



Is robotic utilization associated with increased minimally invasive colorectal surgery rates? Surgeon-level evidence

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Abstract

Background It is unclear whether robotic utilization has increased overall minimally invasive colorectal surgery rates or if robotics is being adopted instead of laparoscopy. The goal was to evaluate whether increasing robotic surgery utilization is associated with increased rates of overall colorectal minimally invasive surgery.

Methods The Statewide Planning and Research Cooperative System (New York) was used to identify patients undergoing elective colectomy or proctectomy from 2009 to 2015. Individual surgeons were categorized as having increasing or non-increasing robotic utilization (IRU or non-IRU, respectively) based on the annual increase in the proportion of robotic surgery performed. The odds of surgical approach across the study period were evaluated with multinomial regression.

Results Among 72,813 resections from 2009 to 2015, minimally invasive-surgery increased (47–61%, $p < 0.0001$). For colectomy, overall minimally invasive-surgery rates increased (54–66%, $p < 0.0001$), laparoscopic remained stable (53–54%), and robotics increased (1–12%). For proctectomy, overall minimally invasive-surgery rates increased (22–43%, $p < 0.0001$), laparoscopic remained stable (20–21%), and robotics increased (2–22%). Over the study period, 2487 surgeons performed colectomies. Among 156 surgeons with IRU for colectomies, robotics increased (2–29%), while laparoscopy decreased (67–44%), and open surgery decreased (31–27%). Overall, surgeons with IRU performed minimally invasive colectomies 73% of the time in 2015 versus 69% in 2009. Over the study period, 1131 surgeons performed proctectomies. Among 94 surgeons with IRU for proctectomies, robotics increased (3–42%), while laparoscopy decreased (25–15%), and open surgery decreased (73–44%). Overall, surgeons with IRU performed minimally invasive proctectomy 56% of the time in 2015 versus 27% in 2009. Patients in the latter study period had 57% greater odds of undergoing robotic surgery.

Conclusions Overall, minimally invasive colorectal resections increased from 2009 to 2015 largely due to increasing robotic utilization, particularly for proctectomies.

Keywords Robotic surgery · Colorectal surgery · Colectomy · Proctectomy

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Colon and rectal resections are among the most common operations performed in the United States [1]. Since the advent of minimally invasive techniques in the early 1990's, there has been a concerted effort to critically assess the role of minimally invasive-surgery (MIS) in colorectal resections [2–4]. By the mid 1990's, 25 randomized controlled trials were published addressing whether MIS was superior to open techniques. A Cochrane Library meta-analysis demonstrated that compared to open colorectal resections, MIS was associated with reduced post-operative pain, faster resolution of post-operative ileus, shortened hospitalizations, and reduced morbidity [5]. Over the past 2 decades, many studies have built on this early evidence supporting MIS for

the treatment of benign and malignant colorectal pathology [6–10].

Studies evaluating minimally invasive colorectal surgery have largely focused on colectomies alone or rarely distinguish them from proctectomies [11, 12]. Studies of proctectomies suggest that there has been slower adoption of MIS compared to colectomies [13]. Consequently, some experts have suggested that a potential route toward increasing value and outcomes in rectal surgery could be through expanded robotic use as the robot has technical advantages in the constraints of the pelvis [14]. At the surgeon-level, the trends of robotic utilization for colon and rectal surgery have not been studied beyond small samples. Whether robotic surgery increases MIS for colon, and especially rectal, resections remains unclear.

A population-based, all-payer study was performed to evaluate whether an overall increase in MIS has occurred for colectomies and proctectomies over time. We aimed to determine whether robotic surgery is being increasingly adopted over open techniques or whether an intra-MIS migration has occurred with cases shifting from laparoscopic to robotic. A priori, our hypothesis was that for colectomies, robotic surgery has largely replaced laparoscopy resulting in a modest increase in the overall rate of MIS. Conversely for proctectomies, we hypothesized that robotic operative approaches have supplanted both open and laparoscopic approaches resulting in significantly increased rates of minimally invasive proctectomies.

