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Rates of Minimally Invasive Surgery After Introduction of Robotic-Assisted Surgery for Common General Surgery Operations

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Importance: Many patients who would benefit from minimally invasive surgery (MIS) have open surgery; robotic-assisted surgery (RAS) addresses some of the limitations of laparoscopic surgery and could increase rates of MIS across different patient populations.

Objective: To determine whether the introduction of RAS increases MIS rates and whether increases are seen across different patient populations undergoing common general surgery procedures.

Design: A retrospective cohort study was performed to compare rates of MIS in the year before and after the index date for hospitals that did and did not introduce RAS. Generalized estimating equation regression models were used to compare rates in MIS over time.

Setting: PINC AI Healthcare Database, an all-payor discharge database of hospitals in the United States.

Participants: Hospitals that performed cholecystectomy, inguinal hernia repair, ventral hernia repair, and colorectal resection from 2016 to 2022.

Exposure: RAS hospitals performing at least 1 common general surgery procedure using RAS.

Main Outcome and Measure: The primary analysis examined rates of MIS, defined as the rate of common general surgeries that were minimally invasive (laparoscopic or RAS) in a hospital. The secondary analysis examined MIS rates for common general surgeries, across age, sex, race, ethnicity, and payor.

Results: Of 408 hospitals included in the study, 153 (38%) introduced RAS for common general surgeries. The relative MIS rate for hospitals that introduced RAS compared with hospitals that did not went from 1.08 (95% confidence interval [CI], 1.02–1.14; $P < 0.01$) before the index date to 1.15 (95% CI, 1.09–1.22; $P < 0.01$) after the index date ($P_{interaction} < 0.01$), indicating a larger increase in MIS rates among hospitals introducing RAS. MIS rates increased significantly more in hospitals that introduced RAS across patient age, sex, ethnicity, race, and payor compared with hospitals that did not introduce RAS.

Conclusions and Relevance: Hospitals that introduced RAS for common general surgery procedures were associated with an increase in MIS rates across different patient populations compared with hospitals that did not introduce RAS.

Keywords: minimally invasive surgery, robotic assisted surgery, general surgery operations

Key Points

Question: Has robotic-assisted surgery (RAS) increased the use of minimally invasive surgery (MIS)? Does RAS introduction result in increased MIS across different patient populations?

Findings: In this retrospective cohort study of 408 hospitals, the rate of MIS for common general surgeries increased significantly in hospitals that began using RAS for these procedures. Hospitals that introduced RAS saw significant increases in MIS across patient age, sex, ethnicity, race, and payor.

Meaning: There was a significant increase in MIS in hospitals that introduced RAS, and this increase was seen across patient populations.

INTRODUCTION

Minimally invasive surgery (MIS) has improved patient outcomes across many different surgical procedures.[1–4] MIS has traditionally been performed using laparoscopic devices, which have their own set of challenges, including incomplete articulation of instruments, ergonomic limitations, and 2D visualization.[5] Robotic-assisted surgery (RAS) is able to overcome some of the barriers associated with laparoscopy with wristed instruments that improve surgeon dexterity and visualization and, as such, diminishes the learning curve associated with performing procedures in a minimally invasive fashion.[6–8] The use of RAS has increased substantially over the past decade; however, there is mixed evidence regarding whether this increased use has resulted in a substantial increase in MIS overall or whether RAS has just replaced laparoscopic procedures, rather than replacing open procedures.[9–12]

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Access and availability of MIS also vary significantly for different US populations.[13–15] Significant variation in rates of MIS has been noted across race and ethnicity for a wide range of procedures, including hysterectomies and myomectomies, mitral valve surgery, common abdominal procedures, and surgeries to treat cancer, with non-Hispanic Black individuals generally associated with the lowest rates of undergoing MIS.[16–20] Differences have also been noted across payor status; individuals with private insurance having greater access to MIS than those that have public insurance or are uninsured.[21,22] These differences in the use of and access to MIS have been attributed to factors such as lack of surgeon training, surgeon skills, and health literacy.[5] It is also unknown whether the introduction of RAS has resulted in higher rates of MIS across different patient populations.

In this study, we analyzed evidence from a large real-world database to assess whether the introduction of RAS has increased the use of MIS for common general surgery procedures and whether this increase was seen across different patient populations.

