The cost of robotics: an analysis of the added costs of robotic-assisted versus laparoscopic surgery using the National Inpatient Sample

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Abstract

Background Robotic-assisted surgery (RAS) with its advantages continues to gain popularity among surgeons. This study analyzed the increased costs of RAS in common surgical procedures using the National Inpatient Sample.

Methods Retrospective analysis of the 2012–2014 Healthcare Cost and Utilization Project-NIS was performed for the following laparoscopic/robotic procedures: cholecystectomy, ventral hernia repair, right and left hemicolectomy, sigmoidectomy, abdominoperineal resection, and total abdominal hysterectomy (TAH). Patients with additional concurrent procedures were excluded. Costs were compared between the laparoscopic procedures and their RAS counterparts. Total costs and charges for cholecystectomy (the most common procedure in the dataset) were compared based on the payer and characteristics of hospital (region, rural/urban, bed size, and ownership).

Results A total of 91,630 surgeries (87,965 laparoscopic, 3665 robotic) were analyzed. The average cost for the laparoscopic group was $10,227 \pm $4986 versus $12,340 \pm $5880 for the robotic cases ($p < 0.001$). The overall and percentage increases for laparoscopic versus robotic for each procedure were as follows: cholecystectomy $9618 versus $10,944 (14%), ventral hernia repair $10,739 versus $13,441 (25%), right colectomy $12,516 versus $15,027 (20%), left colectomy $14,157 versus $17,493 (24%), sigmoidectomy $13,504 versus $16,652 (23%), abdominoperineal resection $17,708 versus $19,605 (11%), and TAH $9368 versus $9923 (6%). Hysterectomy was the only procedure performed primarily using RAS and it was found to have the lowest increase in costs. Increased costs were associated with even higher increases in charges, especially in investor-owned private hospitals.

Conclusion RAS is more costly when compared to conventional laparoscopic surgery. Additional costs may be lower in centers that perform a higher volume of RAS. Further analysis of long-term outcomes (including reoperations and readmissions) is needed to better compare the life-long treatment costs for both surgical approaches.

Keywords Robotic surgery · Laparoscopic · Costs · Cholecystectomy · Ventral hernia repair · Colectomy · Hysterectomy

Robotic-assisted surgery (RAS) is a growing branch of minimally invasive surgery (MIS) that is becoming more popular as robotic devices are more available. Although the advantages of RAS are difficult to quantify, its use of 3D visualization, seven degrees of freedom, elimination of the fulcrum effect, and better ergonomic positioning are believed by many to make it superior to conventional laparoscopic surgery (LS) [1, 2]. Initially the role of RAS was limited to certain procedures [3]. Now its use has expanded to include less complex procedures such as cholecystectomy and hernia repair [4].

Although usage of RAS has continued to rise throughout the United States, universal adoption has yet to occur. This is likely due to insufficient evidence to support superiority and consideration of the cost [5]. The cost barrier debate was historically centered on LS in comparison to open surgical procedures. As evidence mounted, the superiority of LS for many procedures became obvious during the 1990s. Now two decades later, the fiscal discussion is dominated by the comparison of RAS to LS [6].

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This study was undertaken at the national level to help quantify the financial aspect of RAS to better inform surgeons and institutions. An analysis of the added costs of RAS compared to conventional LS was performed for seven prevalent surgical procedures using the National Inpatient Sample.

Methods

This study is a retrospective analysis of the 2012–2014 Healthcare Cost and Utilization Project-National Inpatient Sample (HCUP-NIS). The NIS is the largest all-payer inpatient health care database in the United States, including national estimates of hospital inpatient admissions. The database collects data from more than 7 million hospital admissions annually and is one of the largest longitudinal hospital care databases in the United States. HCUP-NIS provides researchers with information on clinical conditions, healthcare costs, outcomes, and practice patterns at the national, state, and community levels. Since 2012, the NIS includes approximately a 20% stratified sample of all discharges from community hospitals (excluding rehabilitation and long-term acute care hospitals). The NIS consists of all patients, including uninsured and insured patients (Medicaid, Medicare, and private insurances) [7].

This is a retrospective analysis of a hospital-based discharge dataset that is available to the public from the Agency for Healthcare Research and Quality (AHRQ). After reviewing the study, the Institutional Review Board (IRB) of the University of Oklahoma—Tulsa verified that this project does not require formal IRB approval since it is not involving human subjects protected information. The first author (ZK) completed the data user agreement with HCUP–AHRQ and obtained the de-identified dataset. The HCUP–AHRQ data user agreement precludes reporting frequencies < 11 for patient confidentiality which was followed in the current study.