Materials and methods

Data source and study population

Adults who underwent elective colectomy or proctectomy between 2009 and 2015 in the Statewide Planning and Research Cooperative System (SPARCS) database were included. This database is an all-payer, population-based, hospital reporting system from the New York Department of Health which captures patient-level data on all non-Veteran Affairs hospitals. Unique hospital and surgeon identifiers are captured for each admission; numerous previous studies have described the unique identifiers [10, 15–17]. SPARCS was linked to the American Medical Association Physician Masterfile and American Board of Medical Specialties database (Medical Marketing Service, Inc, Woodale, IL) to determine surgeon board certification and duration of practice. Linkage to the American Hospital Association database from the Council of Teaching Hospitals was performed to attain urban or rural location and major academic status as defined by the Council of Teaching Hospitals.

Patient-, surgeon- and hospital-level factors

Age, sex, race, receipt of Medicaid insurance and comorbidity burden were captured for each patient. Comorbidities were captured as previously described and the Van Walraven Elixhauser modification was used to compare comorbidity as derived from administrative data ICD codes; the disease burden was classified as low-, moderate- and high-risk [18–21]. In addition to surgeon-years in practice and board certification, surgeon volume for colectomy (low < 12, medium 12–32, high \geq 33) and proctectomy (low < 5, medium 6–18, high \geq 19) was calculated and categorized by tertile. In addition to hospital rural or academic status, hospital volume for colectomy (low < 97, medium 98–218, high \geq 219) and proctectomy (low < 34, medium 34–87, high \geq 88) was calculated and categorized by tertile.

Outcome measures

Surgeons were classified as having increasing or non-increasing robotic utilization (IRU or non-IRU, respectively) for colectomy and proctectomy. Surgeons with IRU had an overall increasing trend in robotic utilization over time whereas non-IRU surgeons did not have an increasing trend in robotic utilization over time. The primary outcome was change in operative approach rates over time; this was further explored among surgeons with IRU. Factors associated with operative approach were also examined.

Statistical analysis

Linear regression models were used to estimate the association between year of surgery and yearly rates of robotic surgery for each surgeon. The slope for year of surgery represents the average annual change in proportional use of robotic surgery. If the slope averaged over all years was positive, surgeons were classified as having IRU, whereas surgeons who did not have a positive average slope were classified as having non-IRU [22]. For example, if a surgeon had 1 year of increased proportional use of robotic surgery, 1 year of decreased proportional use of robotics but a smaller percentile change than the increase, and then otherwise stable usage, then the overall slope would still remain positive and this surgeon would be considered to have IRU. Surgeon characteristics across IRU or non-IRU groups were evaluated using the χ^2 test, two-sided *t* test and Kruskal–Wallis test, as appropriate to the data. Similarly, patient characteristics were compared by operative approach. Bayesian multinomial regression, accounting for clustering at the hospital- and surgeon-level was used to estimate the odds of surgical approach at the patient-level. The R package MCMCglmm was used to perform the multinomial regression analysis (R

version 3.5.1; R Foundation, Vienna, Austria). All other data manipulation and analyses were performed on SAS software version 9.4 (SAS Institute, Cary, NC, USA). The study was approved by the University of Rochester (IRB#00054886) Institutional Review Board.

Results

Between 2009 and 2015, 72,813 patients met eligibility criteria (Fig. 1 and Table 1). Overall, 2487 surgeons (156 or 6% had IRU for colectomy) performed 57,237 elective colectomies. Over the same period, 1311 surgeons (94 or 7% had IRU for proctectomy) performed 15,576 elective proctectomies. Thirty-seven percent of the colectomy IRU surgeons were board certified in colorectal surgery, and while this group tended to have had fewer years in practice, 29% still had greater than 21 years of experience (Table 2). Fifty-three percent of the proctectomy IRU surgeons were board certified in colorectal surgery, and while they tended to be less experienced, 28% still had over 21 years of experience. The majority of proctectomy IRU surgeons also were colectomy IRU surgeons; however, only 46% of colectomy IRU surgeons also had IRU for proctectomies. Among surgeons with IRU, the rate of conversion-to-open among robotic cases decreased from 5.5% in 2009 to 2.8% in 2015 (p -value 0.1894).

For the entire cohort, the rate of minimally invasive colorectal resections increased from 47% in 2009 to 61% in 2015, $p < 0.0001$. For colectomies, the rate of MIS increased from 54% in 2009 to 66% in 2015 ($p < 0.0001$). For colectomies, this overall increase in MIS was accompanied by increased rates of robotics from 1% in 2009 to 12% in 2015 and stable rates of laparoscopic colectomy at 53% in 2009 and 54% in 2015 ($p < 0.0001$, Fig. 2).