METHODS

Data Source

We used the PINC AI Healthcare Database (PHD), formerly known as the Premier Healthcare Database, for this retrospective cohort study. PHD is a large US hospital discharge database that collects healthcare data from >1180 geographically diverse nonprofit, nongovernmental, community, and teaching hospitals and health systems from rural and urban areas.[23] PHD includes nearly 8 million inpatient admissions per year, representing ≈25% of annual US inpatient admissions. Outpatient visits to emergency departments, ambulatory surgery centers, and alternate sites of care are also included, with >71 million visits per year.[23]

This observational study used aggregated, deidentified patient data, and as such, institutional review board approval and patient consent were not required. The study followed the Strengthening the Reporting of Observational Studies in Epidemiology reporting guidelines.

Common General Surgery Procedures

We included the 4 most common general surgery procedures determined from previously published robust state-wide quality collaboratives: cholecystectomy, inguinal hernia repair, ventral hernia repair, and colorectal resection.[9] Procedures were identified using Current Procedural Terminology codes and the International Classification of Diseases, version 10 (Supplemental Table S1, see http://links.lww.com/AOSO/A454).

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Surgical Modality

MIS rates were defined for common general surgery operations among individuals aged ≥18 years during the study period. Procedures were classified as open or MIS, which included both laparoscopic and RAS. Individuals who had an International Classification of Diseases, version 10, procedure or Current Procedural Terminology/Healthcare Common Procedure Coding System modifier code for RAS or a documented charge code for robotic instrumentation were defined as having an RAS procedure (Supplemental Table S1, see http://links.lww.com/AOSO/A454). Next, individuals who had a laparoscopic modifier code were defined as having a laparoscopic procedure. The remaining individuals were identified as having an open procedure.

We used an intention-to-treat analytic approach, in which cases were defined by their original planned surgical approach; this means that if a robotic or laparoscopic case was converted to open during the surgery, the procedure remained classified as the original modality (Supplemental Table S1, see http://links.lww.com/AOSO/A454).

Study Population

All hospitals that contributed data to PHD and had common general surgery operations from 2016 to 2022 were included (n = 1,105; Supplemental Figure S1, see http://links.lww.com/AOSO/A454). Among these hospitals, those that had at least 1 general surgery procedure conducted by RAS were identified as having RAS capabilities (n = 752); these hospitals were required to have contributed data to PHD for at least 1 year before and 1 year after their first RAS general procedure (defined as the index date; n = 153). Hospitals without RAS capabilities were required to have contributed data to PHD for at least 2 continuous years (n = 255); the index date was a randomly selected date in the index date eligibility range (1 year after the start of coverage to 1 year before the end of coverage).

Hospital Characteristics

Studies have shown that MIS rates vary based on hospital characteristics.[1] To account for these differences, we examined the location (urban/rural), size (small, medium, and large), teaching status, and index year of each hospital. Urban was defined as a location in which core census blocks have a density of at least 1000 people per square mile and are surrounded by census blocks with a density of at least 500 people per square mile.[23] MIS rates vary across procedures; therefore, we also examined the case mix in the year before the index date.

Individual Characteristics

We examined disparities in MIS use for general surgery procedures across individual characteristics. Specific characteristics examined were sex (male, female, and unknown), age (18–34, 35–44, 45–64, and >65 years), race (Black, White, Asian, other, and unknown), ethnicity (Hispanic, non-Hispanic, and unknown), and payor (commercial, Medicare, Medicaid, and other).

Statistical Analysis

Average MIS rates in the year before and in the year after the index date were compared for hospitals that did and did not introduce RAS for common general surgery operations. We obtained relative rates (RRs) before and after the index date from generalized estimating equation regression models applying a Poisson distribution. These models account for correlated observations using an independent correlation matrix. The log of the population is included as an offset to ensure the modeling of RR as opposed to a relative count of events. To determine whether there was a significant difference in the RR before and after the index date, we obtained the *P* value of the interaction term of time (before/after the index date) and exposure (RAS/non-RAS hospital). An adjusted model also accounted for hospital characteristics, case mix, and index year. A stratified analysis was conducted to examine changes in MIS rates across each specific procedure.

In our secondary analysis, we determined whether there were differences in the use of MIS in common general surgery procedures before and after the index date for individual characteristics and if differences varied for RAS and non-RAS hospitals. To assess changes in MIS rates across individuals by hospital type, we limited each analysis to hospitals that had individuals with that characteristic both before and after the index date (eg, common general surgery procedures were done for individuals aged >65 years both before and after the index date). We obtained adjusted RRs by comparing average MIS rates before and after the index date for each category of each characteristic examined in RAS and non-RAS hospitals. For each characteristic category, we obtained the adjusted *P* value of the interaction term between time and exposure to determine whether changes in MIS rates differed between RAS and non-RAS hospitals.

