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Adoption of robotic technology for treating colorectal cancer

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Abstract

BACKGROUND—Debate exists regarding the role of robotic-assisted surgery in colorectal cancer. Robotic-assisted surgery has been promoted as a strategy to increase the availability of minimally-invasive surgery which is associated with improved short-term morbidity; however robotic-assisted surgery is much more expensive than laparoscopic surgery.

OBJECTIVE—We aimed to understand hospital and patient trends in adoption of robotic-assisted surgery.

DESIGN—Cross-sectional and longitudinal designs

SETTINGS—2010 and 2012 American Hospital Association surveys, 2010–2012 Nationwide Inpatient Sample

PATIENTS—U.S. hospitals responding to the American Hospital Association Survey. Colorectal cancer patients undergoing elective minimally invasive surgery or open resection.

INTERVENTIONS—None

MAIN OUTCOME MEASURES—Robotic-assisted surgery adoption by U.S. hospitals. Colorectal cancer patients treated with robotic surgery.

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RESULTS—In 2010, 20.1% of hospitals adopted robotic-assisted surgery, increasing to 27.4% by 2012. Hospitals more likely to adopt robotic-assisted surgery included teaching hospitals, those with more advanced imaging services, in metropolitan rather than rural areas, and those performing the highest inpatient surgery volume. Robotic-assisted surgery only accounted for 1.3% of colorectal cancer operations during 2010–2012, but patient probability of robotic-assisted surgery ranged from 0.1% to 15.2%. The percentage of colorectal cancer patients that were treated robotically among those undergoing minimally invasive surgery increased over time (2010: 1.5%, 2012: 3.6%). Robotic-assisted surgery is increasing more rapidly in rectal cancer patients with minimally invasive surgery (2010: 5.5%, 2012: 13.3%) versus colon cancer (2010: 1.3%, 2012: 3.3%) among patients treated with minimally invasive surgery.

LIMITATIONS—Observational study design

CONCLUSIONS—Robotic-assisted surgery uptake remains low for colon cancer, but higher for rectal cancer surgery, suggesting a more thoughtful adoption of robotic-assisted surgery for colorectal cancer by focusing its use on more technically challenging cases.

Keywords

Robotic Surgical Procedures; Colonic Neoplasms; Rectal Neoplasms; Diffusion of Innovation; Trends; American Hospital Association; Minimally Invasive Surgical Procedures; Laparoscopy

Introduction

Laparoscopic surgery has gained widespread acceptance for resection of colorectal cancer, with better short term complication rates and similar long-term outcomes relative to conventional open surgery.^{1, 2} In 2000, the da Vinci Surgical System® was approved by the FDA, as a commercially-available tool for ‘robotic’ surgery. Robotic surgical devices allow a surgeon at a console to operate remote-controlled robotic arms to facilitate the performance of complex MIS. Advantages of robotic surgical devices that address limitations of traditional laparoscopy include improved dexterity, avoidance of a fulcrum effect, stable camera platform and improved three-dimensional imaging, motion scaling, and improved physician ergonomics. Some of these advantages may be especially important in specific types of surgery, such as surgery in confined spaces for prostate or rectal cancer.^{3–5} Use of the system has been proven to be safe and feasible, but may be more time consuming, and is more expensive, without any proven clinical advantages over conventional laparoscopy for CRC.^{6, 7} In an era where a changing healthcare system forces optimization of resource utilization and critical consideration of every dollar spent on healthcare, the value of robot-assisted surgery (RAS) merits examination.⁶

Despite a lack of convincing evidence of superiority of the robot-assisted approaches in colorectal cancer, use of RAS appears to be increasing. Many hospitals in the United States have installed robotic systems. Hospitals acquire new technology for many reasons, such as the desire to improve clinical care and patient outcomes, competitive pressure from nearby hospitals resulting from the fear of being “left behind” in important developments, profit seeking, and availability of capital to adopt new technologies. Early adopters of new technologies (e.g., CT colonography, advanced imaging) tend to be teaching hospitals,

hospitals with higher patient volumes, and hospitals located in areas with higher average incomes.^{8,9} Information about the types of hospitals that are early adopters in the use of robotic surgery is lacking.