Similarly, for proctectomies, the overall MIS rate increased from 22 to 43% ($p < 0.0001$). When classifying by type of MIS proctectomy, robotic use increased from 2% in 2009 to 22% in 2015 while laparoscopy remain unchanged at 20% in 2009 and 21% in 2015 ($p < 0.0001$, Fig. 3).

Both surgeons with IRU and non-IRU for colectomy had increased rates of MIS over time, from 69 to 73% for IRU surgeons ($p = 0.0006$) and 48–61% for non-IRU surgeons ($p < 0.0001$). Among surgeons with IRU for colectomy ($n = 156$), the rate of robotic use increased from 2% in 2009 to 29% in 2015; meanwhile, there was a large decrease in the proportion of laparoscopic cases over time from 67 to 44% and a smaller decrease in the proportion of open cases 31–27% ($p < 0.0001$, Fig. 4).

Both surgeons with IRU and non-IRU for proctectomy had increased rates of MIS overtime from 27 to 56% for IRU surgeons ($p < 0.0001$) and 20–31% for non-IRU surgeons ($p < 0.0001$). Among surgeons with IRU for proctectomies ($n = 94$), the rate of robotic use increased from 3% in 2009 to 42% in 2015; meanwhile, there was a small decrease in the proportion of laparoscopic cases over time from 25 to 15% and a large decrease in the proportion of open cases from 73 to 44% ($p < 0.0001$, Fig. 5).

In multivariable analysis, after controlling for patient-, surgeon- and hospital-level characteristics (Table 3), patients were more likely to undergo robotic surgery in recent years (2013–2015) as compared to earlier years (2009–2012). Compared to a robotic approach, the odds of laparoscopic surgery decreased in recent years by 76%, and the odds of open surgery also decreased in recent years by 82%. As compared to robotic surgery, patients age 75 or greater had 42% greater odds of receiving laparoscopic surgery and 65% greater odds of receiving open surgery. As compared to patients without Medicaid insurance, those who had Medicaid insurance had 52% greater odds of receiving open surgery instead of robotic. The odds of operative approach did not significantly vary by race in multinomial analysis. As compared to robotic surgery, patients with medium and high comorbidity scores were 43% and 121%, respectively, more likely to undergo open surgery. Patient who had operations by high volume surgeons were 71% less likely to undergo open surgery as compared to robotic, than patients who had surgery by low volume surgeons. Patients who had operations at higher volume hospitals, as compared to robotic surgery, were less likely to undergo laparoscopic and open surgery. As surgeon experience increases, the odds of performing laparoscopic surgery, as compared to robotic, significantly decreases (Fig. 6).

