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A retrospective study of the effects of minimally invasive colorectal surgery on Patient Safety Indicators across a five-hospital system

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Abstract

Background The Agency for Healthcare Research and Quality uses Patient Safety Indicators (PSI) to gauge quality of care and patient safety in hospitals. PSI 90 is a weighted combination of several PSIs that primarily comprises perioperative events. This score can affect reimbursement through Medicare and hospital quality ratings. Minimally invasive surgery (MIS) has been shown to decrease adverse events and outcomes. We sought to evaluate individual PSI and PSI 90 outcomes of minimally invasive versus open colorectal surgeries using a large medical database from 5 hospitals.

Methods A health system administrative database including all inpatients from 5 acute care hospitals was queried based on ICD 10 PC codes for colon and rectal surgery procedures performed between January 2, 2018 and December 31, 2019. Surgeries were labeled as MIS (laparoscopic) or open colorectal resection surgery. Patient demographics, health information, and case characteristics were analyzed with respect to surgical approach and PSI events. Statistical relationships between surgical approach and PSI were investigated using univariate methods and multivariate logarithmic regression analysis. PSIs of interest were PSI 8, PSI 9 PSI 11, PSI 12, and PSI 13.

Results There were 1382 operations identified, with 861 (62%) being open and 521 (38%) being minimally invasive. Logistic modeling showed no significant difference between the 2 groups for PSI 3, 6, or 8 through 15.

Conclusion Understanding PSI 90 and its components is important to enhance perioperative patient care and optimize reimbursement rates. We showed that MIS, despite providing known clinical benefits, may not affect scores in the PSI 90. Surgical approach may have little effect on PSIs, and other patient and system components that are more important to these outcome measures should be pursued.

Keywords Surgical quality · Patient safety indicators · Minimally invasive · Colorectal · Laparoscopy

The Agency for Health Care Research and Quality developed Patient Safety Indicators (PSIs) in 2003 to gauge preventable harm by evaluating quality metrics for perioperative and periprocedural patients. These metrics are based on administrative data definitions and were originally meant to be used to identify preventable harm and to assist with local quality improvement initiatives [1]. As of 2020, there are 18 provider-level patient safety indicators endorsed by the National Quality Forum. Over time, however, these indicators have increasingly been used for hospital ranking and for determining hospital reimbursements [2].

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PSI 90 is a composite score made up of varying percentages of contributing individual PSIs. The exact contributing weights have varied over time, but the main components have remained relatively constant. The PSI 90 score is primarily used for reimbursement purposes from the Centers for Medicare and Medicaid Services (CMS) [3] (Table 1). Hospital pay for performance depends on these outcomes. Understanding how they represent surgical care is key to optimizing surgical care, improving hospital ratings, and reimbursement rates. Colorectal surgery, both minimally invasive and open, is common in the USA and is an acceptable specialty from which to evaluate rates of PSIs.

Despite controversy regarding the accuracy of PSIs and how they are measured, they remain an important outcome measure for both hospitals and system quality measures [4–7]. The AHRQ also periodically refines definitions and the contribution of various PSIs to the overall composite to

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Table 1 Composite weights for PSI 90

Indicator	Component weight
PSI 3 Pressure ulcer rate	0.0598
PSI 6 Iatrogenic pneumothorax	0.0535
PSI 8 In-hospital fall with fracture	0.0100
PSI 9 Perioperative hemorrhage or hematoma	0.0853
PSI 10 Postoperative acute kidney injury requiring dialysis	0.0410
PSI 11 Postoperative respiratory failure	0.3049
PSI 12 Perioperative pulmonary embolism or deep vein thrombosis	0.2090
PSI 13 Postoperative sepsis	0.2160
PSI 14 Postoperative accidental puncture laceration	0.0132
PSI 15 Unrecognized abdominopelvic Accidental Puncture or Laceration	0.0070

improve accuracy. The PSIs that most significantly impact the PSI 90 score are the following: PSI 3, pressure ulcer; PSI 6, iatrogenic pneumothorax; PSI 8, in-hospital fracture or fall; PSI 9, perioperative hemorrhage; PSI 10, postoperative acute kidney injury; PSI 11, postoperative respiratory failure; PSI 12, perioperative venous thrombosis; and PSI 13, postoperative sepsis.

