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Cost-effectiveness analysis of robotic-assisted laparoscopy for newly diagnosed uterine cancers

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Abstract

Objective—We assessed the direct costs of 3 surgical approaches in uterine cancer and the cost impact of incorporating robot-assisted surgery.

Methods—A cost system that allocates the actual cost of resources used to treat each patient, as opposed to borrowing cost data from a billing system, was used to determine direct costs for patients who underwent surgery for uterine cancer from 2009–2010. These costs included all aspects of surgical care up to 6 months after discharge. Total amortized direct costs (AC) included the capital cost of 3 dual console DaVinci Si platforms with 5 years of service contracts. Non-amortized costs (NAC) were also calculated (excluded capital costs). Modeling was performed to estimate the mean cost of surgical care for patients presenting with endometrial cancer from 2007–2010

Results—Of 436 cases (132 laparoscopic, 262 robotic, 42 laparotomy), total mean AC/case was \$20,489 (laparoscopy), \$23,646 (robot), and \$24,642 (laparotomy) ($P<0.05$ [robot vs laparoscopy]; $P=0.6$ [robot vs laparotomy]). Total NAC/case was \$20,289, \$20,467, and \$24,433, respectively ($P=0.9$ [robot vs laparoscopy]; $P=0.03$ [robot vs laparotomy]). The planned surgical approach in 2007 was laparoscopy-68%, robot-8%, and laparotomy-24% compared to 26%, 64%, and 9%, respectively, in 2010 ($P<0.001$). The modeled mean AC/case was \$21,738 in 2007 and \$22,678 in 2010 (+\$940). NAC was \$21,298 in 2007 and \$20,573 in 2010 (–\$725).

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Conclusion—Laparoscopy is least expensive when including capital acquisition costs. Laparoscopy and robotic surgery are comparable if upfront costs are excluded. There is cost neutralization with the robot when it helps decrease laparotomy rates.

INTRODUCTION

Uterine cancer is the most common gynecologic malignancy with nearly 50,000 new cases annually (1). Surgery at the time of diagnosis is the cornerstone of initial treatment and involves, at a minimum, total hysterectomy (2). The Gynecologic Oncology Group confirmed that laparoscopy results in lower complications, decreased length of stay, and improved patient quality of life as compared to laparotomy, without an adverse impact on survival (3–5). Similar findings have been reported in patients undergoing hysterectomy for benign indications (6,7). A recently published meta-analysis reported that total laparoscopic hysterectomy was associated with reduced postoperative pain scores and hospital stay compared to vaginal hysterectomy (8). Every effort to reduce laparotomy rates for patients with malignant indications should be the goal..

The implementation of minimally invasive surgery has been hindered by the limitations of available laparoscopic instrumentation, especially for more complex and difficult hysterectomies. In the United States, only 14% of all hysterectomies performed for benign indications are completed laparoscopically (9). One of the barriers to performing laparoscopy is the associated technical difficulty (10). Computer-based (“robotic”) platforms may allow surgeons to increase the rate of laparoscopy (11,12).

There are many criticisms of the robotic platform. Recently reported analyses of the Perspective database concluded that robotic hysterectomy is associated with an incremental cost per case of \$1,291 to \$2,189 over laparoscopy (13,14). These data compared successfully completed laparoscopic and robotic cases without taking into consideration the experience of the surgeons or the drivers of cost. The impact on laparotomy rates with the introduction of the robotic platform was also not taken into account. The introduction of the robotic platform has been reported to significantly reduce laparotomy rates, leading to an actual reduction in overall hospital costs (11). We sought to analyze the costs of incorporating the robotic platform in patients with newly diagnosed uterine cancers at an experienced laparoscopic center after an initial robotic learning and development period.