Robotic surgical systems have high fixed (capital) costs, ranging from \$1–\$2.5 million per unit. The use of robotics also adds significant cost per procedure compared with conventional laparoscopy because of longer operative times and expensive disposable equipment.¹⁰ This additional hospital spending is likely to affect the expenditures of public and private insurers.¹⁰

The use of new technology in medicine has historically outpaced the availability of data to support its rapid adoption. The process of diffusion of an innovation (e.g., new technology) can be illustrated by graphing its cumulative uptake over time.¹¹ This diffusion curve typically displays an S-shaped distribution: early in the diffusion process few individuals adopt or receive the innovation, the rate of uptake then accelerates, and finally it increases at a slower rate as fewer and fewer remaining potential individuals adopt or receive it. However, innovations often diffuse at different rates among subgroups in the population. In some instances, availability of new technology may initially increase health disparities resulting from the types and location of hospitals acquiring this technology and characteristics of patients that have access to them for various reasons.¹² In urologic surgery, where robotic surgery is employed in over 50 percent of radical prostatectomies, access is greater among whites, those who live in more affluent areas, and in teaching hospitals.¹³ The use and potential disparities associated with availability and acquisition of robot-assisted devices for patients diagnosed with colon or rectal cancer are largely unknown. The diffusion of RAS may be different from other technologies that have been proven to be effective.

Our purpose was to describe 1) the availability in 2010 and acquisition by 2012 of robotic systems across US hospitals using American Hospital Association data, 2) characteristics of patients diagnosed with malignancies of the colon and rectum that received robot-assisted surgery using the 2008–2012 Nationwide Inpatient Sample. Knowledge of the adoption patterns will help policy-makers estimate the financial impact of this technology, and will help clarify whether RAS has increased access to lower-morbidity MIS surgery for patients with colorectal cancer.

Materials and methods

American Hospital Association (AHA) data

Data were obtained from the 2010 and 2012 AHA annual cross-sectional survey to describe the availability and acquisition of robotic systems. This annual survey is mailed to all hospital CEOs in the United States, asking them to circulate it to the individuals most appropriate to complete different sections. The survey provides a cross-sectional view of US hospitals and collects data about hospital size, ownership, geographic location, services offered, and staffing. We limited our analysis to hospitals that were classified as general medical and surgical, surgical, cancer, chronic disease, or other specialty hospitals that

completed the survey. Response rate among these hospitals was 80.0% in 2010 and 80.2% in 2012.

The AHA survey asks respondents to check a box if robotic surgery, defined as the use of mechanical guidance devices to remotely manipulate surgical instrumentation, is provided by the hospital or its subsidiary. Respondents are instructed to leave the box blank if the service is not provided. We examined 1) whether or not hospitals offered robot-assisted surgery in 2010 and 2) if hospitals newly acquired this technology between 2010 and 2012.

We selected characteristics of hospitals from the 2010 AHA data that were adopters of RAS based on studies that examined adoption of new imaging tests (64-slice computed tomography and CT colonography).^{8,9} We included data about hospital ownership; size, based on total annual inpatient surgical operations; teaching status, as determined by membership in the Council of Teaching Hospitals and Health Systems; membership in the cancer program approved by American College of Surgeons; implementation of an electronic health record; provision of oncology services; and having a medical/surgical intensive care unit. We also included whether hospitals were members of hospital systems because these hospitals may (1) have different technology-adoption decision-making processes than free standing hospitals, and (2) access capital more readily. Location of hospitals was based on ten state census divisions (core based statistical areas) and whether hospitals were located in Metro, Micro, Division, or Rural counties. As a measure of early adoption of new technology, we summed the number of new imaging tests offered at each hospital (range: 0–5): Multi-slice spiral computed tomography 64, Positron emission tomography, positron emission tomography/CT, Single photon emission computerized tomography (SPECT), and virtual colonoscopy (CT colonography). We also included whether hospitals had plans to develop, execute, or evaluate diversity strategies or plans and calculated point distance to the nearest hospital with RAS as a measure of local competitiveness using ArcGIS. We used multivariable logistic regression to calculate odds ratios and 95% confidence intervals to identify predictors of hospital RAS adoption between 2010 and 2012. Hospitals that already adopted RAS by 2010 were excluded in this analysis of hospital RAS adoption.