RESULTS

Of the 408 hospitals included in the study, 153 (38%) started using RAS for general surgery procedures during the study period of 2017 to 2021. Hospitals that introduced RAS were more likely to be in urban areas, large hospitals, and teaching hospitals; they also had higher rates of colorectal resection and lower rates of inguinal hernia than hospitals that did not introduce RAS (Table 1).

In hospitals that did not introduce RAS for common general surgery operations, the rate of MIS increased slightly from 56.1% to 57.0%. In hospitals that introduced RAS for these procedures, the rate of MIS increased significantly from 60.5% to 65.8% (Fig. 1). The relative MIS rate for hospitals that introduced RAS compared with hospitals that did not went from 1.08 (95% confidence interval, 1.02–1.14; P < 0.01) before the index date to 1.15 (95% confidence interval, 1.09–1.22; P < 0.01) after the index date ($P_{\text{interaction}}$ < 0.01), indicating that there was a significantly larger increase in MIS rates among hospitals that introduced RAS. The results did not change when adjusting for the hospital characteristics presented in Table 1 (Supplemental Table S2, see http://links.lww.com/AOSO/A454).

A stratified analysis compared MIS rates in hospitals that did and did not introduce RAS for each specific procedure in the year before and after the index date. For inguinal and ventral hernia repair and colorectal resection, the MIS rates increased significantly more in hospitals that introduced RAS (Fig. 2; Supplemental Table S2, see http://links.lww.com/AOSO/A454). MIS rates for cholecystectomy were >95% in hospitals that did and did not introduce RAS, both before and after the index date.

MIS Rates Across Individual Characteristics

There was significant variation in baseline MIS rates across individuals in hospitals that introduced RAS and hospitals that did not introduce RAS. Across age, sex, ethnicity, race, and payor, individuals aged 18 to 34 years, females, Hispanic patients, Asian patients, and patients receiving Medicaid had the highest rates of MIS (Table 2). MIS rates increased significantly more in hospitals that introduced RAS than in hospitals that did not across many individual characteristics. When looking at age, MIS rates increased significantly for patients aged ≥35 years in hospitals that introduced RAS but not in hospitals that did not introduce RAS (Table 3). A similar trend was seen for males and females, for Hispanic patients and White patients, and for patients who had commercial or Medicare insurance coverage.

Table 1.

Hospital-Level Characteristics for Hospitals Included in the Study

	Introduced RAS (N = 153), n (%)	Did Not Introduce RAS (N = 255), n (%)	χ^2 *P* value
Location			<0.01
Urban	108 (70.6)	91 (35.7)	
Rural	45 (29.4)	164 (64.3)	
Bed size			<0.01
<100	46 (30.1)	167 (65.8)	
100–299	83 (54.3)	78 (30.7)	
>300	24 (15.7)	10 (3.9)	
Teaching status			0.01
Teaching	33 (21.6)	31 (12.2)	
Nonteaching	120 (78.4)	224 (87.8)	
Case mix in year before index date			
Proportion cholecystectomy, mean (SD)	0.47 (0.13)	0.46 (0.14)	0.41
Proportion colorectal resection, mean (SD)	0.13 (0.11)	0.08 (0.09)	<0.01
Proportion inguinal hernia repair, mean (SD)	0.18 (0.09)	0.23 (0.11)	<0.01
Proportion ventral hernia repair, mean (SD)	0.22 (0.08)	0.23 (0.11)	0.32
Index year			0.04
2017	51 (33.3)	62 (24.3)	
2018	30 (19.6)	54 (21.2)	
2019	33 (21.6)	42 (16.5)	
2020	22 (14.4)	44 (17.3)	
2021	17 (11.1)	53 (20.8)	

DISCUSSION

In this study of 408 hospitals from across the United States, we found that hospitals that introduced RAS had significantly higher increases in rates of MIS compared with hospitals that did not introduce RAS. We also found that MIS rates increased across individual characteristics, demonstrating that many patient populations are benefiting from the introduction of RAS.