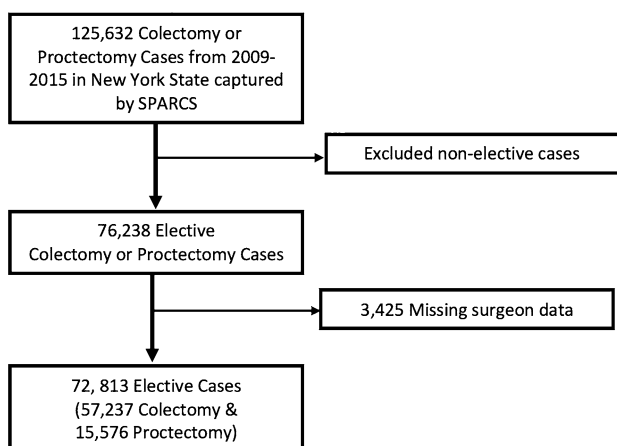


Fig. 1 Study population

Table 1 Factors associated with operative approach

	Robotic	Lap	Open
Surgery year* [^]			
2009–2012	1163 (26.3%)	21,398 (59.1%)	20,360 (63.3%)
2013–2015	3263 (73.7%)	14,802 (40.9%)	11,827 (36.7%)
Patient age* [^]			
≤ 60	2292 (51.8%)	17,519 (48.4%)	14,285 (44.4%)
61–74	1450 (32.8%)	12,015 (33.2%)	10,584 (32.9%)
≥ 75	684 (15.4%)	6666 (18.4%)	7318 (22.7%)
Male patient* [^]			
	2214 (50.0%)	17,099 (47.2%)	14,247 (44.3%)
Medicaid insurance*			
No	4290 (96.9%)	35,136 (97.1%)	30,718 (95.4%)
Yes	136 (3.1%)	1064 (2.9%)	1469 (4.6%)
Patient race* [^]			
White	3606 (81.5%)	28,190 (77.9%)	24,343 (75.6%)
Black	298 (6.7%)	3043 (8.4%)	3279 (10.2%)
Other	522 (11.8%)	4967 (13.7%)	4565 (14.2%)
Surgery* [^]			
Proctectomy	1744 (39.4%)	3333 (9.2%)	10,499 (32.6%)
Colectomy	2682 (60.6%)	32,867 (90.8%)	21,688 (67.4%)
ECS risk* [^]			
Low	1442 (32.6%)	13,964 (38.6%)	8700 (27.0%)
Medium	1888 (42.7%)	13,990 (38.6%)	13,000 (40.4%)
High	1096 (24.8%)	8246 (22.8%)	10,487 (32.6%)
Surgeon Volume (tertile)* [^]			
Low	299 (6.8%)	5553 (15.3%)	11,206 (32.8%)
Med	935 (21.1%)	11,556 (31.9%)	11,414 (35.5%)
High	3192 (72.1%)	19,091 (52.7%)	9567 (29.7%)
Hospital volume (tertile)* [^]			
Low	648 (14.6%)	8418 (23.3%)	11,445 (35.6%)
Med	1862 (42.1%)	12,458 (34.4%)	9805 (30.4%)
High	1916 (43.3%)	15,324 (42.3%)	10,937 (34.0%)
Rural hospital* [^]			
No	4359 (98.5%)	34,671 (95.8%)	30,225 (93.9%)
Yes	67 (1.5%)	1529 (4.2)	1962 (6.1%)
Academic hospital* [^]			
No	1820 (41.1%)	18,287 (50.5%)	15,972 (49.6%)
Yes	2606 (58.9%)	17,913 (49.5%)	16,215 (40.5%)
Colorectal surgery boarded* [^]			
No	1090 (24.6%)	19,367 (53.5%)	20,047 (62.3%)
Yes	3336 (75.4%)	16,833 (46.5%)	12,140 (37.7%)
Surgeon-years of experience* [^]			
< 5 years	375 (8.5%)	4475 (12.4%)	2484 (7.8%)
5–9 years	1099 (24.8%)	7478 (20.7%)	4792 (14.9%)
10–14 years	757 (17.1%)	6231 (17.2%)	4856 (15.1%)
15–19 years	794 (17.9%)	5700 (15.7%)	5003 (15.5%)
20–24 years	870 (19.7%)	5135 (14.2%)	5450 (16.9%)
≥ 25 years	531 (12%)	7181 (19.8%)	9602 (29.8%)

**p*-value < 0.05 for robotic compared to open[^]*p*-value < 0.05 for robotic compared to laparoscopic

Table 2 Surgeon characteristics

	Surgeons performing Colectomy (<i>n</i> = 2487)	
	Surgeons with IRU (<i>n</i> = 156, 6.3%)	Surgeons with non-IRU (<i>n</i> = 2331, 93.7%)
Surgeon years of experience		
10 or less	53 (34.0%)	566 (24.3%)
11–20	58 (37.2%)	654 (28.1%)
21 or more	45 (28.8%)	1111 (47.7%)
Colorectal surgery boarded		
No	99 (63.5%)	2221 (95.3%)
Yes	57 (36.5%)	110 (4.7%)
	Surgeons performing proctectomy (<i>n</i> = 1311)	
	Surgeons with IRU (<i>n</i> = 94, 7.2%)	Surgeons with non-IRU (<i>n</i> = 1217, 92.8%)
Surgeon years of experience		
10 or less	30 (31.9%)	279 (22.9%)
11–20	38 (40.4%)	342 (28.1%)
21 or more	26 (27.6%)	596 (48.9%)
Colorectal surgery boarded		
No	44 (46.8%)	1101 (90.5%)
Yes	50 (53.2%)	116 (9.5%)