Nationwide Inpatient Sample

Data (2010–2012) were obtained from the Nationwide Inpatient Sample to identify characteristics of CRC patients diagnosed with malignancies of the colon and rectum that received robot-assisted surgery.^{14–16} The 2010–2011 NIS is a nationally representative sample of about 20% of U.S. hospitals, resulting in a sampling frame of 97% of all discharges. About 1,000 hospitals contributed data to the NIS during 2010 and 2011. In 2012, the NIS was redesigned as a sample of discharges from all hospitals. Data elements in the 2010–2012 NIS are drawn from hospital discharge abstracts regarding admission, patient demographics and location, payer, diagnosis and procedures, and hospital characteristics.

We limited discharge data to CRC patients who underwent elective laparoscopic or open colon or rectal surgery during 2010–2012 as identified from International Classification of Disease ninth revision, Clinical Modification (ICD-9 CM) codes. We used ICD9-CM diagnostic codes 153.x to identify colon cancer, and 154.0, 154.1, 154.2, and 154.8 to

identify rectal cancer.¹⁷ We used ICD-9 CM procedure codes to identify laparoscopic surgery (17.31, 17.32, 17.33, 17.34, 17.35, 17.39, or 45.81) and open surgery (45.71, 45.72, 45.73, 45.74, 45.75, 45.76, 45.82, 45.79) and conversion from laparoscopic to open surgery (V64.41).^{17, 18} We used ICD-9 CM procedures codes 17.4× to identify robot-assisted cases.^{17, 19}

We included patient race, sex, location of residence (NCHS rural-urban code, median household income in patient zip code), expected primary payer, DRG-based mortality risk, and year of admission. We used the All Patient Refined Diagnosis Related Group (APR-DRG) mortality risk algorithm as a surrogate marker of disease severity.²⁰ This algorithm (mild, moderate, severe, and extreme) is based on patient's age, diagnosis, and procedure codes, and has high predictive validity.²¹ We constructed a hospital-level variable describing the number of robotic surgeries for non-colorectal cancer diagnoses. Because nearly 75% of hospitals did not bill for any robotic surgery, we constructed four groups of hospitals: 0 robotic surgeries, 1–59 surgeries, 60–180 surgeries, 181 or more robotic surgeries (per 3 years).

We used multivariable logistic regression to calculate odds ratios and 95% confidence intervals to identify factors predictive of RAS use, incorporating recommended discharge weights, resulting in national estimates for all analyses.

All statistical analyses for the AHA and NIS databases were conducted using SAS version 9.4 (SAS institute, Cary, NC) and Stata 13.1. Statistical significance was set at $p < 0.05$ and all tests were two sided.

Results

Hospital availability of RAS in 2010 and adoption by 2012

In 2010, 6268 hospitals responded to the AHA Survey. In 2010, 795 (20.1%) of 3963 study hospitals offered RAS (not necessarily for colorectal cancer). By 2012, 274 (9.8%) additional hospitals had adopted this technology among 2795 hospitals that did not offer RAS in 2010, for 27.4% of all hospitals in 2012. Some hospitals may have closed or opened between 2010 and 2012 resulting in different denominators.

Hospital adoption of RAS in 2010 varied according to their characteristics and locations (Table 1). RAS adoption by 2010 was highest among teaching hospitals (73.0%), hospitals accredited by the American College of Surgeons (48.3%), those with the highest quartile of inpatient surgeries (49.4%), those providing oncology services (32.2%), and those that offered more advanced imaging. These were also the types of hospitals that were more likely to acquire this technology between 2010 and 2012. By 2012, teaching hospitals owned 78.6% of all RAS, hospitals with the highest quartile of inpatient surgeries owned 86.9% of all RAS, and those providing oncology services owned 93.6% of all RAS. Of all hospitals with RAS in 2012, 66.7% were located in metropolitan areas and only 0.8% in rural hospitals.

At least one out of every four hospitals located in New England, Mid Atlantic, South Atlantic, and Pacific states offered RAS in 2010. Only one in ten hospitals located in West North Central states offered RAS in 2010. Hospitals in the West North Central states adopted this technology at lower rates than hospitals in other states.