Previous research examining the impact of RAS introduction on MIS rates demonstrated mixed results. A study of 300 US academic hospitals from 2008 to 2015 found that hospitals that introduced RAS had a decrease in laparoscopic surgery, but not in open surgery, resulting in the overall rate of MIS not changing.[10,24] Another study using Michigan state-level data from 2012 to 2018 found that the introduction of RAS in a hospital corresponded to a decrease in both laparoscopic and open surgery, increasing the overall rate of MIS.[9] Our data include a more representative mix of hospitals from across the United States. Furthermore, we present more recent data that potentially represent more contemporary paradigms where more practicing surgeons were trained in RAS and older surgeons have overcome their learning curves.[25] It is possible that as more surgeons gain familiarity and expertise with RAS, more open operations are being converted to MIS through RAS, potentially explaining our findings that there was a significant increase in MIS after the introduction of RAS in a hospital.

We also found that rates of MIS increased significantly across many patient populations after a hospital introduced RAS for common general surgery operations. Several cross-sectional studies have found that MIS rates were lowest among non-Hispanic Black patients.[16–20] In our study, we found that Black and White patients had similar MIS rates before and

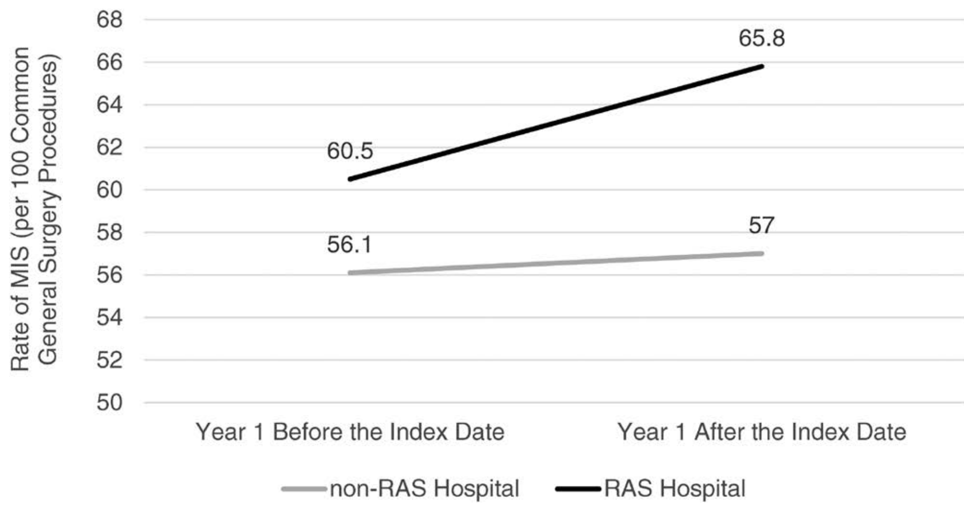

FIGURE 1. Trends in MIS use over time for common general surgery procedures by RAS introduction status.