A search was performed using specific ICD-9 codes for the following laparoscopic and robotic procedures: cholecystectomy, ventral hernia repair, right and left hemicolectomy, sigmoidectomy, abdominoperineal resection and total abdominal hysterectomy (TAH). Patients with concurrent procedures (minor or major) were excluded. Hospital total charges were converted to cost estimates using hospital specific cost-to-charge ratios provided by HCUP. Admissions with total charges below the 0.1 percentile or above the 99.9 percentile were considered outliers and excluded from further analysis ($N = 182$).

The cohorts were then divided into subgroups based on procedure. To better outline current national practice patterns, the technique frequency for LS versus RAS was determined for each procedure. The average total cost of hospitalization was compared for the LS and RAS cohorts. The percentage difference between the average costs of the laparoscopic operation vs robotic operation were calculated for each surgical subgroup. Length of stay for each subgroup was also compared to determine association with overall costs.

To assess the differences in costs and charges based on the payer and characteristics of the hospital, we analyzed admissions with cholecystectomy (the most common procedure in the dataset). Total costs and charges were compared based on the payer (Medicare, Medicaid, private insurance, and self-pay) and characteristics of hospital including region (Northeast, Midwest, South, and West), location (rural, urban teaching, urban non-teaching), bed size (small, medium, large), and control/ownership (non-federal governmental, not-for-profit private, investor-owned private).

Data analysis was performed using IBM SPSS Statistics for Windows, version 23 (IBM Corp., Armonk, NY, USA). A Mann–Whitney U test was employed for comparison of continuous variables. A p value of < 0.05 was considered statistically significant.

Results

A total of 91,630 surgeries (87,965 laparoscopic, 3,665 robotic) were analyzed. LS and RAS groups were similar in age, gender, and race (Table 1). The average cost of the LS cohort was $10,227 ± $4986. In comparison, the average cost of the RAS cohort was $12,340 ± $5880 ($p < 0.001$). LS was the predominant method of intervention for each surgical procedure examined with the exception of TAH. Sixty percent of TAH cases were performed robotically. Length of stay for RAS was equal to or shorter than for their laparoscopic counterparts. Table 2 details the average cost, number of interventions, and length of stay for each subgroup.

Subgroup analysis based on type of procedure was performed to determine overall percent change between

Table 1 Comparison of demographic and baseline characteristics of patients with laparoscopic versus RASs

	Laparoscopic $N = 87,965$	Robotic $N = 3,665$
Age, mean ± SD (years)	51 ± 18.6	50.6 ± 15.9
Female, n (%)	56,813 (64.6%)	2,694 (73.5%)
Race		
White	55,103 (62.6%)	2312 (63.1%)
Black	8267 (9.4%)	436 (11.9%)
Hispanic	15,310 (17.4%)	522 (14.2%)
Other	6612 (7.5%)	292 (8%)
Unknown	2673 (3%)	103 (2.8%)

Table 2 Comparison of number, length of stay, and cost of laparoscopic versus RASs in each subgroup (mean, standard deviation)

Procedure	N	Laparoscopic		N	Robotic	
		LOS	Cost		LOS	Cost
Cholecystectomy	69,402	2.8 ± 2.1	$9618 ± 4630	1271	2.9 ± 2	$10,944 ± 4315
Ventral hernia repair	3600	2.7 ± 1.9	$10,739 ± 4812	99	2.9 ± 3.1	$13,441 ± 5540
Right colectomy	7243	4.3 ± 2	$12,516 ± 5281	442	3.8 ± 1.6	$15,027 ± 6049
Left colectomy	1026	4.6 ± 2.7	$14,157 ± 5976	79	4.4 ± 1.9	$17,493 ± 6880
Sigmoidectomy	5599	4.2 ± 2	$13,504 ± 5649	445	3.8 ± 1.9	$16,652 ± 6401
Abdominoperineal resection	292	5.6 ± 3.1	$17,708 ± 8667	141	5.1 ± 2.2	$19,605 ± 6757
TAH	803	1.4 ± 0.9	$9368 ± 4849	1188	1.2 ± 0.6	$9,923 ± 4631
Total	87,965	3.1 ± 2.2	$10,227 ± 4986	3665	2.7 ± 2	$12,340 ± 5880

