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ORIGINAL ARTICLE

Differences in Effectiveness and Use of Robotic Surgery in Patients Undergoing Minimally Invasive Colectomy

M. Schootman[1,2] · **S. Hendren**[3] · **T. Loux**[4] · **K. Ratnapradipa**[1] · **J. M. Eberth**[5] · **N.O. Davidson**[2,6]

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Abstract
Background We compared patient outcomes of robot-assisted surgery (RAS) and laparoscopic colectomy without robotic assistance for colon cancer or nonmalignant polyps, comparing all patients, obese versus nonobese patients, and male versus female patients.
Methods We used the 2013–2015 American College of Surgeons National Surgical Quality Improvement Program data to examine a composite outcome score comprised of mortality, readmission, reoperation, wound infection, bleeding transfusion, and prolonged postoperative ileus. We used propensity scores to assess potential heterogeneous treatment effects of RAS by patient obesity and sex.
Results In all, 17.1% of the 10,844 of patients received RAS. Males were slightly more likely to receive RAS. Obese patients were equally likely to receive RAS as nonobese patients. In comparison to nonRAS, RAS was associated with a 3.1% higher adverse composite outcome score. Mortality, reoperations, wound infections, sepsis, pulmonary embolisms, deep vein thrombosis, myocardial infarction, blood transfusions, and average length of hospitalization were similar in both groups. Conversion to open surgery was 10.1% lower in RAS versus nonRAS patients, but RAS patients were in the operating room an average of 52.4 min longer. *We found no statistically significant differences ($p > 0.05$) by obesity status and gender.*
Conclusions Worse patient outcomes and no differential improvement by sex or obesity suggest more cautious adoption of RAS.

Keywords MESH: colon cancer · Robotic surgical procedures · Comparative effectiveness research · Mortality

✉ M. Schootman
schootm@slu.edu

1 Department of Epidemiology, College for Public Health and Social Justice, Saint Louis University, 3545 Lafayette Avenue, Saint Louis, MO 63104, USA

2 Alvin J. Siteman Cancer Center at Barnes-Jewish Hospital and Washington University School of Medicine, Saint Louis, MO, USA

3 Department of Surgery, University of Michigan, Ann Arbor, MI, USA

4 Department of Biostatistics, College for Public Health and Social Justice, Saint Louis University, 3545 Lafayette Avenue, Saint Louis, MO 63104, USA

5 Department of Epidemiology and Biostatistics, Arnold School of Public Health, University of South Carolina, Columbia, SC, USA

6 Department of Medicine, Division of Gastroenterology, Washington University School of Medicine, Saint Louis, MO, USA

Introduction

Laparoscopic colectomy has gained widespread acceptance for resection of colorectal cancer (CRC), with better short-term complication rates and similar long-term outcomes relative to conventional open surgery [1,2]. With the increasing use of robotic surgery in CRC as part of laparoscopic surgery [3], it is timely to ask if this expensive technology is being used appropriately by maximizing patient outcomes and minimizing complications and costs, particularly among specific patient subgroups. The key is to strike a balance between the potential benefits of robot-assisted surgery (RAS), its high costs, and patient preferences [4].

Variation in the use of RAS may reflect differences in the availability of robotic devices and optimizing patient selection in complex or technically challenging situations in order to identify patients most likely to benefit [5]. For example, the narrow male pelvis makes laparoscopy technically challenging, and the robot may help in overcoming this limitation by allowing better visualization deep in the pelvis [6]. However, unlike the examination of the effectiveness of robotic surgery in subgroups of patients with other cancers (e.g., obese patients with endometrial cancer [7] and high-risk prostate cancer) [8,9], the effectiveness in specific colon cancer patients remains unknown. Overweight and male CRC patients may especially benefit if RAS can help avoid conversion to open surgery compared to normal weight and female patients. Obesity is also a risk factor for wound infection and anastomotic leaks [10]. Moreover, the prevalence of obesity in colon cancer patients continues to be large and is a significant burden on the healthcare system [11].