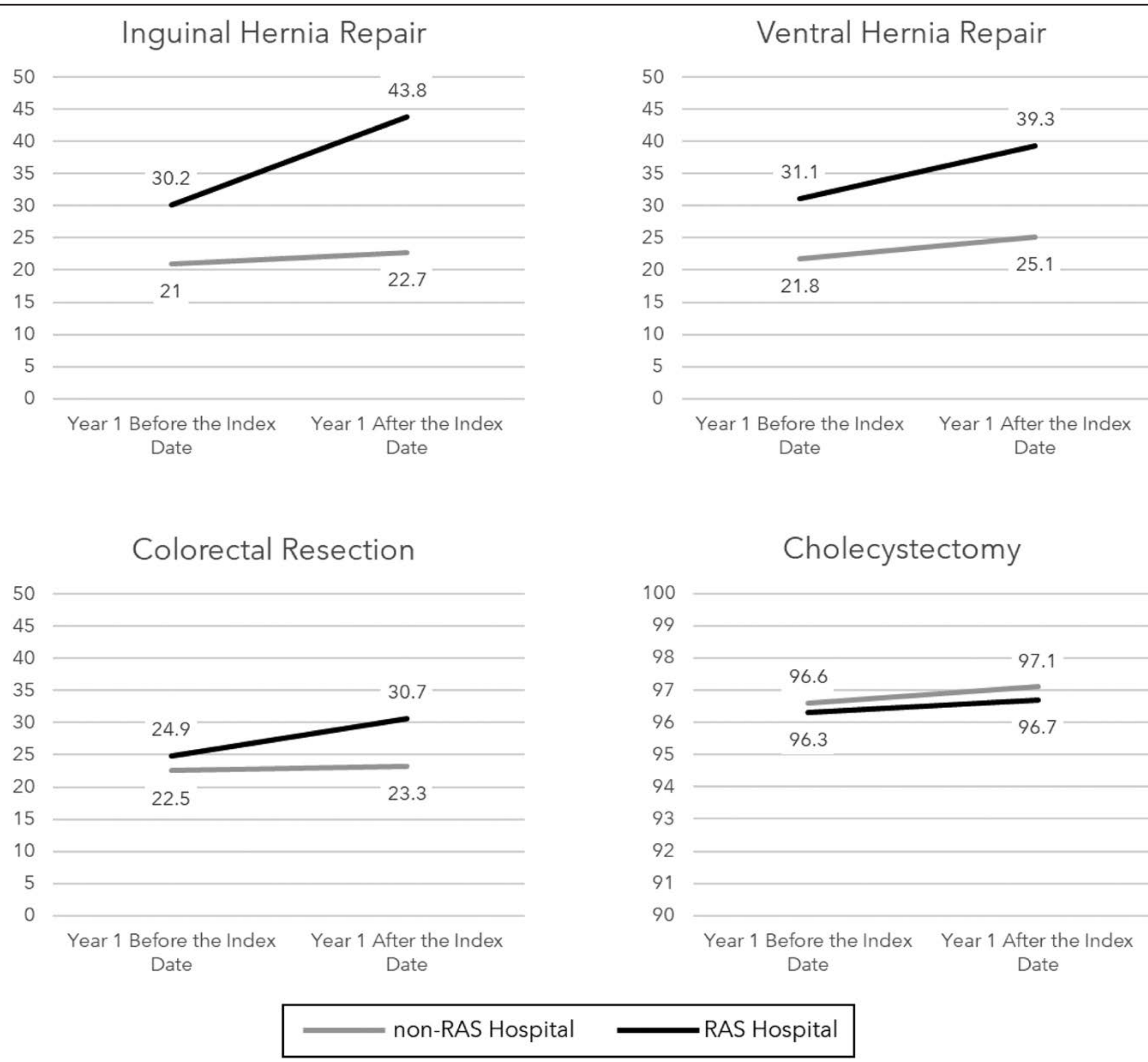

FIGURE 2. Trends in MIS use over time by procedure and RAS introduction status.

Table 2.

Average MIS Rates Before and After the Index Date Across Individual Characteristics by Hospital Type

	Non-RAS Hospital			RAS Hospital		
	N Hospitals	Average MIS Rate Before	Average MIS Rate After	N Hospitals	Average MIS Rate Before	Average MIS Rate After
Age, yr						
18–34	244	75.7	78.4	152	79.3	80.9
35–44	236	64.8	64.7	151	67.8	72.9
45–64	247	54.3	53.3	151	59.2	63.4
>65	246	43.1	46.8	152	49.5	57.0
Sex						
Female	250	73.1	73.0	152	71.7	74.7
Male	253	41.3	43.3	151	50.1	57.1
Unknown	1	0.0	0.4	0	—	—
Ethnicity						
Hispanic	156	69.8	68.5	110	67.8	75.2
Non-Hispanic	224	55.5	56.7	127	61.2	65.4
Unknown	143	55.6	55.3	108	61.6	64.7
Race						
White	248	55.5	56.5	152	60.0	65.1
Black	157	54.0	56.9	133	62.4	64.2
Asian	61	69.3	63.1	79	76.6	73.6
Other	175	61.3	63.3	121	64.2	71.1
Unknown	68	61.2	64.2	63	70.9	75.3
Payor						
Commercial	248	61.0	61.6	149	63.9	69.4
Medicaid	235	65.5	67.2	152	68.0	71.6
Medicare	247	45.9	47.8	152	51.0	57.7
Other	227	56.5	57.6	146	63.9	68.5

Table 3.