Adjusted analysis showed that teaching hospitals, hospitals that offered more advanced imaging services, hospitals located in East, South Central, or Mountain states, and those who performed the largest volume of inpatient surgeries were more likely to acquire RAS between 2010 and 2012 than their respective counterparts (Table 1). Hospitals that were located in Micropolitan or Rural areas were less likely to acquire RAS than metropolitan hospitals. State or local hospitals were less likely to acquire RAS by 2012 compared to nongovernment nonprofit hospitals. Hospital characteristics not predictive of RAS acquisition by 2012 included accreditation by the American College of Surgeons, implementation of electronic health records, oncology service provision, diversity plan, distance to the nearest hospital with RAS, and being part of a hospital network. Model fit was excellent (c-statistic: 0.87; Hosmer and Lemeshow Goodness-of-fit p-value: 0.3174).

Because of its prominence in the model, we examined the influence of the number of inpatient surgeries on our findings by comparing logistic models with and without this variable. The c-statistic was slightly higher for a model with this variable (c-statistic difference: 0.02, $p < 0.01$). Accreditation by the American College of Surgeons, providing oncology services, and having a medical/surgical ICU were predictors of RAS adoption by hospitals in a model without the number of inpatient surgeries, but these variables were no longer predictive of RAS adoption when the number of surgeries was included in the model. This suggests that number of inpatient surgeries in 2010 was a key driver of adoption of RAS by 2012 among hospitals accredited by American College of Surgeons, those providing oncology services, and those having a medical/surgical ICU.

RAS use among CRC patients

There were an estimated 145,340 CRC patients who received surgery during 2010–2012 (36.3% received laparoscopy, 52.9% received open surgery, and 10.8% in whom laparoscopy was converted to open surgery). Table 2 shows that the distribution of type of surgery changed over time for colon cancer patients ($p < 0.001$) but not for rectal cancer patients ($p = 0.17$). Characteristics of patients receiving RAS are displayed in Table 3.

Overall, only 1.3% of CRC patients received RAS during 2010–2012, which increased over time from 0.7% in 2010, to 1.3% in 2011, and 2.0% in 2012 ($p < 0.001$). An estimated 1935 RAS (95% confidence interval: 1573 – 2296) in CRC patients were performed nationally, ranging from 0 to 60 surgeries across hospitals. Of all robotic surgeries for rectal cancer, 72% were done at hospitals with the highest volume of robotic surgeries. This was 79% for colon cancer. The percentage of CRC patients that were treated robotically among those undergoing MIS increased over time from 1.5% in 2010, to 2.5% in 2011, and 3.6% in 2012 ($p < 0.001$). The percentage of colon cancer patients that received RAS increased from 0.6% in 2010 to 1.6% in 2012 ($p < 0.001$). The percentage of rectal cancer patients that received RAS increased from 1.9% in 2010 to 5.1% in 2012 ($p = 0.002$). RAS increased rapidly in patients that received minimally-invasive surgery (5.5% in 2010, 13.3% in 2012, $p = 0.0295$).

RAS increased from 1.3% in 2010 to 3.3% in 2012 ($p=0.0137$) in colon cancer patients who received laparoscopy.

Independent factors predicting RAS use included type of cancer, mortality risk, year of admission and the interaction between year of diagnosis and type of cancer. Patients were less likely to receive RAS if they had higher than moderate DRG-related mortality risk (Table 4). Use of RAS increased in 2011 and 2012 relative to 2010 for colon cancer patients. Use of RAS was only increased in 2012 for rectal cancer patients relative to 2010 (not in 2011 versus 2010). RAS use was unaffected by patient race, sex, insurance type, or median income of the zip code of residence. The predicted percentage of CRC patients receiving RAS ranged from 0.1% to 15.2% (mean: 1.4%), suggesting wide variability across patients characteristics despite low overall use. Males and females were equally likely to receive RAS when diagnosed with rectal cancer ($p=0.4410$).