Colorectal surgery is increasingly being performed as a minimally invasive procedure, with increasing national rates [8]. Studies have shown improved outcomes in patients who undergo minimally invasive surgery (MIS), either robotic or laparoscopic, compared to open surgery [9, 10]. Operations done in an open manner are often assumed to be more complicated, either in terms of a patient's presentation or disease process, thus increasing postoperative complications. As the minimally invasive approach is becoming the standard of care in most instances, we sought to understand whether the mode of operation (MIS vs open) would affect rates of contributing indicators to the overall PSI 90.

Despite their importance, PSI rates remain variable in terms of documentation and patient sociodemographic and clinical variables. Variability in PSI rates based on documentation practices at teaching versus for profit institutions has been observed [11]. Also, significant differences occur between groups depending on race and insurance status, even within the same hospital or system [12–14]. Clinically modifiable variables surrounding PSI rates are also not well understood. While there is a clear clinical benefit of MIS for patients, this has not yet been validated in the literature regarding PSI.

Our aim was to close this knowledge gap by assessing PSI data from the Henry Ford Health System, a large 5-hospital health system located in southeast Michigan with variations among its practice sites, surgeons, and patient populations. It includes one main teaching hospital with residents working at 3 of the 5 hospitals. The main hospital has the dual purpose of being a safety net hospital for the surrounding population as well as a quaternary care referral center. The health system has significant diversity in its patient population, with approximately 40% of patients being African American. There is also variation among insurance providers and acuity of care. Surgical methods that lead to fewer adverse surgical events can improve a hospital's overall PSI scorecard and greatly enhance patient care. We hypothesized that minimally invasive colorectal surgeries would have more favorable PSI 90 rates than open surgeries because of the lower likelihood of adverse events from the minimally invasive approach.

Methods

We used an administrative dataset based on inpatient admissions to the acute care hospitals in the Henry Ford Health System. Prior to analysis, the compiled dataset was anonymized via the removal of all personally identifiable information. The project was reviewed and deemed exempt for review from the Institutional Review Board of the health system because of its retrospective approach. The PSI numerator and denominator data, as defined in 2020 by the AHRQ [3], were merged into this inpatient registry along with coded data regarding procedures and diagnosis. The analysis dataset thus included pertinent clinical and demographic variables, PSI data points, and procedure information.

Colorectal surgery was chosen as the operations of interest for several reasons. They are common operations [15] and are performed by general surgeons, surgical oncologists, colorectal surgeons, and gynecologist oncologists and could well represent a hospital rather than an individual department. Additionally, it can be performed at a wide range of hospitals for multiple indications (neoplasm, infectious inflammatory bowel disease). Because it is common, there is an expected set of risks and complications associated with it. During the study period there was no standardized enhanced recovery protocol used at the hospitals.

The dataset was queried by ICD 10-PCS codes for patients who underwent minimally invasive/laparoscopic and open colorectal resection between January 2, 2018 and December 31, 2019. The patient population was filtered using ICD 10-PCS codes as defined by the CMS in 2020 [16]. The cohort was first narrowed to resection or excisions involving the gastrointestinal system. The dataset was then filtered to operations on the cecum, ascending colon, transverse colon, descending colon, sigmoid colon, large intestine, and rectum (Table 2). ICD 10-PCS codes were also used to classify the approach method, with natural orifice opening surgery excluded. Finally, cases were filtered to those qualifying for inclusion in the denominator of at least one of the studied PSIs.

Common patient demographics, health information, and case characteristics were analyzed with regard to surgical approach. The PSI of interest was those comprising PSI 90, which include the following: PSI 3(pressure ulcer rate), PSI 6 (iatrogenic pneumothorax), PSI 8 (in-hospital fall with hip fracture), PSI 9 (perioperative hemorrhage and hematoma rate), PSI 10 (postoperative acute kidney injury rate), PSI 11 (postoperative respiratory failure), PSI 12 (perioperative