Before-After Adjusted Relative Rates by Hospital Type and Time/Hospital Type Interaction

Patient Population	Non-RAS Hospitals RR* (95% CI)	RAS Hospitals RR* (95% CI)	Interaction *P* value*
Age, yr			
18–34	1.04 (1.00–1.07)†	1.02 (1.00–1.05)	0.44
35–44	1.00 (0.95–1.04)	1.08 (1.03–1.12)†	0.01
45–64	0.98 (0.94–1.02)	1.07 (1.03–1.11)†	<0.01
>65	1.09 (1.04–1.14)	1.15 (1.10–1.21)†	0.07
Sex			
Female	1.00 (0.98–1.02)	1.04 (1.02–1.06)†	<0.01
Male	1.05 (1.00–1.10)†	1.14 (1.10–1.19)†	<0.01
Ethnicity			
Hispanic	0.98 (0.91–1.06)	1.11 (1.03–1.19)†	0.02
Non-Hispanic	1.02 (0.99–1.06)	1.07 (1.04–1.10)†	0.07
Unknown	0.99 (0.90–1.10)	1.03 (0.95–1.13)	0.57
Race			
White	1.02 (0.99–1.05)	1.09 (1.06–1.12)†	<0.01
Black	1.05 (0.96–1.16)	1.03 (0.95–1.11)	0.70
Asian	0.91 (0.76–1.10)	0.96 (0.88–1.05)	0.62
Other	1.03 (0.96–1.11)	1.11 (1.02–1.21)†	0.22
Unknown	1.05 (0.90–1.22)	1.06 (0.93–1.21)	0.91
Payor			
Commercial	1.01 (0.98–1.04)	1.08 (1.05–1.12)†	<0.01
Medicaid	1.03 (0.99–1.07)	1.05 (1.01–1.09)†	0.40
Medicare	1.04 (0.99–1.09)	1.13 (1.08–1.18)†	<0.01
Other	1.02 (0.96–1.09)	1.07 (1.03–1.12)†	0.21

*Adjusted for hospital location (rural/urban), hospital bed size (<100/100–299/>300), hospital teaching status (teaching/nonteaching), index year, and case mix.

†$P < 0.05$.

RR indicates relative risk.

after the index date, and Asian patients had the highest MIS rates. However, when evaluating changes over time attributable to RAS introduction, only White patients saw a significant increase in MIS rates. As with previous research, differences were observed by payor[21]; we found that MIS rates increased across payor types in hospitals that introduced RAS but not in hospitals that did not introduce RAS. Finally, consistent with previous research, we found that MIS rates decreased with patient age[26,27]; our study showed that among hospitals that introduced RAS, MIS rates increased for patients aged ≥35 years; this was not seen among hospitals that did not introduce RAS. While legitimate concerns regarding the potential of some populations not benefiting from the introduction of new technology, our study demonstrated that RAS increased MIS rates across many patient populations potentially by better-assisting surgeons with surmounting the learning curve associated with traditional laparoscopic MIS.

This study had many strengths, including data from diverse hospitals across the United States, and comparisons in MIS rates longitudinally and between hospitals that did and did not introduce RAS. However, the findings of our study should be interpreted in the context of its limitations. First, we examined MIS rates for a composite of 4 common general surgery operations. Our findings may not be generalizable for different operations or for each of the individual procedures included. Second, there are unmeasured individual characteristics for which there may also be variations in rates of MIS. For example, the dataset had information on the location of the hospital (urban/rural) but not on patients' residences. While patients living in rural areas are more likely to access hospitals in rural areas, this is not always the case.[28–30] Third, to compare MIS rates in hospitals before and after the introduction of RAS, we excluded hospitals that did not have a full year of data availability before and after the introduction of RAS; this resulted in the number of RAS hospitals decreasing from 752 to 153. Therefore, the hospitals included may not be representative of all hospitals that introduced RAS. Given the significant drop in included hospital data when requiring longer baseline and follow-up data, we only examined rates in the year before and after the index date. When more data become available, it would be of interest to examine the trends in MIS rates across patient populations when RAS is fully implemented in a hospital for these procedures. In addition, we defined a hospital with RAS capabilities as one utilizing RAS for common general surgery procedures; it is possible that these hospitals were already using RAS for other procedures. Hospitals with a history of RAS likely benefit more quickly from introducing RAS for common general surgery procedures because of existing clinical and operating practices that can be more easily referenced. Finally, given differences in policy and practice, results from this study may not be generalizable outside of the US.

In our study, we demonstrated that hospitals introducing RAS were associated with an increase in overall rates of MIS for common general surgery operations compared with hospitals that did not introduce RAS. In addition, hospitals introducing RAS saw increases in MIS rates across patient age, sex, ethnicity, race, and payor, demonstrating that the introduction of RAS increases access to MIS for many different patient populations.

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