METHODS AND MATERIALS

Laparoscopy has been offered at our institution since 1993. A robotics program was initiated in 2007. Institutional Review Board approval was obtained to analyze this dataset. Direct costs were abstracted for all patients who underwent primary surgical therapy for newly diagnosed uterine cancer at our institution from 1/1/2009 to 12/31/2010. We chose this time period to have concurrent cases to analyze and to overcome any learning curves associated with the robot. These costs included direct costs for all aspects of care during the initial surgical event, immediate postoperative stay, and costs incurred up to 6 months postoperatively (Table 1). Direct costs were obtained using a cost system that allocates the cost of resources used to treat each patient, as opposed to borrowing cost data from the

hospital billing system, providing a more accurate assessment of true direct costs. The amortized costs included the capital cost of 3 dual console DaVinci Si platforms as well as 5 years of service contracts for each of the 3 platforms amortized over 5 years assessed to each case based on a total robotic case volume of 751 cases in 2009 and 886 cases in 2010, as well as the summation of all the direct costs of the other resources used to treat each patient. The total robotic case volume includes all surgical cases performed across all gynecologic and non-gynecologic services using the platform. Capital equipment purchases for standard laparoscopic instrumentation were also calculated. Non-amortized costs were the amortized costs minus the capital equipment costs of the robotic platforms and laparoscopic capital purchases.

The primary analysis was based on intent to treat, i.e., cost for cases converted to laparotomy from planned laparoscopic or robotic approaches were included in the laparoscopic or robotic cohorts, respectively. Nine laparoscopically trained surgeons contributed to the total number of cases. "Laparoscopically trained" indicates that the surgeon received formal training in laparoscopy either post-fellowship in a structured outside program or during fellowship. Additionally, all demonstrated sufficient competency to be granted institutional privileges in laparoscopic approaches, and all had been routinely performing standard laparoscopy. The reasons for planned laparotomy were based on individual surgeon choice and do not reflect a particular institutional policy or guideline.

Chi square or Fischer's exact tests were used as appropriate to compare nominal data between the surgical approaches. The Mann-Whitney U test was used to compare continuous baseline data when 2-group analyses were performed. The Kruskal-Wallis test was used to compare continuous baseline data when 3-group analyses were performed. The student's t-test was used to compare mean costs between the planned laparoscopic and robotic cohorts.

Modeling was then performed to estimate the mean cost of surgical care for patients presenting to our institution for newly diagnosed uterine cancer based on the rate distribution of planned laparoscopy, robotic, and laparotomy from 2007 to 2010, which we have previously published (12). This model was created by calculating weighted projections of total endometrial surgical cost on retrospective case data. The actual costs from 2009 and 2010 were projected onto the 2007 to 2008 cases, weighted by surgical method and case load. We did not adjust for inflation as this should have a limited impact on such a short time period and would have equally affected costs for all three planned approaches. Similar modeling methodology was then performed based on currently reported national rates of laparotomy (9) and the estimated potential reduction of laparotomy rates, which we have previously reported with the introduction of robotics. In this theoretical model, we chose to keep the rates of laparoscopy stable over the theoretical time period since the rates of laparoscopy have been reported to both decrease (13) or increase (14) in various publications. Any set of assumptions could be chosen in this theoretical model.

RESULTS

Direct costs were assessed for 436 cases, which included 132 planned laparoscopic, 262 planned robotic and 42 planned laparotomy cases, for patients with newly diagnosed uterine cancer undergoing surgery at our institution in 2009 and 2010. Table 2 summarizes select characteristics of our cohorts. Median age was the same across all 3 cohorts. The conversion to laparotomy rate was the same for the laparoscopic and robotic cohorts. The median BMI was higher in the robotic cohort compared to the laparoscopic cohort. Importantly, stage distribution was the same across all 3 cohorts. The choice of approach was surgeon dependent, the most common reasons for planned laparotomy being obesity and uterine anatomy, accounting for more than half of the laparotomy cases. Additional details are described in a previous publication (12). Tumor histologies and grades were similar (12). Robotic cases were associated with longer operating room and operative times but shorter length of stay (12). There were more grade 1–2 complications among laparoscopic (12%) compared to robotic (7%) cases (12). The rate of planned laparotomy was similar during these 2 years (11% and 9%). However, the rate of planned laparotomy decreased by approximately 60%, from 24% in 2007 to 9% in 2010 ($P<0.001$).