Our purpose was to describe characteristics of colectomy patients that received RAS or laparoscopic colectomy (LC). We then examined differences in effectiveness of RAS versus laparoscopic colectomy without robot assistance (nonRAS), comparing subgroups of patients: male versus female patients and obese versus nonobese patients. Knowledge of the effectiveness of RAS for specific colectomy patients will help make informed decisions about the use of this technology in minimally invasive surgery.

Materials and Methods

Data Source

Our cohort was constructed using the 2013–2015 American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) Participant Use File and Targeted Colectomy File. Preoperative patient comorbidities, preoperative laboratory results, intraoperative procedure characteristics, and 30-day postoperative mortality rates and complications were abstracted by trained reviewers. Additional details are described elsewhere (https://www.facs.org/quality-programs/acs-nsqip).

Patient Selection

All patients who underwent colectomy as indicated for colon cancer (with or without obstruction) or nonmalignant polyps were eligible for inclusion. Patients with American Society of Anesthesiologists (ASA) class five or who underwent emergent colectomy were excluded from the analysis.

Patients who underwent robotic only or robotic with open assist procedures were classified in the RAS group. Patients who underwent laparoscopic surgery only or laparoscopic surgery with hand-assisted procedures were classified in the LC group.

Patient Outcomes

Outcomes included conversion, operation time, anastomotic leakage, mortality, readmission, reoperation, length of stay, wound infection, transfusion, prolonged postoperative ileus, sepsis, myocardial infarction, deep vein thrombosis, and pulmonary embolism. Conversion occurred when the laparoscopic procedure (robotic or nonrobotic) was converted to an unplanned open surgery. Reoperation was defined as any unplanned return to the operating room for a surgical procedure, for any reason, within 30 days of the colectomy at any hospital or surgical facility. All-cause mortality was defined as deaths within 30 days following colectomy. Readmission was defined as any readmission (to the same or another hospital), for any reason, within 30 days of the colectomy. A wound infection included superficial or deep incisional surgical site infection or any other wound infection. Postoperative bleeding occurrence was defined as any transfusion given from the start of the colectomy to 72 h postoperation. Because of the infrequent occurrence for some of the postoperative outcomes, we constructed a composite outcome of mortality, readmission, reoperation, wound infection, bleeding occurrence, and prolonged postoperative ileus. Patients with at least one adverse outcome were contrasted to those without any such adverse outcomes.

Covariates

Covariates included patient sex, age, Hispanic ethnicity, race, body mass index (BMI), ASA grouping, smoking status, number of chronic comorbid conditions (congestive heart failure, hypertension, chronic obstructive pulmonary disease, shortness of breath, weight loss >10%, bleeding disorder, transfusion), patient functional status, mechanical bowel preparation, AJCC staging, and probability of morbidity. Covariates were selected based on previous studies [12,13]. The patient's most recent height and weight documented in the medical record within the 30 days prior to the colectomy or at the time the patient was being considered a candidate for surgery were used to calculate BMI. Patients were classified as obese (BMI ≥30 kg/m^2) or nonobese (BMI <30 kg/m^2).

Statistical Analysis

We determined the extent to which the variables that made up the composite variable loaded on a single factor using factor analysis and a polychoric correlation matrix, because traditional factor analysis relies on continuous variables. We used chi-squared tests to determine statistical significance between patients in the RAS group and those who received LC without robotic assistance. We calculated adjusted odds ratios (OR) and 95% confidence intervals (CI) using multivariable logistic regression to identify factors associated with RAS use. Adjusted odds ratios >1 represent increased use of RAS, while odds ratios<one represent decreased use of this surgery. All factors were entered into the model regardless of their statistical significance.

We used a 1:1 propensity score matching to obtain patient groups with comparable characteristics to assess the effect of RAS on patient outcomes. Variables included in the propensity score included all aforementioned covariates. We calculated standardized differences for all covariates before and after matching; a standardized difference of less than −0.1 or greater than 0.1 was used as a marker for imbalance [14]. We also compared the means and variances of the covariates after matching in order to determine the balance between both groups. We calculated the average treatment effect among the treated (ATT) and associated 95% confidence intervals to describe the effectiveness of RAS versus LC, *focusing on absolute differences*.