Discussion

The United States leads the world in creating health care technologies. While many advances have substantially improved health at modest cost,²² other technologies, including robotic surgery, have increased spending without producing demonstrable gains in health. In this study, we find that by 2012 over 25 percent of hospitals had adopted RAS in the United States, suggesting that RAS adoption has now moved beyond the tipping point of about 20 percent towards widespread implementation.¹¹ Our results are consistent with other studies finding that early adopters of new technologies tend to be teaching hospitals and those with higher patient volumes.⁹ Distance to the nearest hospital with RAS did not affect the adoption of RAS locally, suggesting that marketing and local competition plays a lesser role compared to the number of inpatient surgeries. One of the goals of this study was to understand the specific use of RAS for colorectal cancer, an arena in which there are clearly lower short-term complication rates for minimally-invasive surgery. Despite RAS not being superior to laparoscopic surgery for CRC, one advantage of RAS might be that it may expand access to MIS surgery to CRC patients who might otherwise have open surgery as their only option. In this study we find that RAS for rectal cancer (but not for colon cancer) did in fact increase disproportionately to laparoscopic surgery. This suggests that RAS may be resulting in more overall MIS surgery for rectal cancer, rather than just exchanging an older technology for a more expensive one.

In contrast to urologic surgery, where robotic surgery is used in over 50 percent of radical prostatectomies,^{13, 19} the overall use of robot-assisted surgery in CRC patients remains low, especially for colon cancer, where laparoscopic surgery is well-established and technically feasible for most cases. However, for the more technically challenging operations for rectal cancer, RAS increased rapidly from 5.5% in 2010 to 13.3% in 2012 (while laparoscopic use increased only from 33.5% in 2010 to 38.1% in 2012). These results may suggest that RAS is being adopted for CRC in a more thoughtful way compared to its rapid adoption across the board in areas such as hysterectomy.²³ However, conversion from minimally invasive to open surgery in rectal cancer is still a significant issue.

Certain groups of patients have less access to new technology, especially rural patients and those of lower socioeconomic status. This study confirms differential access to RAS for rural and urban patients but this was explained by the number of robotic surgeries performed for non-CRC. No patient-level differences by race, income or insurance were found. However, if it is the case that surgeons are reserving RAS for more challenging cases, it is surprising that our study finds that use is equally applied for male and female patients, given that rectal cancer surgery is usually more technically challenging for male patients. This suggests that perhaps individual surgeons adopt a single platform for rectal cancer surgery (open, laparoscopy, or robotic), and then use it for all cases.

This study is limited by its observational nature. This includes some limitations pertaining to the NIS database, such as limited availability of clinical data, possible bias from coding inaccuracies, an inability to show complete episode of care, lack of representation of all hospital types, and lack of information on revenue or cost. The data also underestimate the total number of discharges because it does not include federal hospitals. The CPT code for RAS also does not distinguish between single-site and other RAS platforms. Also, we do not have information about who completed the AHA Survey at the hospitals. It is possible that the individual completing the survey may not have known whether the hospital provides RAS, particularly if the service was recently added. No data was available in the AHA Survey about the number of prostatectomies, which likely account for the majority of robotic procedures. Finally, the acquisition of additional robotic systems among hospitals with RAS was unable to be determined from the AHA Survey data.

In sum, future increases in healthcare spending could be moderated if costly new medical services such as RAS were adopted more selectively. It appears that for CRC patients, RAS is in fact being adopted more thoughtfully – for the more challenging subset of rectal cancer cases, and not for colon cancer cases. Nevertheless, there is wide variation in use of this technology that likely is related to market forces, and there is still a great deal of variation in access to MIS surgery for CRC across patients and hospitals.

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Table 1

Characteristics of hospitals offering RAS in 2010 and those that adopted RAS by 2012.

Hospital characteristic	Offering RAS in 2010 on site		Adoption of RAS by 2012 (among those without technology in 2010)		Adjusted odds ratio (95% CI)
	N	%	n	%	
Overall	3,963	20.1	2,795	9.8	N/A
Organizational structure					
Government, nonfederal	911	10.1	743	4.2	0.56 (0.35 – 0.89)
Nongovernment, nonprofit	2,402	25.4	1,635	11.6	1.00
Investor	576	14.6	377	12.7	1.00 (0.65 – 1.53)
Government, federal	74	10.8**	40	15.0**	0.60 (0.20 – 1.82)
Teaching hospital					
Yes	293	73.0	70	35.7	2.31 (1.20 – 4.45)
No	3,670	15.8**	2,725	9.1**	1.00
Accredited by American College of Surgeons					
Yes	1,284	48.3	596	24.7	1.14 (0.82 – 1.59)
No	2,679	6.5**	2,199	5.8**	1.00
Electronic health record					
Yes (fully/partially implemented)	2,943	24.0	2,064	11.2	1.47 (0.94 – 2.31)
No	546	5.9**	731	3.8**	1.00
Missing	474	12.0			
Oncology services					
Yes	2,368	32.2	1,440	16.2	1.14 (0.74 – 1.74)
No	1,595	2.0**	1,355	3.0**	1.00
Diversity plan/program					
Yes	2,354	28.9	1,510	12.8	0.97 (0.68 – 1.43)
No	1,226	7.1	1,018	5.1	1.00
Missing	383	7.3**	267	10.9**	2.26 (1.23 – 4.16)
Medical/surgical ICU					
Yes	2,914	26.6	1,905	13.8	1.14 (0.56 – 2.31)