Table 3 describes the results of our primary analyses. The mean amortized cost total was \$3,157 more for robotic compared to laparoscopic cases ($P<0.05$) when accounting for the capital purchase and maintenance fees of 3 dual-console platforms used for 1,637 total robotic cases in 2009–2010. The mean amortized cost total was \$996 less for robotic cases compared to laparotomy cases ($P=0.6$). Excluding the capital costs of the platforms and laparoscopy, the mean non-amortized cost total was \$178 more for robotic compared to laparoscopic cases ($P=0.9$). The non-amortized cost total was \$3,966 less for the robotic compared to laparotomy cases ($P=0.03$). Cost differences for other parameters can be seen in Table 3.

Table 4 describes our cost modeling analysis using our mean cost results per planned surgical approach depicted in Table 3 based on the distribution of planned surgical approaches from 2007 to 2010 as previously published (12). There was a 63% reduction in laparotomy rates from 2007 to 2010, with an 8-fold increase in robotic and 62% decrease in laparoscopic cases. The mean amortized cost total increased by \$940 per patient presenting with newly diagnosed uterine cancer and undergoing surgery from 2007 to 2010. However, excluding capital equipment costs, the mean non-amortized cost total decreased by \$725 from 2007 to 2010.

Table 5 describes cost modeling based on one theoretical scenario, recognizing that this model can be modified in multiple ways. This chosen model uses a Year 1 laparotomy rate of 66% based on published national data (9). It assumes a laparoscopic rate of 34% and robotic rate of 0% in Year 1, with subsequent changes in surgical rates based on a 63% reduction in laparotomy rates without a decrease in laparoscopy. We used our amortized cost data, which include the purchase of 3 dual-console platforms. The amortized costs would change if only one platform, or more than 3, were to be amortized. Reducing laparotomy rates by 63% from an initial rate of 66% would result in a reduction in mean

amortized cost total by \$418 per case. The mean non-amortized cost total would be reduced by \$1,666 per patient.

DISCUSSION

The key conclusion from our data, in conjunction with other published data, is that the costs of robotics must take into account how it impacts the rate of laparotomy and not just comparing successfully completed robotic to laparoscopic cases, since these are both laparoscopic (i.e., minimally invasive) approaches using different instrumentation. Also, it is important to take into account post-discharge cost outcomes. Our data further validate and support the data from Lau and colleagues (11). The enhancement of laparoscopic programs with the introduction of the robotic platform and a concomitant decrease in laparotomy rates leads to cost neutralization of the robotic platform and potentially a cost savings overall. These effects will be greatest among surgeons and hospitals that have struggled with adopting laparoscopy and have a high laparotomy rate. This may also help experienced laparoscopic centers further develop their programs as they expand their ability to offer minimally invasive surgery to even more patients. Surgeons and hospitals that feel they can offer the highest possible rates (>70–80%) of minimally invasive surgery with standard laparoscopic instrumentation may not derive benefits from acquiring or incorporating the robotic platform.

Despite nearly 40 years of availability, laparoscopic hysterectomies still comprise only a small percentage of all hysterectomies in the United States and the world (9). There are gynecologic surgeons who provide safe and efficient laparoscopic surgery, and it is important to continue to support their efforts. Unfortunately, they only represent a minority of all gynecologic surgeons. The robotic platform is a device that overcomes some of the limitations of standard laparoscopic instrumentation and has increased minimally invasive approaches (11,12,15).