To assess potential heterogeneous treatment effects of RAS by sex, we first matched patients who received RAS to those who received LC. Matching was done in a 2:1 ratio using optimal matching on the propensity score, $e(x)$, with a caliper of 0.25 × SD ($e[x]$) [15]. Once patients were matched, we ran separate regressions in the robotic and nonrobotic groups to predict respective outcomes. The coefficients for male versus female patients were compared between the two models to assess treatment heterogeneity due to these factors [16]. A similar approach was used to assess treatment heterogeneity due to obesity.

We conducted a series of analyses to challenge the robustness of the findings. First, we conducted a formal sensitivity analysis to assess the extent to which the initial indication for colectomy (colon cancer, nonmalignant polyps) might explain our results. Second, we compared patients with RAS and LC only, excluding those with assistive procedures. Third, we examined the ATT using inverse probability weighting and the nearest neighbor propensity score matching. Alpha was set at 0.05.

Results

Patients

Data were collected on 66,031 patients with colectomies in the 2013–2015 National Surgical Quality Improvement Program (NSQIP) data. Of those, primary indication for 36,734 patients was colectomy for colon cancer with or without obstruction or for nonmalignant polyps. Of those, 1968 patients had ASA class five or had emergency surgery and were excluded from further analysis. In all, 21,689 patients received open surgery and were excluded also. Of the remaining 13,077 patients, 2233 patients received RAS and 10,844 patients received laparoscopic surgery without robotic assistance and comprised the study population.

Table 1 shows that patients were predominantly white (71.1%) and non-Hispanic (84.0%). About one out of three patients were obese. Most patients had ASA class two or three (93.0%), were nonsmokers (85.9%), and had at least one comorbid condition (59.8%). The variables comprising the composite outcome were loaded on a single factor based on the eigenvalues, scree plot, and goodness of fit statistics, with factor loadings ranging from 0.4 to 0.7.

RAS Use

Of all laparoscopic surgeries for colon cancer or nonmalignant polyps, 17.1% were performed with robotic assistance. In a multivariable model containing all variables (Table 1), patients were more likely to receive RAS if they were male (OR: 1.18), underwent surgery in 2015 (OR: 2.79), had preoperative mechanical bowel preparation (OR: 1.39), or had TNM stage 0 colon cancer (OR: 1.50). Patients were less likely to receive RAS if they were age 75 or older (OR 0.56), African American (OR: 0.70), had right-sided disease (OR = 0.35), were diagnosed with stage IV cancer (OR: 0.70), or had at least three comorbid conditions. Obese patients were equally likely to receive RAS as nonobese patients (OR: 0.98). The interaction between sex and BMI in predicting RAS use was not statistically significant ($p = 0.087$). The adjusted percentage of RAS use was highest among nonobese males (17.5%), followed by obese males (17.2%), *nonobese females* (*15.2%*), and obese females (14.9%).

Unmatched Outcomes

Of all patients, 22.1% experienced at least one adverse postoperative outcome (Table 2), which was higher in RAS (23.5%) versus nonRAS patients (21.8%). Overall, mortality was 0.8%, which was similar in RAS (0.6%) versus nonRAS patients (0.9%). In all, 7.9% of the patients were readmitted within 30 days, which was higher in RAS patients (9.3%) versus nonRAS patients (7.6%). Overall, 3.3% of the patients were reoperated, which was higher in RAS patients (4.4%) versus nonRAS patients (3.1%). Wound infections were similar in RAS patients (3.5%) versus nonRAS patients (3.5%). No differences existed between RAS and nonRAS patients in occurrence of sepsis, pulmonary embolism, deep vein thrombosis, and myocardial infarction. Ileus was prolonged in RAS patients (10.4%) versus nonRAS patients (8.7%). Of all patients, 5.5% required blood transfusion, which was similar between RAS (4.8%) and nonRAS patients (5.6%). Length of stay was an average of 5.3 days, which was similar for RAS (5.1 days) and nonRAS patients (5.3 days). In all, 7.5% of the patients were converted to open surgery, but this was much lower in the RAS (5.7%) versus the nonRAS group (18.6%). Length of operation was on average 178.5 min, but RAS patients were longer in the operating room (235.6 min)