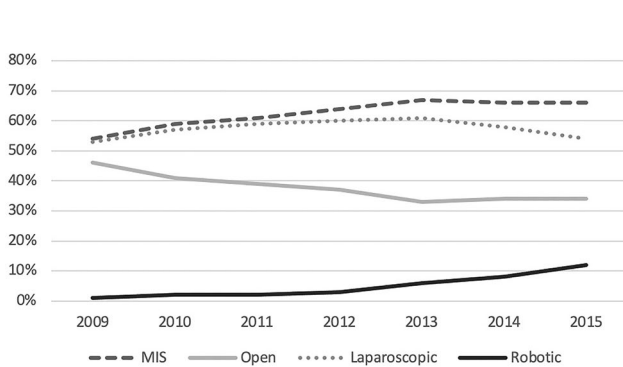


Fig. 2 Colectomy surgical approach over time

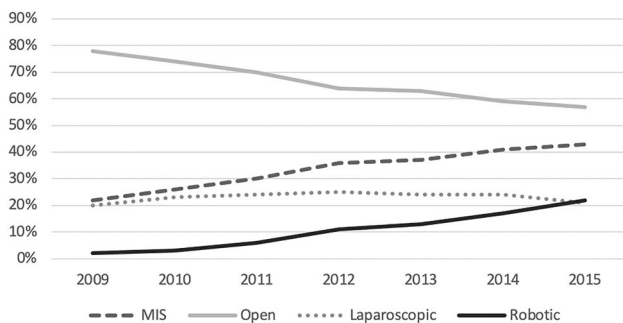


Fig. 3 Proctectomy surgical approach over time

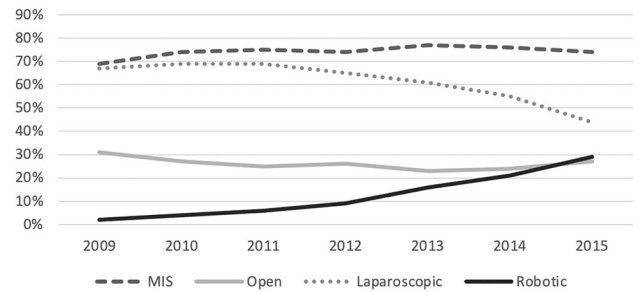


Fig. 4 Colectomy surgical approach over time among surgeons with increasing robotic utilization

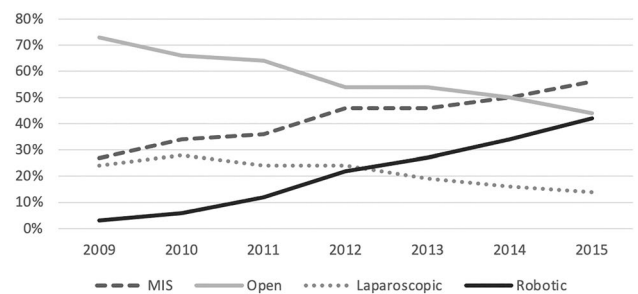
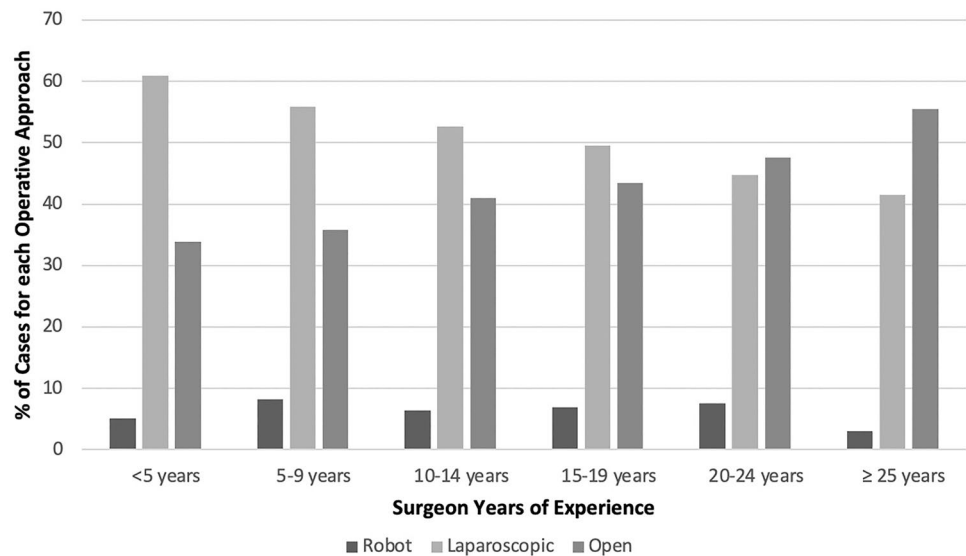