Table 2 ICD 10 codes included

ICD 10 Code	Description of Surgical Procedure
0DBN0ZZ	Excision of Sigmoid Colon; Open Approach
0DBL4ZZ	Excision of Transverse Colon; Percutaneous Endoscopic Approach
0DBL0ZZ	Excision of Transverse Colon; Open Approach
0DTG4ZZ	Resection of Left Large Intestine; Percutaneous Endoscopic Approach
0DTL0ZZ	Resection of Transverse Colon; Open Approach
0DTF4ZZ	Resection of Right Large Intestine; Percutaneous Endoscopic Approach
0DTK0ZZ	Resection of Ascending Colon; Open Approach
0DTN0ZZ	Resection of Sigmoid Colon; Open Approach
0DTK4ZZ	Resection of Ascending Colon; Percutaneous Endoscopic Approach
0DBP0ZZ	Excision of Rectum; Open Approach
0DTF0ZZ	Resection of Right Large Intestine; Open Approach
0DBP4ZZ	Excision of Rectum; Percutaneous Endoscopic Approach
0DBN4ZZ	Excision of Sigmoid Colon; Percutaneous Endoscopic Approach
0DBK4ZZ	Excision of Ascending Colon; Percutaneous Endoscopic Approach
0DTH0ZZ	Resection of Cecum; Open Approach
0DTG0ZZ	Resection of Left Large Intestine; Open Approach
0DBF0ZZ	Excision of Right Large Intestine; Open Approach
0DBK0ZZ	Excision of Ascending Colon; Open Approach
0DBE4ZZ	Excision of Large Intestine; Percutaneous Endoscopic Approach
0DTNFZZ	Resection of Sigmoid Colon; Via Natural Or Artificial Opening With Percutaneous Endoscopic Assistance
0DBH0ZZ	Excision of Cecum; Open Approach
0DTN4ZZ	Resection of Sigmoid Colon; Percutaneous Endoscopic Approach
0DBM4ZZ	Excision of Descending Colon; Percutaneous Endoscopic Approach
0DTP4ZZ	Resection of Rectum; Percutaneous Endoscopic Approach
0DTE0ZZ	Resection of Large Intestine; Open Approach
0DBG0ZZ	Excision of Left Large Intestine; Open Approach
0DTE4ZZ	Resection of Large Intestine; Percutaneous Endoscopic Approach
0DBM0ZZ	Excision of Descending Colon; Open Approach
0DBH4ZZ	Excision of Cecum; Percutaneous Endoscopic Approach
0DBN0ZX	Excision of Sigmoid Colon; Open Approach; Diagnostic
0DTP0ZZ	Resection of Rectum; Open Approach
0DBE0ZZ	Excision of Large Intestine; Open Approach
0DTL4ZZ	Resection of Transverse Colon; Percutaneous Endoscopic Approach
0DBF4ZZ	Excision of Right Large Intestine; Percutaneous Endoscopic Approach
0DTH4ZZ	Resection of Cecum; Percutaneous Endoscopic Approach
0DTM0ZZ	Resection of Descending Colon; Open Approach
0DBP0ZX	Excision of Rectum; Open Approach; Diagnostic
0DBNFZZ	Excision of Sigmoid Colon; Via Natural Or Artificial Opening With Percutaneous Endoscopic Assistance

deep vein thrombosis or pulmonary embolism), PSI 13 (postoperative sepsis), PSI 14 (postoperative wound dehiscence rate), and PSI 15 (unrecognized abdominopelvic accidental puncture/laceration rate). Currently, PSI 90 comprises 10 separate PSI, with varying contributing percentages. Currently the major components are PSI 3 (6.0%), PSI 6 (5.3%), PSI 8 (1.0%), PSI 9 (4.1%), PSI 10 (4.1%), PSI 11 (30.5), PSI 12 (20.9%), PSI 13 (21.6%), PSI 13 (1.3%), and PSI 15 (0.7%) (Table 1). This shows that the largest components of PSI 90 are postoperative respiratory failure, postoperative deep vein thrombosis or pulmonary embolism, and postoperative sepsis, all of which are important in colon and rectal surgery [3].

Statistical relationships between surgical approach and PSIs were investigated using univariate methods and multivariate logarithmic regression analysis. The data were deidentified prior to analysis and were analyzed using R within R-Studio. A p-value < 0.05 was considered statistically significant. All data preparation and analysis were performed using version 3.5.2 of the R programming language (R Project for Statistical Computing; R Foundation) [17].