Table 1 Patient characteristics by laparoscopic surgery, with or without robot assistance, 2013–2015

Patient characteristic	Total (*n* = 13,077)	Robot-assisted laparoscopic surgery (*n* = 2233)	Laparoscopic surgery without robot assistance (*n* = 10,844)	Adjusted odds ratio (95% CI)
Sex*				
Male	49.6	55.1	48.5	1.18 (1.07; 1.30)
Female	50.4	44.9	51.5	1.00
Age group (years)*				
<45	5.5	6.9	5.3	1.00
45–54	17.4	22.4	16.4	1.00 (0.80; 1.25)
55–64	24.8	26.7	24.4	0.84 (0.68; 1.05)
65–74	27.8	27.8	28.0	0.80 (0.64; 1.01)
75+	24.5	17.4	26.0	0.56 (0.44; 0.72)
Race*				
White	71.1	69.0	81.0	1.00
African	10.9	11.4	8.2	0.70 (0.59; 0.83)
American				
Other	4.8	4.9	4.5	0.63 (0.50; 0.80)
Unknown	13.3	14.7	6.3	0.73 (0.57; 0.93)
Hispanic ethnicity*				
No	84.0	92.7	82.2	1.00
Yes	3.8	3.8	3.8	0.80 (0.62; 1.04)
Unknown	12.2	3.5	14.0	0.30 (0.22; 0.40)
Body mass index*				
≥30 kg/m^2	33.7	36.5	33.1	0.98 (0.88; 1.09)
<30 kg/m^2	65.8	63.4	66.3	1.00
Unknown	0.5	0.1	0.6	
ASA category*				
1	2.6	1.7	2.8	1.00
2	45.0	45.5	45.0	1.14 (0.76; 1.70)
3	48.0	50.4	47.5	1.02 (0.66; 1.57)
4	4.2	2.5	4.6	0.63 (0.37; 1.06)
Unknown	0.2	0.0	0.2	
Current smoker				
Yes	14.1	14.4	14.0	0.87 (0.75; 1.00)
No	85.9	85.6	86.0	1.00
Preoperative mechanical bowel preparation*				
Yes	59.1	67.2	57.4	1.39 (1.22; 1.57)
No	24.9	17.6	26.3	1.00
Unknown	16.1	15.2	16.3	1.12 (0.95; 1.33)
Cancer location*				
Left	31.1	54.3	26.3	1.00
Right	28.8	19.1	30.8	0.35 (0.30; 0.39)
Other	40.1	26.7	42.9	0.29 (0.25; 0.35)
AJCC stage*				
0	1.8	3.0	1.6	1.50 (1.07; 2.11)
I	12.2	15.6	11.5	1.17 (0.96; 1.42)
II	11.8	11.0	10.7	1.00
III	11.7	13.3	11.4	0.95 (0.78; 1.16)
IV	3.0	2.8	3.1	0.70 (0.51; 0.97)

Table 1 (continued)

Patient characteristic	Total (*n* = 13,077)	Robot-assisted laparoscopic surgery (*n* = 2233)	Laparoscopic surgery without robot assistance (*n* = 10,844)	Adjusted odds ratio (95% CI)
Unknown	35.8	35.2	35.9	0.92 (0.77; 1.08)
Nonmalignant	26.6	19.1	25.8	1.29 (1.03; 1.62)
Number of comorbid conditions*				
0	40.2	43.5	39.5	1.00
1	36.9	35.7	37.2	0.91 (0.81; 1.03)
2	17.5	16.9	17.6	0.94 (0.80; 1.11)
3 or more	5.5	3.8	5.8	0.65 (0.49; 0.86)
Mean estimated prob. of morbidity (SD)*	11.0% (5.1)	10.7% (4.6)	11.0% (5.2)	

Other race includes American Indian, Alaskan Native, Native Hawaiian, Pacific Islander, or Asian. Cox-Snell R-square: 0.096

CI confidence interval, *SD* standard deviation

*$p < 0.05$

than nonRAS patients (166.7 min). Anastomotic leak occurred in 2.6% of all patients and was higher in RAS (3.6%) than nonRAS patients (2.3%).