The robotic platform has been criticized as being unnecessary and expensive (13,14). Comparative- and cost-effectiveness analyses are highly complex.. The manner in which the cost data are entered, the drivers of those costs, the experience of those surgeons performing laparoscopy and robotics, the complexity of cases, etc, are often not accounted for. Most importantly, the impact on laparotomy rates is rarely addressed. Laparotomy results in much higher rates of complications (both acute and long term), lengthier hospital stays and readmissions, more pain, and lengthier delays of patients returning to normal activities. Laparotomy is the most expensive surgical approach on a societal basis (16). Long-term adhesion-related and incisional hernia care after laparotomy is extremely costly.

Lau et al evaluated the effect of introducing a robotic program for uterine cancer surgery on cost and patient outcomes at their institution (11). They compared 143 cases after introducing robotics to 160 patients before this “robotic era”. They were able to increase their minimally invasive rates from 17% to 98% within 2 years simply by incorporating robotics. Overall complications decreased significantly from 42% to 13%. Mean cost decreased by \$2,000 per patient even when including the amortization of one platform (11).

Our incorporating the 6-month postoperative period captures the costs associated with surgical complications. Early on in our analysis, we recognized errors in the costs assigned by our financial managers and required extensive review by clinicians, highlighting the need for clear guidelines when entering cost data into public databases and access to that data. Surgical cost analyses should also include costs of post-discharge care, not just the immediate surgical event and length of stay. These include repeated office visits, home nursing, antibiotics, and delayed return to normal activities.

A potential limitation of our current analysis, beyond its retrospective nature, was that we did not perform a risk-adjusted analysis due to the small number of planned laparotomies, which is beyond the scope of this report. However, we did consider some of the potential risks of adversely affecting costs in laparotomy cases. Stage distribution was similar among the 3 surgical approaches. The percentage of stage III and IV cases was higher in the laparotomy cohort, but this was not significant with such a small group of planned laparotomies, and the only stage IV cases were in the laparoscopic and robotic cohort. Of note, we included cases converted to laparotomy in the laparoscopic and robotic cohorts as part of our intent-to-treat analysis. Excluding these cases or placing them in the laparotomy cohort would have further favored our laparoscopic and robotic cohorts over laparotomy. We also recognize that these are not data from a randomized protocol, which would truly provide more robust results. However, randomization of patients with uterine cancer to a protocol arm involving laparotomy will likely never be done again in light of the results of Gynecologic Oncology Group study LAP2.

Hospitals must take into account capital costs to decide on purchasing new equipment; therefore, amortized cost is relevant. However, amortized cost is highly dependent on the number of platforms purchased and how many years they are used. Our amortized costs factored in 3 dual-console platforms. The amortized cost for a single platform would obviously reduce this cost by two-thirds. Amortized costs per case will also decrease with an increasing number of cases performed. Our current analysis amortized the cost of more than 1,637 total cases performed in 2009 and 2010. Since then, our total number of cases has increased significantly, with over 1,400 cases performed in 2012 and an estimated 1,800 cases for 2013.

Many institutions will already have a robotic platform in place.. Therefore, the calculated amortized cost does not actually reflect an additional actual cost each time the platform is used since that equipment has already been acquired. In reality, the amortized costs will decrease with increasing use, as described above. The non-amortized cost reflects the actual cost of that case. Operative time and disposable equipment are two of the greatest drivers of cost beyond capital cost (17). We, and others, have reported a learning curve of approximately 20–50 robotic cases, after which operative times decrease significantly (12,18,19). Median operating room and actual operative times equal those of similar laparoscopic cases after this learning curve (12). Our current cost analysis demonstrates that in a time period after which most, but not all, surgeons had overcome this learning curve, use of the robotic platform did not translate into an incremental non-amortized cost.