Hospital characteristic	Offering RAS in 2010 on site			Adoption of RAS by 2012 (among those without technology in 2010)		
	N	%	n	%	Adjusted odds ratio (95% CI)	
No	1,049	1.9**	890	1.4**	1.00	
Number of inpatient surgeries						
Q1 (0 – 87)	784	0.1	700	0.3	1.00	
Q2 (88 – 567)	816	0.5	698	1.6	2.76 (0.57 – 13.44)	
Q3 (568 – 1677)	854	5.2	699	8.2	7.74 (1.62 – 37.08)	
Q4 (1678+)	1,509	49.4**	698	29.2**	22.82 (4.65 – 111.95)	
Part of network						
Yes	1,510	25.0	1,032	11.1	1.12 (0.83 – 1.50)	
No	2,453	17.0**	1,763	9.0	1.00	
Core Based Statistical Area						
Division	547	36.8	282	20.6	1.23 (0.82 – 1.83)	
Metropolitan areas	1,735	32.1	1,013	16.5	1.00	
Micropolitan areas	715	4.8	623	6.9	0.62 (0.39 – 0.96)	
Rural areas	966	0.4**	877	0.7**	0.26 (0.10 – 0.68)	
Region						
New England	162	26.5	100	7.0	0.61 (0.22 – 1.65)	
Mid Atlantic	341	31.1	209	12.9	0.74 (0.37 – 1.49)	
South Atlantic	583	26.1	363	13.2	1.39 (0.75 – 2.57)	
East North Central	637	22.5	447	10.5	1.16 (0.63 – 2.14)	
East South Central	350	16.0	255	11.4	2.51 (1.26 – 5.02)	
West North Central	575	9.7	489	4.1	1.00	
West South Central	632	13.5	492	9.8	1.60 (0.85 – 2.99)	
Mountain	291	20.3	207	10.6	2.50 (1.21 – 5.16)	
Pacific	383	24.8**	233	11.2**	1.05 (0.53 – 2.10)	
Advanced imaging						
0	1,414	2.4	1,187	1.9	1.00	
1	884	10.9	698	9.6	1.99 (1.16 – 3.41)	
2	748	23.1	516	15.7	2.42 (1.39 – 4.19)	
3	430	40.9	233	24.0	3.38 (1.86 – 6.14)	

Hospital characteristic	Offering RAS in 2010 on site		Adoption of RAS by 2012 (among those without technology in 2010)		Adjusted odds ratio (95% CI)
	N	%	n	%	
4	297	53.2	131	27.5	3.10 (1.61 – 5.97)
5	190	83.2**	30	36.7**	4.38 (1.71 – 11.18)
Distance to nearest hospital with RAS (miles)					
Quartile 1	989***	45.7**	699****	21.0	1.00
Quartile 2	987	20.4	697	8.5	0.96 (0.65 – 1.42)
Quartile 3	988	9.9	701	5.3	1.06 (0.64 – 1.74)
Quartile 4	988	4.4	698	4.4**	1.00 (0.59 – 1.73)

*
p<0.05;

**
p<0.001

New England: ME,NH,VT,MA,RI,CT; Mid Atlantic: NY,NJ,PA; South Atlantic: DE,MD,DC,VA,NC,SC,GA,FL; East North Central: OH,IN,IL,MI,WI; East South Central: KY,TN,AL,MS; West North Central: MN,IA,MO,ND,SD,NE,KS; West South Central: AR,LA,OK,TX; Mountain: MT,ID,WY,CO,NM,AZ,UT,NV; Pacific: WA,OR,CA,AK,HI; Associated areas: Marshall Islands, Puerto Rico, Virgin Islands, Guam, American Samoa, Northern Mariana Islands