Propensity Score-Matched Outcomes

The percentage of patients who experienced at least one of the composite outcomes was 3.1% higher in RAS versus nonRAS patients (Table 2). For every 32 patients treated with RAS, there was one additional adverse postoperative outcome. Mortality was similar in both patient groups. The percentage of patients readmitted within 30 days was 1.4% higher in RAS versus nonRAS patients. Reoperation rates were similar between both groups (0.7%) as were wound infections (−0.3%). No difference existed between both groups in the percentage of patients *with prolonged ileus* (*1.8%*), developing sepsis (0.1%), pulmonary embolisms (0.0), deep vein thrombosis (−0.2), myocardial infarction (0.1%), needing blood transfusion 0.4%, or mean lengths of stay (−0.2). The percentage of patients converted to open surgery was 10.1% lower in RAS versus nonRAS patients. However, RAS patients were in the operating room an average of 52.4 min longer. The percentage of RAS patients with anastomotic leaks was similar for both groups of patients. For all comparisons, RAS and nonRAS patients were well balanced after matching based on the standardized differences as well as the means and variances of the covariates.

Heterogeneity in RAS Effectiveness

Table 3 shows that composite outcomes and length of stay were similar among obese and nonobese patients in propensity-adjusted analysis ($p = 0.848$ and $p = 0.412$, respectively). The average length of time of operation was statistically greater among RAS versus nonRAS for both obese and nonobese patients; however, the difference between RAS and nonRAS was similar among obese and nonobese patients ($p = 0.437$). Conversion to open surgery was lower in RAS versus nonRAS for both obese and nonobese patients. This difference, however, did not vary by obesity status ($p = 0.068$).

Table 4 shows that postoperative outcomes *and length of stay* were similar among male and female patients in propensity-adjusted analysis ($p = 0.367$ and $p = 0.195$, respectively). *The average length of operation time was statistically greater among RAS versus nonRAS; however, the difference was similar between genders* ($p = 0.411$). Conversion to open surgery was lower for RAS versus nonRAS patients, but was similar between males and females ($p = 0.380$).

Sensitivity Analyses

Our findings were robust with respect to the reason for colectomy (malignant or nonmalignant polyps), the different methods of propensity score matching, and the definition of the RAS and nonRAS groups when excluding assistive procedures (results not shown).

Discussion

To our knowledge, this is the first and largest study to examine differences in the use and effectiveness of RAS *in minimally invasive surgery*, specifically focused on differences by sex and obesity. In matched analysis, RAS patients had worse outcomes and longer average operation times, but lower conversion to open surgery compared with nonRAS patients. Both groups were similar in terms of mortality, wound infections, transfusions, and length of stay. Differences between RAS and nonRAS were similar in obese versus nonobese patients and in male versus female patients.

Table 2 Patient outcomes by laparoscopic surgery with or without robot assistance, NSQIP 2013–2015