Results

There were a total of 1382 operations reviewed in the dataset, from which 861 (62%) were open and 521 (38%) were MIS. There were no significant differences between the groups for biologic sex, racial identity, or dual-eligible beneficiary status. More patients with Medicare/Medicaid had open surgery (540, 63%) than those with private insurance (318, 37%) ($p = 0.02$) (Table 3). Comorbidities were similar between the 2 groups other than patients with congestive heart failure (15% vs 9.2%, $p < 0.001$) and renal disease (16% vs 10%, $p < 0.001$) who had open surgery more often. There was no difference in Charlson Comorbidity Index between the groups. Patients who had surgery for colonic neoplasm had MIS in 58% of cases ($p < 0.001$), and 28% of MIS were done for non-neoplastic diagnoses ($p < 0.001$) (Table 3).

The MIS approach was used in 51.2% (463/905) of elective operations ($p < 0.001$) and 12% (57/474) of emergent operations ($p < 0.001$). MIS was done less often than open surgery for patients transferred to the operating hospital (1.5% vs 7.3%; $p < 0.001$). The community hospitals performed more open operations than the academic hospital (566, 66% vs 295, 34%; $p < 0.001$). Type of surgery differed based on admitting services ($p < 0.001$). Admission to the colorectal surgery service resulted in MIS more often (284, 55%) than general surgery (206, 40%) or acute care surgery (2, 0.4%). Patients who had open surgery were more likely to have a higher median MS-DRG diagnosis weight (2.52; interquartile range [IQR], 2.47–4.91) than patients who had minimally invasive operations (2.47; IQR, 1.69–2.52) ($p < 0.001$) (Table 3).

Univariate analysis showed several differences between the surgical groups as shown in Table 4. Postoperative length of stay significantly varied depending on mode of operation ($p < 0.001$). Patients who had open surgery had median inpatient stay of 6 days (IQR, 4–10) compared to 3 days (IQR, 2–4; $p < 0.001$) for patients who had MIS. of patients who required readmission within 30 days of surgery, 116 (13%) had open surgery compared to 41 (7.9%) who had MIS ($p = 0.001$). Univariate analysis demonstrated no significant difference between MIS and open surgery groups for the following PSIs: PSI 3, PSI 6, PSI 8, PSI 9, PSI 10, PSI 11, PSI 13, PSI 14, and PSI 15 (Table 5) Excluded cases for each PSI vary based on the individual PSI inclusion/exclusion criteria based on AHRQ definitions. However, PSI 12 (postoperative pulmonary embolism or deep vein thrombosis) occurred more often in open surgeries ($p = 0.016$).

Using binomial logistic regression, no significant differences in regard to patient characteristics and operative approach were observed (Table 6). Racial identity, ethnicity, and dual-eligible beneficiary status were not significantly different between MIS and open surgery groups. In terms of medical comorbidities, the only comorbidity that was significantly associated with a surgical approach was open operation with peptic ulcer disease (odds ratio, [OR] 1.61; 90% CI 1.15–2.45; $p = 0.023$). Admission to an academic hospital was close to being significantly associated with a decreased risk of open surgery (OR 0.64; 90% CI 0.43–0.91; $p = 0.051$) (Table 6).

Using the binomial logistic regression model, we observed no significant relationship between any variables and PSI rates. Additionally, there was no significant difference between the 2 surgical groups in respect to PSI 3, 6, and 8 through 15 (Table 7).

Discussion

Using a large 5-hospital health system dataset, we examined rates of the major PSI that contribute to PSI 90 for minimally invasive versus open colorectal surgery. Using both univariate and binomial logistic regressions, we observed minimal to no effect of operative approach on rates of major PSI outcomes. However, we observed that open operations were performed significantly more often than MIS in emergent situations and for infectious indications. Open operations showed an association with non-neoplastic diagnosis, transfer status, emergent, and non-colorectal surgery service. Surgical admission to colorectal surgery service was associated with MIS but had no effect on PSI rates. Surgical diagnosis also had no effect on PSI outcomes.

