomy and hysterectomy were described in the 1990s, the percentage of prostatectomies and hysterectomies performed laparoscopically was insignificant until the advent of the surgical robotics. This delay in the adoption of minimally invasive techniques in these two very common pelvic surgeries is directly related to their degree of technical difficulty associated with conventional laparoscopy, especially with laparoscopic intracorporeal suturing. However, it is possible to master the requisite laparoscopic skills without robotic assistance. Therefore, it is imperative that rigorous assessment of cost efficiency and possible reduction in learning curve associated with robotic surgery is performed before widespread adoption of robotics is recommended.

There are significant financial obstacles to universal adoption of robotic-assisted laparoscopic surgery: high cost of the robotic platform, disposable instruments, and annual service contracts. The robotic systems are sold to hospitals for a cost of $1.0–$2.3 million, depending on the model. Mandatory annual service agreements range from $100,000 to $170,000 per year. There are also significant costs related to mandatory training at the manufacturer's facility ($3–4000) and the often required proctoring by an outside surgeon for 3–5 cases ($3000 per session). While the acquisition cost of the da Vinci robotic system is compelling ($1.2–2.4 million), the cost could be offset by the institution if other sources of cost savings can be achieved. However, robotic surgery requires significant costs for disposable or limited use instruments (e.g., shears, needle drivers, graspers, forceps) at a cost of approximately US$1–2000 per instrument every 10 surgeries [9]. These costs are generally higher when compared to the mostly reusable instruments in standard laparoscopic surgery. The available literature suggests that robotic surgery takes consistently longer than open or laparoscopic surgery, thus there is no cost savings in operating room or anesthesia time. This leaves the only potential for cost savings in a decreased length of hospital stay when compared to open. Other limitations to robotic-assisted laparoscopic surgery include the lack of tactile feedback [10], the large and cumbersome footprint of the robot, the fixed positioning of the operating table after the robot has been docked, the longer operative time compared to open surgery, and the limited outcomes data.

Several cost comparison studies have evaluated the relative cost drivers of robotic surgery versus open surgery. The largest cost comparison study was recently published in European Urology by Bolenz et al. [9]. The study compared operating costs (not including maintenance and equipment purchase) of robotic (RALP), laparoscopic (LRP), and open radical prostatectomy (ORP) for prostate cancer in a sample of 643 consecutive patients. Results showed that the cost of RALP was 50 % higher than the cost of ORP even before the cost of purchasing and maintaining the robot was factored in to the calculations. The median cost for the RALP was $6752, followed by LRP at $5687 and RRP at $4437 (all adjusted to 2007 US dollars). RALP had higher surgical supply costs and higher OR cost due to increased average length of procedure. The one cost benefit for RALP was the shorter average length of hospital stay (1 day) relative to LRP and ORP (2 days). However, the shorter RALP hospital stay relative to LRP and ORP did not make up for the RALP higher operating costs, even before considering the additional cost for the purchase and maintenance of the robot. It is also unclear if the all study groups followed the same postoperative plan because both RALP and LRP groups' patients should have had the same minimally invasive advantage. The additional cost for the purchase and maintenance of the robot ($340,000 per year when amortized over a presumed 7 years life of the robot) would add an additional $2698 per patient undergoing a RALP (assuming 126 cases per year) [9].

A similar cost comparison study was recently completed for robotic versus open radical cystectomy for bladder cancer at the University of North Carolina at Chapel Hill. In this study, the 20 most recent cases of robotic cystectomy were compared with the 20 most recent cases of open cystectomy. The total cost (including base OR costs, OR disposable equipment costs, amortized purchase cost of the robot distributed over 5 years, and yearly maintenance costs) of the robotic radical cystectomy was $1640 more than the open radical cystectomy ($16,248 versus $14,608). In the breakdown of the costs, the majority of the difference came from the higher mean fixed OR costs for robotic cases (OR disposable equipment costs, amortized purchase cost, and yearly maintenance cost distributed over 288 cases per year). The OR variable costs were also slightly higher for the robotic cystectomy due to the increased length of these cases.