Q1: 0 – 6.2; Q2: 6.3 – 25.0; Q3: 25.1 – 49.8; Q4: 49.9 miles

Q1: 0 – 13.1 ; Q2: 13.2 – 32.4 ; Q3: 32.5 – 57.3 ; Q4: 57.4+ miles

Table 2

Distribution in type of surgery (%) over time for colon and rectal cancer, 2010–2012.

	Year	Minimally Invasive Surgery	Open surgery	Conversion from minimally invasive to open surgery	Total Number (%)
Colon cancer *	2010	35.6	57.2	7.2	43,436 (100.0)
	2011	39.7	51.4	8.8	45,897 (100.0)
	2012	40.5	51.3	8.3	42,520 (100.0)
Rectal cancer **	2010	11.7	52.6	35.7	4,269 (100.0)
	2011	14.9	48.1	37.1	4,779 (100.0)
	2012	15.2	47.2	37.6	4,440 (100.0)

* p<0.001;

** d=0.1708

Table 3

Colon and rectal cancer patients receiving robot-assisted surgery, 2010–2012.

Patient characteristic	Weighted n	% received RAS
Primary expected payer		
Medicare	87,085	1.2
Medicaid	5,682	1.6
Private, including HMO	46,998	1.5
Self-pay	2,399	1.4
No charge	354	1.4
Other	2,533	0.9
Race		
White	103,630	1.4
Black	13,940	1.3
Hispanic	7,795	1.6
Asian/Pacific Islander	3,274	1.5
Native American	520	1.0
Other	3,213	2.3
Sex		
Male	70,299	1.4
Female	74,903	1.3
Location of residence		
Central counties of metro areas 1 million population or more	36,804	1.8
Fringe counties of metro areas 1 million population or more	34,375	1.2
Counties in metro areas 250,000–999,999 population	27,447	1.5
Counties in metro areas 50,000–249,999 population	13,973	1.0
Micropolitan counties	17,513	0.5
Not metropolitan/micropolitan counties	12,882	0.7**
Median household in patient zip code		
\$1–\$38,999	35,516	1.0
\$39,000–\$47,999	37,262	1.1
\$48,000–\$62,999	36,011	1.5
\$63,000+	33,883	1.7*
Type of cancer		
Colon	131,853	1.2
Rectal	13,487	3.0**
Mortality risk		
Minor	56,470	1.7
Moderate	59,528	1.1
Major	21,949	1.0
Extreme	7,383	1.0**
Illness severity/loss of function		

Patient characteristic	Weighted n	% received RAS
Minor	37,693	1.8
Moderate	68,952	1.2
Major	30,014	1.1
Extreme	8,681	1.3 *
Year of admission		
2010	47,705	0.7
2011	50,675	1.3
2012	46,960	2.0 **
Number of non-CRC robotic surgery (per 3 years)		
0 surgeries	51,066	0.0
1–59 surgeries	10,933	0.9
60–180 surgeries	15,188	2.2
181 or more surgeries	68,154	2.2 **

* P<0.05;

** p<0.0001

Table 4

Multivariable model of colon and rectal cancer patients receiving robot-assisted surgery, 2010–2012.

Patient characteristic	OR (95% CI)
Number of non-CRC robotic surgery (per 3 years)	
0 surgeries	No robotic surgeries
1–59 surgeries	0.33 (0.19 – 0.57)
60–180 surgeries	0.62 (0.42 – 0.92)
181 or more surgeries	1.00
Mortality risk	
Minor	1.00
Moderate	0.76 (0.60 – 0.97)
Major	0.77 (0.53 – 1.11)
Extreme	0.87 (0.48 – 1.56)
Cancer type - year of diagnosis	
Colon – 2010	1.00
Colon – 2011	2.57 (1.33 – 4.99)
Colon – 2012	3.10 (1.56 – 6.15)
Rectal – 2010	1.00
Rectal – 2011	0.95 (0.45 – 1.99)
Rectal – 2012	3.31 (1.63 – 6.74)