Table 3 Univariate analysis of surgical approach across demographic, health, and operation variables with reported *p*-values and *q*-values

	Laparoscopy/MIS, *n* = 521 (38)	Open, *n* = 861 (62)	*p*-value	*q*-value
Demographic information				
Age, years, Median (IQR)	63 (54, 72)	64 (53, 73)	0.3	0.5
Biologic sex, *n* (%)			0.8	0.9
Female	268 (51%)	450 (52%)		
Male	253 (49%)	411 (48%)		
Racial identity, *n* (%)			0.12	0.2
White	379 (73%)	636 (74%)		
Black	94 (18%)	169 (20%)		
Other	23 (4.4%)	19 (2.2%)		
Unspecified	25 (4.8%)	37 (4.3%)		
Ethnicity, *n* (%)			0.4	0.6
Not Hispanic/Latinx	475 (91%)	798 (93%)		
Hispanic/Latinx	10 (1.9%)	18 (2.1%)		
Unspecified	36 (6.9%)	45 (5.2%)		
Insurance provider, *n* (%)			0.009	0.023
Private	234 (45%)	318 (37%)		
Medicare/Medicaid	285 (55%)	540 (63%)		
Other	2 (0.4%)	3 (0.3%)		
Dual-eligible beneficiary, *n* (%)	37 (7.1%)	75 (8.7%)	0.3	0.5
Preferred language, *n* (%)			0.4	0.5
English	509 (98%)	829 (96%)		
Non-English	8 (1.5%)	20 (2.3%)		
Unspecified	4 (0.8%)	12 (1.4%)		
Health characteristics				
Comorbidities				
Myocardial Infarction, *n* (%)	51 (9.8%)	110 (13%)	0.10	0.2
Congestive Heart Failure, *n* (%)	48 (9.2%)	133 (15%)	< 0.001	0.003
Peripheral Vascular Disease, *n* (%)	50 (9.6%)	86 (10.0%)	0.9	> 0.9
Cerebrovasculer Disease, *n* (%)	31 (6.0%)	76 (8.8%)	0.061	0.14
Dementia, *n* (%)	12 (2.3%)	45 (5.2%)	0.008	0.021
Chronic Obstructive Pulmonary Disease, *n* (%)	138 (26%)	217 (25%)	0.6	0.7
Rheumatoid Disease, *n* (%)	16 (3.1%)	26 (3.0%)	> 0.9	> 0.9
Peptic Ulcer Disease, *n* (%)	11 (2.1%)	46 (5.3%)	0.003	0.009
Mild Liver Disease, *n* (%)	7 (1.3%)	20 (2.3%)	0.2	0.4
Diabetes without Complications, *n* (%)	120 (23%)	219 (25%)	0.3	0.5
Diabetes with Complications, *n* (%)	47 (9.0%)	89 (10%)	0.5	0.6
Hemiplegia or Paraplegia, *n* (%)	3 (0.6%)	10 (1.2%)	0.4	0.5
Renal disease, *n* (%)	52 (10.0%)	142 (16%)	< 0.001	0.003
Cancer, *n* (%)	222 (43%)	277 (32%)	< 0.001	< 0.001
Moderate or Severe Liver Disease, *n* (%)	4 (0.8%)	7 (0.8%)	> 0.9	> 0.9
Metastatic Solid Tumor, *n* (%)	58 (11%)	94 (11%)	> 0.9	> 0.9
AIDS/HIV, *n* (%)	0 (0%)	0 (0%)		
Comorbidity count grouped, *n* (%)			0.2	0.4
None	149 (29%)	239 (28%)		
One	150 (29%)	217 (25%)		
> One	222 (43%)	405 (47%)		
Comorbidity Count, Median (IQR)	1 (0, 3)	1 (0, 3)	0.2	0.3
Charlson Comorbidity Index Score, Median (IQR)	2 (0, 3)	2 (0, 4)	0.5	0.6
Operation characteristics				

Table 3 (continued)