Similar to the robotic prostatectomy cost data, there was some cost savings due to a shorter postoperative stay as well as a lower frequency of postoperative transfusion after open cystectomy. While these savings were not enough to overcome the increased OR costs of the robotic cystectomy, the cost differential of $1640 per surgery was much closer than the robotic prostatectomy cost study [11].

The field of robotic-assisted laparoscopic surgery is being actively assessed for a variety of applications as demonstrated by the rapid growth and dissemination of the applications for the approach. Yet with the rising cost of health care becoming a critical element in the assessment of value-based health care, one cannot dismiss the need for cost efficiency. At this point in time, the only argument in favor of robotic-assisted laparoscopy from the cost perspective is the reduction in length of stay compared to open surgery. This creates a very high bar when the technology must compete against established laparoscopic procedures performed by trained and highly skilled laparoscopic surgeons. This contention was eloquently presented in a recent review by Satava [12] where the entire cost benefit or adopting robotics was based upon the ability of an institution to create capacity for other sources of revenue generation by other surgical admissions. Under no scenario assessed, did the robotic platform create positive cash flow for the facility.

22.1 Cholecystectomy

Recently, Intuitive Surgical launched an elegant single-incision platform for cholecystectomy designed to resolve many of the technical limitations associated with the single port approach performed with two-dimensional conventional laparoscopy and the frequent need to cross hands. Although the technology is truly groundbreaking, the limited potential benefits associated with single port vs. multiport laparoscopic colectomy (quote the PRCT multicenter trial) coupled with the limited reimbursement for the procedure raises significant concerns regarding the sustainability of the procedure. Unfortunately, these kinds of economic assessments are unavailable at this time.

According to Lucas et al., single-incision surgery when compared to multi-port cholecystectomy was associated with better cosmesis. Patient preference based on cosmesis was more prominent for females, patients younger than 50 years old, and for benign surgical indications. It is interesting that the authors did not query whether patients were willing to pay the additional cost [13]. This concept warrants further assessment because a da Vinci cholecystectomy has higher variable costs compared to an outpatient laparoscopic cholecystectomy ($2383 vs. $1926 per case). As with the Satava analysis, it is unclear that a hospital may be able to offset the added variable cost per robotic single-site cholecystectomy procedure based solely on cost shifting to a more favorable payer mix.

22.2 Colorectal Surgery

There has been a steady increase in reports regarding the role of robotic-assisted laparoscopic colectomy since the initial report in 2001, albeit few data directly comparing conventional to robot-assisted colectomy. There is some data comparing the two techniques in proctectomy, including an ongoing randomized multicenter trial for rectal cancer [14, 15]. In general, the data have supported the feasibility of total mesorectal dissection and suggested a variety of robotic benefits related to the attributes of multiple degrees of freedom and improved three-dimensional imaging. Despite the limited clinical evidence supporting robotic-assisted colectomy, Tyler et al. found a trend toward increased use during the 15-month study period [16]. The authors found no difference in overall morbidity rates between robot-assisted colectomy and conventional laparoscopic colectomy. However, the robotic approach was associated with an increased rate of ostomy a bias in case selection with either greater use in distal resections or less comfort leaving unprotected anastomoses. The operative times were also significantly longer with the robotic approach and are consistent with several other reports. The other consistent theme in this report was an increase in cost, on average, of $3424 per colectomy over the laparoscopic approach. Similarly, a review by Fung et al. of 15 available high quality studies comparing conventional laparoscopic and robotic-assisted laparoscopic colorectal surgery confirmed a longer operative time and total cost [17].

Huettner et al. presented 70 consecutive robotic-assisted laparoscopic colectomies over 5 years. The component operative times for right colectomies were: port setup time 33.6 ± 12.1 (20–64) min, robotic time 147.2 ± 44.4 (53–306) min, and total case time 221.3 ± 43.7 min. The median LOS was 3 (2–27) days. Times for the sigmoid colectomies were: port setup time 30.0 ± 9.8 (10–57) min, robotic time 101.8 ± 25.3 (67–165) min, and total case time 228.4 ± 40.5 (147–323) min. The median LOS was 4 (2–27) days. This was accomplished with a conversion rate of 11 %. The authors concluded that the approach was feasible and appeared safe without providing comparative outcomes to standard laparoscopy [18].