Patient outcome	Total	Unmatched analysis		Propensity-matched analysis	
	laparoscopic surgery (n = 13,077)	Robot-assisted laparoscopic surgery (n = 2233)	Laparoscopic surgery without robot assistance (n = 10,844)	Average treatment effect: RAS versus nonRAS (%)	Total number of patients (1:1 match)
Postoperative					
Composite outcome (%)[a]	22.1	23.5	21.8	3.1 (1.0; 5.2)	4462
Mortality (%)	0.8	0.6	0.9	0.0 (−0.5; 0.3)	4462
Readmission (%)	7.9	9.3*	7.6	1.4 (0.0; 2.9)	4462
Reoperation (%)	3.3	4.4*	3.1	0.7 (−0.3; 1.8)	4462
Wound infection (%)	3.5	3.5	3.5	−0.3 (−1.2; 0.7)	4462
Sepsis (%)	2.2	2.4	2.2	0.1 (−0.7; 0.9)	4462
Pulmonary embolism	0.4	0.5	0.4	0.0 (−0.5; 0.3)	4462
Deep vein thrombosis	0.7	0.6	0.7	−0.2 (−0.6; 0.3)	4462
Myocardial infarction	0.5	0.6	0.5	0.1 (−0.3; 0.5)	4462
Prolonged postoperative ileus (%)	9.0	10.4*	8.7	1.8 (−0.3; 2.9)	4456
Bleeding requiring blood transfusion (%)	5.5	4.8	5.6	0.4 (−0.7; 1.6)	4462
Mean length of stay in days (median, SD)	5.3 (4, 5.2)	5.1 (4, 4.6)*	5.3 (4, 5.3)	−0.2 (−0.4; 0.1)	4446
Peri-operative					
Conversion (%)	7.5	5.7*	18.6	−10.1 (−11.4; −8.7)	4730
Mean length of operation in minutes (SD)	178.5 (90.0)	235.6 (104.4)*	166.7 (81.9)	52.4 (47.3; 57.5)	4448
Anastomotic leak (%)	2.6	3.6*	2.3	0.7 (−0.2; 1.7)	4450

SD standard deviation

*$p < 0.05$ in unadjusted RAS versus LC comparison

[a] Composite outcome includes readmission, reoperation, wound infection, blood transfusion, prolonged ileus, sepsis, myocardial infarction, deep vein thrombosis, pulmonary embolism, and mortality

Studies to date comparing RAS and nonRAS consist predominantly of single-institution studies, meta-analyses, claims-based analysis, and reviews. Many studies were limited by small sample sizes, resulting in unstable estimates of many patient outcomes. Similar to other larger studies [6,17], RAS patients experienced lower conversion rates compared to nonRAS patients. However, unlike other studies that have shown that complications were similar between RAS and nonRAS patients [17,18], our data show significantly higher complication rates (readmission, reoperation, prolonged ileus,

Table 3 Effect of robotic surgery by obesity, NSQIP 2013–2015

Patient outcome	Obese patients		Nonobese patients		p^a
	RAS	nonRAS	RAS	nonRAS	
Composite adverse postoperative outcome (%)	24.1	22.8	23.5	21.3	0.848
Mean length of stay in days (SD)	5.1 (5.2)	5.4 (5.2)	5.0 (4.3)	5.3 (5.3)	0.412
Mean length of operation in min (SD)	245.5 (104.0)*	179.3 (86.9)	229.9 (104.2)*	160.2 (78.3)	0.437
Conversion (%)	8.3*	23.0	4.1*	16.1	0.068

Obese: ≥30 kg/m^2. Composite outcome includes readmission, reoperation, wound infection, blood transfusion, prolonged ileus, sepsis, myocardial infarction, deep vein thrombosis, pulmonary embolism, and mortality

RAS robot-assisted surgery, *LC* laparoscopic colectomy, *SD* standard deviation

*$p < 0.05$ in unadjusted analysis

[a] Based on propensity score-matched patients comparing RAS and nonRAS patients

Table 4 Effect of robotic surgery by sex, NSQIP 2013–2015

Patient outcome	Male patients		Female patients		p^a
	RAS	nonRAS	RAS	nonRAS	
Composite adverse postoperative outcome (%)	26.2	24.1	20.7	19.7	0.380
Mean length of stay in days (SD)	5.5 (5.4)	5.5 (5.8)	4.6 (3.4)*	5.1 (4.9)	0.195
Mean length of operation in min (SD)	248.7 (112.2)*	177.2 (86.2)	219.4 (91.3)*	156.9 (76.4)	0.411
Conversion (%)	6.3*	20.7	4.8*	16.5	0.380

Composite outcome includes readmission, reoperation, wound infection, blood transfusion, prolonged ileus, sepsis, myocardial infarction, deep vein thrombosis, pulmonary embolism, and mortality

RAS robot-assisted surgery, *LC* laparoscopic colectomy, *SD* standard deviation

*$p < 0.05$ in unadjusted analysis

[a] Based on propensity score-matched patients comparing RAS and nonRAS patients patients

anastomotic leak) in RAS versus nonRAS patients. Surgeons may opt for more challenging cases in teaching hospitals that perform the majority of RAS [3] or RAS is starting to be adopted in smaller hospitals that are performing laparoscopic procedures that are associated with higher technical difficulty and a learning curve. This may have resulted in adverse patient outcomes compared to nonRAS patients in our study. Thirty-day patient follow-up beyond index hospitalization and large sample size may also have contributed to differences between our results and other studies. Similar to many [6,19–21] but not all studies [17,22], we observed no difference in average length of stay between RAS and LC patients.