Fig. 5 Proctectomy surgical approach over time among surgeons with increasing robotic utilization

Table 3 Multinomial regression: factors associated with surgical approach

	Robotic	Lap	Open
Surgery year			
2009–2012	Ref	Ref	Ref
2013–2015	Ref	0.242 (0.214, 0.265)	0.180 (0.163, 0.202)
Patient age			
≤ 60	Ref	Ref	Ref
61–74	Ref	1.059 (0.937, 1.173)	1.007 (0.901, 1.118)
≥ 75	Ref	1.418 (1.245, 1.648)	1.651 (1.427, 1.893)
Female	Ref	Ref	Ref
Male	Ref	0.937 (0.846, 1.009)	0.823 (0.752, 0.889)
Medicaid insurance			
No	Ref	Ref	Ref
Yes	Ref	1.005 (0.825, 1.237)	1.528 (1.220, 1.918)
Patient race			
White	Ref	Ref	Ref
Black	Ref	1.084 (0.916, 1.271)	0.992 (0.882, 1.172)
Other	Ref	1.099 (0.922, 1.277)	0.980 (0.875, 1.132)
Surgery			
Proctectomy	Ref	Ref	Ref
Colectomy	Ref	7.070 (6.507, 8.077)	1.155 (1.037, 1.273)
ECS risk			
Low	Ref	Ref	Ref
Medium	Ref	1.074 (0.978, 1.155)	1.433 (1.306, 1.588)
High	Ref	1.073 (0.998, 1.153)	2.209 (2.004, 2.382)
Surgeon volume (tertile)			
Low	Ref	Ref	Ref
Med	Ref	1.012 (0.786, 1.290)	0.489 (0.392, 0.591)
High	Ref	1.354 (1.024, 1.612)	0.288 (0.224, 0.341)
Hospital volume (tertile)			
Low	Ref	Ref	Ref
Med	Ref	0.553 (0.453, 0.651)	0.596 (0.483, 0.715)
High	Ref	0.551 (0.418, 0.681)	0.423 (0.327, 0.544)
Rural hospital			
No	Ref	Ref	Ref
Yes	Ref	0.709 (0.369, 1.970)	1.485 (0.67, 3.754)
Academic hospital			
No	Ref	Ref	Ref
Yes	Ref	0.758 (0.321, 1.637)	0.666 (0.331, 1.272)
Colorectal surgery boarded			
No	Ref	Ref	Ref
Yes	Ref	0.310 (0.215, 0.474)	0.345 (0.242, 0.536)
Surgeon years of experience			
< 5 years	Ref	Ref	Ref
5–9 years	Ref	0.624 (0.504, 0.744)	0.906 (0.749, 1.203)
10–14 years	Ref	0.601 (0.491, 0.792)	0.986 (0.781, 1.283)
15–19 years	Ref	0.338 (0.247, 0.498)	0.702 (0.533, 1.046)
20–24 years	Ref	0.160 (0.117, 0.255)	0.423 (0.301, 0.655)
≥ 25 years	Ref	0.190 (0.144, 0.291)	0.689 (0.517, 0.985)

Fig. 6 Years of surgeon experience vs operative approach



Discussion

In this population-based, all-payer study, the proportion of patients undergoing minimally invasive colorectal resections increased significantly from 2009 to 2015. Importantly, while increased robotic utilization was associated with some decreased laparoscopy use there was also a simultaneous decrease of open resections. This was observed for both colectomies and proctectomies; however, the increasing utilization of robotic surgery was far more pronounced for surgeons performing proctectomies. Together, these findings suggest that although the increased utilization of a robotic approach for colectomies is largely due to a transition from a laparoscopic approach to a robotic one, with similar colectomy MIS rates, the robotic approach appears to be superseding both laparoscopic and open approaches for proctectomies in real world practice, with increased proctectomy MIS rates.