Deutsch et al. provided one of the largest retrospective analyses of 171 patients who underwent robotic and laparoscopic colectomies (79 and 92, respectively). The results indicated no statistical difference in length of stay, time to return of bowel function, and time to discontinuation of patient-controlled analgesia between robotic and laparoscopic left and right colectomies. They did report some of the best data on operating time for laparoscopic versus robotic-assisted as the differences were not clinically relevant (140 min vs. 135 min for right colectomy; 168 min vs. 203 min for left colectomy). The authors did not assess cost [19].

de Souza et al. compared 40 robot-assisted right hemicolectomies to 135 laparoscopic right hemicolectomies performed by a group of highly skilled laparoscopic surgeons at a single institution [20]. There were no significant differences in surgical quality measures or short-term clinical outcomes. Unlike the Deutsch data mentioned earlier, the operative time was significantly longer for the robotic assistance group (158 min vs. 118 min). In addition, the cost was almost $3000 greater despite a similar length of stay, and no difference in complications was shown. The authors concluded that this was a good training case; however, one should be cautioned by the fact that 40 cases were not sufficient for an expert team to match their conventional results [20].

These data question why the putative advantages of robotic assistance fail to translate into tangible superiority in the operating room. In addition, the recurring theme of high cost needs to be addressed by proponents before widespread adoption can be encouraged. Future investigations should focus on direct comparisons with conventional laparoscopic colorectal surgery with an emphasis beyond subjective parameters, which do not translate into superior clinical outcomes with at least equivalent resource consumption [20].

22.3 HPB Procedures

Pancreatic resection is amongst the most complex and challenging of abdominal operations. Even in highly experienced centers, open pancreatic surgery is associated with morbidity rates of 30–40 % and mortality rates of approximately 2 % [21, 22]. New, minimally invasive techniques may reduce postoperative morbidity. Therefore, in recent years, laparoscopic pancreatic surgery has been introduced as an alternative to open surgery. Laparoscopic techniques have potential benefits; they can decrease pain and blood loss, fewer complications, faster recovery, and shorter hospital length of stay (LOS) [15, 23]. Early experiences have shown that laparoscopic pancreatic surgery is safe and feasible in selected patients, and that morbidity rates range from 16 to 40 % [24, 25]. Although a growing number of studies on laparoscopic pancreatic surgery have been published, it has not gained wide acceptance. This is probably explained by the known limitations of conventional laparoscopic surgery, such as the decreased range of motion this technique affords and the two-dimensional vision of the operative field, which make its practice difficult.

The use of a robotic system may overcome some of these shortcomings. Robot-assisted surgery provides three-dimensional vision and a magnified view of the operative field. These advantages, combined with the increased freedom of movement of surgical instruments and the elimination of tremor, lead to improved precision in operative technique and may lead to safer anastomoses compared with laparoscopic pancreatic surgery.

For highly selected patient, robotic PD is feasible with similar morbidity and mortality compared to open or purely laparoscopic approaches. Data on cost analysis are lacking, and further studies are needed to evaluate also the cost-effectiveness of the robotic approach for PD in comparison to open or laparoscopic techniques [26].

The emergence of minimally invasive surgery for liver resection procedures has thrived with the introduction of novel technologies, including flexible fiber-optic imaging systems, and hemostatic options, such as clips, staplers, and electrical or ultrasonic energy-induced hemostasis, and laparoscopic liver resection has been shown to be safe in experienced hands, with acceptable morbidity and mortality rates for both minor and major hepatic resections [27, 28]. Previous studies conducted on selected groups of patients have shown that the 5-year survival rates for patients undergoing laparoscopic HCC resection were comparable to those of patients undergoing open hepatic resection [28, 29]. The advantages of minimally invasive surgery are well known. Shorter hospital stays, decreased postoperative pain, rapid return to preoperative activity, improved cosmesis, and decreased postoperative ileus are among the benefits of the laparoscopic approach [27]. However, laparoscopic liver surgery, although it has benefitted from advances in minimally invasive surgery, is not without inherent limitations, including limited degrees of freedom for manipulation, fulcrum effect against the port, tremor amplification, awkward ergonomics, and two-dimensional imaging adaptation [4].