LOS length of stay; *TAH* total abdominal hysterectomy
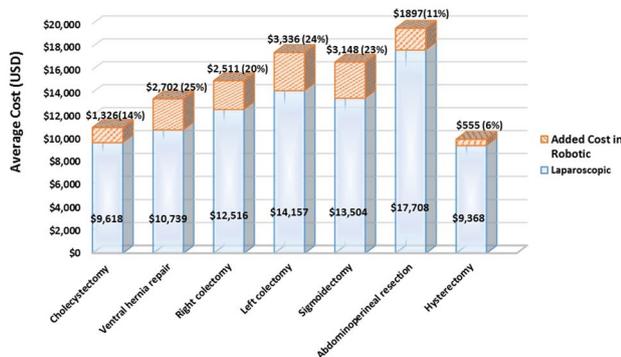
Fig. 1 Cost difference between laparoscopic and robotic surgeries

laparoscopic and robotic procedures (Fig. 1). TAHs had the narrowest percent cost change with laparoscopic TAH averaging $9368 and robotic TAH averaging $9923 (5.9% cost change). The remaining cost analyses for laparoscopic versus robotic surgeries were as follows: cholecystectomy $9618 versus $10,944 (13.8%), ventral hernia repair $10,739 versus $13,441 (25.2%), right colectomy $12,516 versus $15,027 (20.1%), left colectomy $14,157 versus $17,493 (23.6%), sigmoidectomy $13,504 versus $16,652 (23.3%), and abdominoperineal resection $17,708 versus $19,605 (10.7%). All cost differences were statistically significant.

Table 3 shows the comparison of costs and charges of cholecystectomy based on the payer and hospital characteristics. In laparoscopic groups, costs were higher for Medicare, in hospitals in the western region of the US, small bed size, rural hospitals, and non-federal governmental hospitals. Charges were 3–5.9 times higher than the costs in laparoscopic group. In the robotic group, costs were lower in investor-owned private hospitals ($10,412), while the average total charges were 7 times higher at $73,089.

Discussion

MIS has become a common approach for many surgical procedures. RAS as a method of MIS is becoming more popular and widely accepted in recent years. The benefits of RAS are believed to be 3D visualization, improved range of motion, and superior ergonomics. However, the increased costs of RAS cannot be overlooked by the fiscally conscious surgeon [4, 8].

RAS received FDA approval in 2000. It initially used two arms and one camera holder; however, it soon transitioned to three arms in the surgical field. Since its introduction, it has undergone multiple revisions to improve arm mobility, increase range of motion, and to allow simultaneous operation in multiple quadrants [9]. Despite the nearly two decades of use, the operating costs of RAS still exceed those of LS. Financial concerns are legitimate with an average machine cost of approximately $1.5–2 million dollars plus additional related costs (e.g., service and repair, training staff, increased operating time especially during learning curve) [10]. In addition, limited-use and disposable instruments add further intraoperative expenses compared to common laparoscopic surgical procedures [11].

Of the surgical procedures that were examined, RAS was significantly more expensive than its laparoscopic counterpart. Differential costs ranged from 6 to 28%. In terms of US dollars, additional costs for RAS ranged from $600 to more than $4000. These results are in line with other recent cost-comparison studies. A meta-analysis performed by Solaini et al. examined 11 studies totaling 8,257 right colectomies. They reported the total cost was $12,299 for RAS and $10,335 for LS [12]. Similarly, a comparison of RAS and LS for 237 cholecystectomies by Strosberg et al. showed a total cost of $8870 and $5771, respectively [13]. These increased costs are concerning given the potential pass-through of additional charges to patients and payers. Our review of charges for cholecystectomy in private, investor-owned hospitals showed that charges can be up to 7 times costs of RAS, and up to 5.9 times the cost of LS.

Table 3 Costs and charges of laparoscopic versus robotic cholecystectomy (mean ± standard deviation)