	Laparoscopy/MIS, $n = 521$ (38)	Open, $n = 861$ (62)	*p*-value	*q*-value
Hospital type, *n* (%)			< 0.001	< 0.001
Community Hospital	279 (54%)	566 (66%)		
Academic Hospital	242 (46%)	295 (34%)		
Admitting service, *n* (%)			< 0.001	< 0.001
Family/Internal Medicine	14 (2.7%)	63 (7.3%)		
Intensive Care	5 (1.0%)	36 (4.2%)		
Acute Care Surgery	2 (0.4%)	165 (19%)		
General Surgery	206 (40%)	337 (39%)		
Gynecology/Oncology	0 (0%)	7 (0.8%)		
Colon/Rectal Surgery	284 (55%)	218 (25%)		
Other	10 (1.9%)	35 (4.1%)		
Elective Surgery, *n* (%)	463 (89%)	442 (51%)	< 0.001	< 0.001
Urgent/Emergent Surgery, *n* (%)	57 (11%)	417 (48%)	< 0.001	< 0.001
Transfer, *n* (%)	8 (1.5%)	63 (7.3%)	< 0.001	< 0.001
MS-DRG Diagnosis Weight, Median (IQR)	2.47 (1.69, 2.52)	2.52 (2.47, 4.91)	< 0.001	< 0.001
Neoplasm, *n* (%)	302 (58%)	275 (32%)	< 0.001	< 0.001

IQR interquartile range, *MIS* minimally invasive surgery, *MS-DRG* medicare severity-diagnosis-related group

Table 4 Univariate analysis of surgical approach across outcome variables with reported *p*-values and *q*-values

	Laparoscopy/MIS, $n = 521$ (38)	Open, $n = 861$ (62)	*p*-value	*q*-value
Outcome information				
Mortality, *n* (%)	2 (0.4%)	29 (3.4%)	< 0.001	< 0.001
In-patient LOS, days, Median (IQR)	3 (2, 4)	6 (4, 10)	< 0.001	< 0.001
ICU LOS, days, Median (IQR)	2 (1, 4)	3 (1, 7)	0.002	0.004
Duration of Mechanical Ventilation, days, Median (IQR)	2 (2, 5)	3 (2, 6)	0.8	0.8
Total Laboratory Tests, Median (IQR)	13 (8, 22)	31 (15, 68)	< 0.001	< 0.001
Laboratory Tests per LOS, Median (IQR)	4.00 (3.00, 4.83)	4.67 (3.67, 6.75)	< 0.001	< 0.001
Time to Readmission, days, Median (IQR)	23 (7, 60)	21 (6, 48)	0.3	0.3
Readmission to ICU (≤ 48 h), *n* (%)	0 (0%)	0 (0%)	0.085	0.10
Readmission (≤ 7 days), *n* (%)	21 (4.0%)	57 (6.6%)	0.039	0.053
Readmission (≤ 30 days), *n* (%)	41 (7.9%)	116 (13%)	0.001	0.002
Readmission (≤ 90 days), *n* (%)	75 (14%)	190 (22%)	< 0.001	< 0.001

ICU intensive care unit, *IQR* interquartile range, *LOS* length of stay, *MIS* minimally invasive surgery

The findings of this study contrast with our hypothesis that MIS would result in fewer PSI occurrences than open operations. Our hypothesis was based on the widespread support in clinical practice and the literature that MIS results in fewer complications for patients, shorter lengths of stay, and better outcomes in general [18]. While it is generally accepted that MIS provides clinical benefit to patients, this has not previously been examined using PSIs. Because PSIs, and PSI 90 in particular, are so important to hospital-reported outcomes and reimbursement, it is necessary to better understand the nuances of care that could affect rates of PSI 90. The diversity within the Henry Ford Health System in terms of patient population, patient acuity, teaching status, and payer mix make it a compelling location to study components of PSI 90.

Our study found no significant difference between race and ethnicity, insurance status, and teaching status of the hospital with rates of MIS surgery or rates of examined PSIs. Given the diversity in patient population, insurance status, and teaching status of the hospitals within our health system, this is an important distinction. The literature does describe existing differences in surgical approach, outcomes, and

Table 5 Univariate analysis of surgical approach across patient safety indicators which significantly compose PSI 90 score along with reported *MIS* minimally invasive surgery