Robotic liver resection has emerged as a new modality in the field of minimally invasive surgery. However, the effectiveness of this approach for liver resection is not yet known. Robotic methods may have the potential to overcome certain laparoscopic disadvantages, but few studies have drawn a matched comparison of outcomes between robotic and laparoscopic liver resections. Tsung et al. published the largest series comparing robotic to laparoscopic liver resections. Patients undergoing robotic liver surgery had significantly longer operative times (median: 253 vs. 199 min) and overall room times (median: 342 vs. 262 min) compared with their laparoscopic counterparts. However, the robotic approach allowed for an increased percentage of major hepatectomies to be performed in a purely minimally invasive fashion (81 % vs. 7.1 %, $P<0.05$) [30].

Robotic and laparoscopic liver resection display similar safety and feasibility for hepatectomies. Although a greater proportion of robotic cases were completed in a totally minimally invasive manner, there were no significant benefits over laparoscopic techniques in operative outcomes [30]. The feasibility and safety of robotic surgery for HCC has been displayed in many studies, with favorable short-term outcome. However, the long-term oncologic results remain uncertain [31, 32]. In the subgroup analysis of minor liver resection, when compared with the conventional laparoscopic approach, the robotic group had similar blood loss, morbidity rate, mortality rate, and R0 resection rate. However, the robotic group had a significantly longer operative time (202.7 min vs. 133.4 min) [31].

Robotic liver resection is safe and feasible in experienced hands. It requires an expert patient-side surgeon with advanced laparoscopic skills. Wristed instruments are useful in a variety of maneuvers, such as looping Glissonian pedicles (especially on the left side of the liver) and in suturing bleeding points. Long-term oncologic outcomes are unclear, but short-term perioperative results indicate that robotic liver resection is comparable to conventional laparoscopic liver resection [32].

In conclusion, many advanced surgical procedures benefit from a minimally invasive approach. Future assessments of the relative role of three-dimensional conventional laparoscopy versus robotic assistance are required to confirm the relative impact of the approaches on value-based surgical care. The impact of learning curve, adoption, and technical complications should be the measures used for these comparisons to ultimately define the cost efficiency of robotic-assisted laparoscopic surgery compared to conventional laparoscopy. Potential future cost savings for both hospitals and patients can be found in shorter operative times as surgeons complete their learning curves. This will also allow more procedures to be performed, which spreads the fixed costs of the robot over more patients. Also improved surgical technique coupled with shorter OR times could lead to even shorter hospital stays decreasing costs to patients and allowing for further revenue opportunities for hospitals.

Finally, as robotic technology expands its cost, just like the cost of all other technologies before it, will decrease over time with the inevitable advent of competitors in the market place. It may be this factor in the end that provides the greatest cost savings to both patients and hospitals, allowing more patients the indisputable benefits of minimally invasive surgery within an economically responsible framework.

22.4 Key Points

- The fixed (equipment and maintenance) and variable (instruments) costs for robotic surgery are higher than both conventional laparoscopic or open surgery.
- The OR costs of robotic surgery are negatively impacted by the increased length of the procedure over open surgery (though not necessarily over conventional laparoscopic surgery).
- When the total (fixed, variable, OR, and hospital stay) costs for robotic surgery and open surgery

are comparable, it is due to a considerable shortening of the length of hospital stay after the robotic surgery, resulting in total cost savings. However, these data are almost exclusively comparisons for moving from open to robotic.

- Conventional laparoscopic surgery shares the minimally invasive benefits of robotic surgery and is less expensive due to lower variable costs; however, there remain many procedures that the majority of surgeons are not able to perform laparoscopically due to the prohibitively long learning curve. This will need to be compelling data confirming that the learning curve and adoption rates for robotic assistance are superior to conventional laparoscopic surgery.

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