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Table 1

Cost assessments and definitions

Cost Component	Details	Calculation Method	Dependency
Surgeon Costs	Physician cost per surgery	Estimated using physician cost for day of surgery	Surgery type
Theater Costs	Costs associated with the operating room	Varies by OR component	NA
OR Equipment	Cost of fixed equipment used for surgery, such as laparoscope or DaVinci Robot	Laparoscopy and laparotomy equipment estimated proportional to time in OR. Robotic equipment cost estimated per patient retrospectively	Surgery type
OR Supplies	Disposable items, such as drapes and needles, and reusable items, such as robot arms	Estimated using supplies needed for surgery type and proportional to time in OR	Surgery type
Nurses and Techs	Cost of staffing the OR	Estimated proportional to time in OR	OR time
OR Use	Cost of running the OR, including facilities and administrative costs	Estimated proportional to time in the OR	OR time
Hospital Accommodation	Room and board for duration of hospital stay associated with surgical admission	Cost of accommodation for each day of stay	Length of stay and room preference
Pharmacy Costs	Costs associated with drugs and their distribution during inpatient stay	Cost of pharmacy needs, by patient	Drug needs
Radiology Costs	Costs associated with imaging including cat scans, MRIs, EKGs, etc, during inpatient stay	Cost of imaging needs, by patient	Imaging needs
Laboratory Costs	Costs associated with lab work during inpatient stay	Cost of lab needs, by patient	Lab needs
Blood Costs	Costs associated with blood work during inpatient stay	Cost of blood need, by patient	Blood needs
Ancillary IP Costs	All costs incurred during inpatient stay that are not directly related to surgical need, including chemo, radiation, physical therapy, etc.	Cost of ancillary services by patient need	Ancillary services need
Inpatient Stay	Total of costs incurred during day of surgery and inpatient stay	Total of all items above	NA
Readmit+Follow-up Cost (6 months)	All costs incurred within 6 months of discharge from surgery, including clinical visits, treatments, readmissions, etc.	Cost of services rendered by patient need	Follow-up and readmissions need
Total Cost (IP Stay + 6 months)	Total cost of surgery, surgical inpatient stay, and 6 month readmissions and follow-up	Sum of all costs above	NA
Inpatient Stay without Equipment	Inpatient Stay as above, without cost of OR equipment	Sum of inpatient stay cost less cost of OR equipment	NA
Total Cost without Equipment	Total Cost as above, without cost of OR Equipment	Sum of total cost less cost of OR equipment	NA

OR=operating room; N/A=not applicable; Techs=surgical technicians; IP=inpatient **Amortized costs** included "Inpatient Stay" and "Total Cost"; **Non-amortized costs** included "Inpatient Stay w/o Equipment" and "Total Cost w/o Equipment"

Table 2

Select characteristics based on planned surgical approach

Variable	Laparoscopy	Robot	P-value LRS vs RBT	Laparotomy	P-value Across all 3
N	132	262		42	
Age (yrs)					
Median (range)	61 (27–88)	60 (31–86)	0.6	62.5 (36–85)	0.8
BMI (kg/m ²)					
Median (range)	27.9 (19.1–52.4)	29 (18.6–66)	0.02	32 (19.1–63)	0.007*
Converted – N(%)	11 (8.3)	22 (8.4)		-	
Stage – N(%)					
I	99 (75)	198 (75.6)	0.7	27 (64.3)	0.1
II	2 (1.5)	9 (3.4)		2 (4.8)	
III	27 (20.4)	47 (17.9)		13 (31.0)	
IV	4 (3)	5 (1.9)		0 (0)	
N/A	-	3 (1.1)		-	
Reason for planned LAP					
Obesity				13 (28.3)	
Uterine anatomy				13 (28.3)	
Patient anatomy				3 (6.5)	
Prior laparotomy				6 (13)	
Tumor related				3 (6.5)	
Co-morbidity				3 (6.5)	
Patient preference				2 (4.3)	
N/A				2 (4.3)	
Ventral hernia				1 (2.2)	

LRS=laparoscopy; RBT=robotic; LAP=laparotomy; N/A=not ascertainable *P=0.1 (laparotomy vs robot) and P=0.004 (laparotomy vs laparoscopy)

Table 3

Mean costs per patient presenting with newly diagnosed uterine cancer based on planned surgical approach (2009–2010, inclusive)