	Laparoscopic N = 69,402		C/C	Robotic N = 1,271		C/C
	Total costs	Total charges		Total costs	Total charges	
Primary payer						
Medicare	11,024 ± 5298	42,067 ± 26,601	3.8	11,858 ± 4988	57,001 ± 34,242	4.8
Medicaid	9429 ± 4413	36,695 ± 21,970	3.9	10,762 ± 4337	55,207 ± 31,580	5.1
Private insurance	8975 ± 4136	34,049 ± 19,939	3.8	10,643 ± 4055	49,845 ± 27,156	4.7
Self-pay	9005 ± 4186	34,932 ± 19,905	3.9	10,216 ± 3720	53,869 ± 30,609	5.3
Region of hospital						
Northeast	8818 ± 4407	32,834 ± 22,084	3.7	10,484 ± 3913	38,469 ± 25,999	3.7
Midwest	9958 ± 4500	29,953 ± 14,618	3	12,257 ± 4444	41,353 ± 19,956	3.4
South	9005 ± 3890	36,649 ± 21,762	4.1	10,227 ± 3592	57,489 ± 31,948	5.6
West	11,164 ± 5639	46,241 ± 26,240	4.1	11,812 ± 5484	63,002 ± 30,939	5.3
Bed size of hospital						
Small	10,390 ± 5332	34,975 ± 21,784	3.4	10,808 ± 3965	44,547 ± 28,036	4.1
Medium	9556 ± 4559	37,159 ± 23,182	3.9	10,603 ± 4391	56,890 ± 32,042	5.4
Large	9419 ± 4412	37,213 ± 22,431	4	11,161 ± 4337	53,554 ± 29,883	4.8
Location of hospital						
Rural	11,092 ± 5854	28,176 ± 16,678	2.5	11,524 ± 3743	51,824 ± 38,922	4.5
Urban teaching	9290 ± 4408	35,792 ± 21,246	3.9	10,714 ± 4319	46,803 ± 27,885	4.4
Urban non-teaching	9619 ± 4456	40,119 ± 24,500	4.2	11,102 ± 4381	60,876 ± 30,251	5.5
Control/ownership of hospital						
Government, non-federal	10,265 ± 5214	30,950 ± 16,629	3	11,318 ± 4612	33,816 ± 15,844	3
Private, not-for-profit	9639 ± 4668	33,767 ± 20,319	3.5	11,298 ± 4732	41,572 ± 22,915	3.7
Private, investor-owned	9061 ± 3905	53,402 ± 26,979	5.9	10,412 ± 3588	73,089 ± 30,894	7

C/C: average charge divided by average cost

In this study, length of stay was shorter for RAS cases as compared to LS. This finding is in line with the current literature [14]. This suggests the additional costs accrued by RAS are predominantly related to the procedure itself, and the additional costs of RAS are not compensated by the savings from shorter hospital stay.

Interestingly, TAH had the lowest increased cost and was the only procedure to be performed more often robotically. This suggests that although RAS costs are higher, the difference may be offset with more routine performance of procedures using the robot. This possible explanation is further strengthened by earlier reports comparing laparoscopic and robotic hysterectomies that showed significantly higher costs of robotic cases [15, 16]. More recently Avondstondt et al. compared total costs of robotic TAH by a single surgeon in 2009–2010 following 5 years of experience. They showed a significant reduction in both procedure and operating room time, as well as total operating room cost [17]. This demonstrates a robotic surgery learning curve and the expected efficiency gained with increased experience [18]. Like any new procedure, surgeons must perform a certain number of cases to become proficient and most efficient with their operating room time. This is also applicable to staff, as it takes multiple people to navigate the robot during the case.

Centers with higher case volumes, more experienced staff, and more efficient surgeons can potentially decrease the cost of RAS.

Ultimately, for RAS to become standard of care, there must be evidence of improved outcomes to justify the additional costs. Further research is needed to better understand differences in outcomes between robotic and conventional LS. Complications, reoperations, and readmissions should be considered when comparing total global costs of robotic and conventional LS. Just as the role for LS was questioned in the 1990s, the role of robotics is now under scrutiny. At this junction, RAS is more costly than conventional LS during the index hospitalization, but as the field of robotics expands, the future is unclear as increased costs may be saved. Finally, the increased transparency of healthcare has empowered patients as consumers. Patients are now taking an increasingly active role in their treatment decisions [19]. Full disclosure of the potential benefits of robotics, as well as the additional costs may be prudent when informing patients as consumers.

This study is strengthened with a national database sample allowing for improved cross-sectional data retrieval. Further, the large sample size substantially reduces our sampling error. However, it is a retrospective study with all of

its possible limitations. More prospective studies are needed to better control confounding factors and to elucidate additional charges that are not accrued at the index hospitalization. In addition, the NIS database provides total charges for each admission but not the actual cost. Cost estimates have been calculated based on total charges and an average cost-to-charge ratio for each hospital. Some studies have been performed for internal validation of these ratios, but overestimation or underestimation of the actual costs is a possibility [20]. Also, the NIS database does not provide details of costs related to supplies and instruments. Local studies or studies using costs from a single hospital system may be more informative for a detailed cost analysis.

Conclusions

During the index hospitalization, RAS is more costly than conventional LS. Total costs may be reduced at centers with higher volume of RAS. Costs may be influenced by surgeon case volume and the inherent learning curve of robotic surgery. Further analysis of long-term outcomes (including reoperations and readmissions) is needed to better compare global treatment costs for both surgical approaches.

Compliance with ethical standards

Disclosures Zhamak Khorgami, Wei T. Li, Theresa N. Jackson, C. Anthony Howard, and Guido M. Sclabas have no conflicts of interest or financial ties to disclose.

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