Some have suggested that, at least in endometrial or uterine cancer, obesity may be an indication for receiving robotic surgery [23,24]. Our results show that obese patients had similar outcomes as nonobese patients. Our results confirm the findings of small studies conducted at single institutions [25,26]. Thus, it is unlikely that increasing RAS among obese patients will disproportionally reduce their high conversion rates and may actually harm them because of the higher rate of adverse patient outcomes in all RAS patients.

Robotic surgery may help overcome the limitation of the narrow male pelvis by allowing better visualization [6]. Although males were slightly more likely to receive robotic surgery, there were no differences in *any of the investigated outcomes*. Thus, although visualization may be better using a robotic system in males, this did not result in better patient outcomes when using RAS compared with female patients.

Our study is the largest patient series not based on claims data and includes multiple hospitals reporting on many different types of patient outcomes. Our study included nearly twice as many RAS patient as a recent meta-analysis [27], which may yield more stable estimates of RAS on patient outcomes. In their 2012–2014 NSQIP analysis, Dolejs and colleges [13] found few differences in patient outcomes but failed to use causal models. We believe that our matched propensity score analysis maximized causal inferences [11]. Rigorous nonrandomized evaluations are needed to determine which patients benefit from RAS approaches [28]. High-quality observational studies can provide information on treatment effectiveness in particular subpopulations [29].

We also recognize the limitations of our findings. For example, even though we included more than 13,000 patients, some outcomes were relatively infrequent, resulting in large confidence intervals. To mitigate the impact of this concern, we constructed a composite outcome, which may be less likely to reflect this limitation. In addition, we were only able to control for variables available in the NSQIP data and some characteristics of hospitals or surgeons were not available because of confidentiality concerns. We recognize this limitation although it is unlikely to impact our findings, since adjusting for surgeon case counts and hospital volume did not alter findings in other studies [17]. Furthermore, we recognize that the NSQIP typically includes data from larger hospitals, limiting generalizability to smaller hospitals not part of the NSQIP, and these data are not a nationally representative sample. However, the vast majority of robotic surgery is performed by surgeons at teaching hospitals and at centers with higher patient volumes [3]. Also, we did not have any information about which hospitals had implemented enhanced recovery after surgery programs. In addition, the NSQIP data preclude the analysis of differences in cost, although most studies have shown higher costs associated with RAS [18,28]. Finally, we recognize that the effectiveness of RAS may vary within the large range of BMIs that is included in our definition of obesity (BMI ≥30 kg/m^2), but the sample size was insufficient to examine RAS effectiveness in patients with BMI ≥40 kg/m^2.

Conclusion

In summary, RAS patients had higher readmission, prolonged ileus, leakage, and longer average operation times, but lower conversion to open surgery compared with nonRAS patients. The effect of RAS was similar in obese versus nonobese patients and in male versus female patients. Worse patient outcomes and no differential improvement by sex and obesity suggest the need for more cautious adoption of this technology.

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Author Contributions Schootman conceptualized the study, wrote the first draft of the manuscript, and performed some of the statistical analysis, and approved the final manuscript; Hendren conceptualized the study, interpreted the findings; and approved the final manuscript; Loux performed the statistical analysis, interpreted the findings, and approved the final version of the manuscript; Ratnapradipa wrote sections of the manuscript, interpreted the findings, and approved the final version of the manuscripts; Eberth conceptualized the study, interpreted the findings, and approved the final manuscript; Davidson conceptualized the study, interpreted the findings; and approved the final manuscript.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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