Cost Component	LRS (n=132)	RBT (n=262)	P*	LAP (n=42)
Surgeon Costs	4,827 ± 1,695	4,771 ± 1,801	0.761	4,820 ± 1,258
Theater Costs				
OR Equipment	200 ± 63	3,179 ± 727	< 0.001	209 ± 81
OR Supplies	1,696 ± 497	2,487 ± 628	< 0.001	1,355 ± 340
Nurses and Techs	1,207 ± 385	1,444 ± 488	< 0.001	1,258 ± 395
OR Use	1,058 ± 307	1,315 ± 389	< 0.001	1,132 ± 383
Hospital Accommodation	1,824 ± 1,024	1,624 ± 1,321	0.099	3,078 ± 1,044
Pharmacy Costs	443 ± 304	428 ± 379	0.681	582 ± 325
Radiology Costs	59 ± 296	56 ± 311	0.922	45 ± 101
Laboratory Costs	1,632 ± 767	1,381 ± 654	< 0.05	1,870 ± 694
Blood Costs	22 ± 110	25 ± 99	0.796	15 ± 46
Ancillary IP Costs	181 ± 383	323 ± 911	< 0.05	717 ± 912
Inpatient Stay	13,150 ± 3,367	17,035 ± 4,211	< 0.001	15,081 ± 3,020
Readmit+Followup (6 months)	7,339 ± 9,754	6,611 ± 8,886	0.472	9,561 ± 9,310
Total Cost (IP Stay + 6 months)	20,489 ± 11,021	23,646 ± 10,825	< 0.05	24,642 ± 10,419
Inpatient Stay w/o Equipment	12,950 ± 3,344	13,856 ± 4,213	< 0.05	14,872 ± 2,977
Total Cost w/o Equipment	20,289 ± 11,001	20,467 ± 10,944	0.879	24,433 ± 10,417

Data are mean \$ ± standard deviation direct costs of patient care associated with each surgical modality.

* Student t-test was performed using 2-sample normal approximation of unequal variance comparing RBT and LRS cohorts

† The cost of the da Vinci Surgical System is amortized according to a 5 year expected life of the system and a retrospective total robotic case volume of 751 cases in 2009 and 886 cases in 2010, plus annual maintenance cost.

Table 4
Cost modeling based on planned surgical approach distributions at our institution (2007–2010)

	2007	2008	2009	2010	2010–2007
Planned approach (ref 12)					
Laparoscopy	68%	46%	33%	26%	
Robot	8%	36%	56%	64%	
Laparotomy	24%	16%	11%	9%	–63%
AC					
Initial perioperative cost	14,769	15,171	15,961	16,005	+1,236
Total cost	21,738	21,880	22,714	22,678	+940
NAC					
Initial perioperative cost	14,329	13,901	14,092	13,900	–429
Total cost	21,298	20,610	20,845	20,573	–725

Data are mean \$ per patient undergoing surgery for uterine cancer in that year

AC=amortized cost; NAC=non-amortized cost

Table 5
Cost modeling based on theoretical surgical approach distribution changes over 4 years

	Year 1	Year 2	Year 3	Year 4	Year 4-Year 1
Planned approach*					
Laparoscopy	34%	34%	34%	34%	
Robot	0%	16%	31%	42%	
Laparotomy	66%	50%	35%	24%	-63%
AC**					
Initial perioperative	14,418	14,730	15,023	15,238	+820
Total	23,230	23,071	22,921	22,812	-418
NAC					
Initial perioperative	14,219	14,056	13,904	13,792	-427
Total	23,024	22,389	21,795	21,358	-1,666

Data are mean \$ per patient undergoing surgery for uterine cancer in that year

AC=amortized cost; NAC=non-amortized cost

* National laparotomy rates of 66% (ref 9) with reduction of 63% (12) by introducing robotic platform and stable LRS rate

** Includes cost of 3 DaVinci Si dual consoles with 3 service plans amortized over 5 years