These New York State, all-payer data support a recent nationwide Medicare study which concludes that robotic colectomy has largely replaced laparoscopic rather than open surgery when looking at hospital-level data [22]. However, given a stable rate of laparoscopic proctectomy over our study period (20% vs 21%), robotic proctectomy has largely replaced open proctectomy with a decrease in open surgery from 78% of cases down to 43%. The Robotic Versus Laparoscopic Resection for Rectal Cancer trial concluded that for cancer, robotic surgery does not confer an advantage over laparoscopic surgery [23]. However, the presented data would challenge that conclusion given that the robot allowed 35% more proctectomy cases to be approached with MIS. As suggested elsewhere, this change is likely due to the shorter learning curve and improved dexterity of the robot, compared to laparoscopy, particularly in pelvic surgery [24, 25].

This study has direct implications regarding quality of care delivery to patients and value of robotic surgery, particularly for rectal surgery, where robotic utilization is associated with the observed increase in MIS proctectomy rather than merely replacing laparoscopic cases which would have instead led to observing stable MIS [22, 26].

The robotic learning curve appears to also apply to older surgeons. Our group previously reported a strong inverse relationship between surgeon-years in practice and the rate of MIS colectomy utilization [27]. Our current data, however, would suggest that the relationship is not inverse if we look specifically at robotic surgery. The youngest surgeons perform robotic cases 5% of the time but this increases with surgeons who have practiced 5–9 years to 8%. Furthermore, surgeons in practice for 20–24 years performed robotic cases 8% of the time as well. While this data are not conclusive, it does suggest that the robotic platform could possibly allow older surgeons to adopt and offer a minimally invasive approach more readily than laparoscopic surgery.

Our study has inherent limitations due to its retrospective nature and data source. There is certainly selection bias with regards to which patients received open versus laparoscopic versus robotic surgery, although the goal of the study was to describe the existing trends in surgical approach which are innately biased. Furthermore, our multinomial analysis has adjusted for the captured confounders. While SPARCS data are abstracted by trained medical records personnel, audited and verified, it remains at risk for miscoding. Nonetheless, there is no reason to believe that miscoding would be differential with regards to the study outcomes. Furthermore, SPARCS is limited to New York State and as such, its generalizability may not apply to all of the United States or abroad. Nevertheless, New York state is not too unlike other states with one

largest metro area, a few smaller metro areas and extensive rural mileage. Moreover, our surgeon characteristics are limited to readily available facts such as years since completion of training and board certification. Data on previous laparoscopic or robotics specialty training or years of robotic usage are not readily available. Additionally, using SPARCS, we cannot discern whether surgeons with IRU versus non-IRU reflects a lack of surgeon access to robotic consoles or console time versus the choice to not utilize robotics. Furthermore, patient preference data are not collected in SPARCS, and as such, we cannot comment how patient preference influenced each individual operative approach nor how it influenced individual surgeons to utilize robotics or not. Additional factors which could drive operative approach choice are also not captured by our data; as such, our data are purely observational and we cannot demonstrate causation. Lastly, our data begins looking at surgeon proportional use in 2009; as such, if a surgeon maximized his/her robotic usage prior to our study period and had only steady usage thereafter, then he/she would not be labeled as a robotic user. However, given that at the onset of our study period only 1% of colectomies and 2% of proctectomies were performed robotically with limited patients in the robotic literature/series prior to 2009, we expect that few surgeons, if any, are missed by our definition.

Notwithstanding these limitations, this is the first study to demonstrate an association between robotic surgery and increasing MIS proctectomy with a concurrent decrease in open proctectomy. While hospital-level data on robotic adoption's influence on MIS have previously been published and argue that there may be limited value with regards to robotic colectomy, surgeon-level data have not been published and proctectomy data have not been published. Here, we are able to demonstrate that during the study period, surgeons who had IRU increased their rate of MIS proctectomy by over 200% (27–56% across study period) while those who had non-IRU only increased by about 50% (20–31% over study period). Furthermore, this study is the first to demonstrate that at the surgeon-level a robotic approach does not markedly decline with years of experience, as does laparoscopy, but actually remains stable.

In conclusion, the rate of MIS for colorectal resections has significantly increased from 2009 to 2015, particularly for proctectomies. The increase in MIS has occurred in the setting of overall stable laparoscopic cases and increased robotic cases, while surgeons with IRU specifically have had increased robotic cases with simultaneous decrease in both open and laparoscopic approaches. Older surgeons also have had IRU, and an inverse relationship between age and robotic usage does not seem to exist as it does for laparoscopy.

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Declarations

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