Patient Safety Indicator	Laparoscopy/MIS, $n=521$ (38)	Open, $n=861$ (62)	p-value	q-value
PSI 03: Pressure Ulcer Rate, n/N (%)	0/374 (0)	0/788 (0)		
Excluded Cases	147	73		
PSI 06: Iatrogenic Pneumothorax Rate, n/N (%)	0/516 (0)	1/813 (0.1)	> 0.9	> 0.9
Excluded Cases	5	48		
PSI 08: In-Hospital Fall with Hip Fracture Rate, n/N (%)	0/472 (0)	0/770 (0)		
Excluded Cases	49	91		
PSI 09: Perioperative Hemorrhage or Hematoma, n/N (%)	0/507 (0)	2/805 (0.2)	0.5	0.8
Excluded Cases	14	56		
PSI 10: Postoperative Acute Kidney Injury Requiring Dialysis Rate, n/N (%)	1/449 (0.2)	2/420 (0.5)	0.6	0.8
Excluded Cases	72	441		
PSI 11: Postoperative Respiratory Failure, n/N (%)	0/441 (0)	4/424 (0.9)	0.057	0.2
Excluded Cases	80	437		
PSI 12: Postoperative Pulmonary Embolism or Deep Vein Thrombosis, n/N (%)	0/515 (0)	9/849 (1.1)	0.016	0.13
Excluded Cases	6	12		
PSI 13: Postoperative Sepsis, n/N (%)	1/342 (0.3)	4/316 (1.3)	0.2	0.5
Excluded Cases	179	545		
PSI 14: Postoperative Wound Dehiscence Rate, n/N (%)	0/459 (0)	1/682 (0.1)	> 0.9	> 0.9
Excluded Cases	62	179		
PSI 15: Unrecognized Abdominopelvic Accidental Puncture or Laceration Rate, n/N (%)	0/518 (0)	4/849 (0.5)	0.3	0.6
Excluded Cases	3	12		

p-values and *q*-values

PSIs based on race, particularly for Black patients [19–23]. Studnicki et al. found that PSI 7 (central line associated bloodstream infection) had highest rates in younger Black and older White patients [21]. Hospital teaching status may also increase rates of PSI due to less precise coding [11], which was not the case in our study. Insurance status is another important factor when evaluating rates of MIS and PSI incidence with concern to non-White patients, who may have open surgery more often [24]. In our study, we found that there was no significant association of dual eligibility or insurance provider with MIS. Access to surgical care based on insurance status has been suggested as a contributor to PSI rates. Patients with less desirable insurance, such as Medicaid or dual eligibility, may therefore have restricted access to surgeons who can perform MIS for more advanced disease states, thus resulting in more unfavorable postoperative outcomes [12–14]. This can even occur in the same hospital or health system [14]. Our study conflicts with this. Across our health system, with different patient populations and groups of surgeons, we found no difference in rates of PSI for either approach to colorectal surgery or admitting surgical service.

Data are conflicting regarding how and if PSI outcomes are related to readmission, which is a key driver of patient satisfaction and a source of cost for hospitals. We found that readmission within 30 days was more common in patients who had open operations. However, length of stay for MIS was shorter, with an average of 3 days compared to 6 days for open surgery. While we identified that patients who had MIS were less likely to be readmitted, there was still no difference based on PSI rates. The literature is inconclusive on this point. While some studies have shown that patients with a PSI occurrence may be at increased risk for readmission [4, 25], Campione et al. describe that when controlling for sociodemographic and hospital factors, no association exists [26]. With the diversity in both race and insurance status in our health system's patient population, we did not find a difference in PSI rates and readmission. Although there was no PSI rate difference, patients who underwent open surgery tended to have more comorbidities and acuity of care compared to patients who had MIS.

A possible explanation for the similarities in PSI outcomes between MIS and open surgery could be due to overall improvement in surgical care, including perioperative optimization and pathways. Currently enhanced recovery

Table 6 Bayesian logistic regression relating open surgical approach to Laparoscopy/MIS surgical approach across demographic, health, and operation variables with reported *p*-values and *q*-values

	OR	90% CI	*p*-value	*q*-value
Demographic information				
Age, years	1.00	1.00, 1.02	0.39	0.69
Racial identity				
White				
Black	1.28	0.98, 1.71	0.19	0.45
Other	0.59	0.30, 1.02	0.18	0.45
Unspecified	1.25	0.63, 2.07	0.54	0.73
Ethnicity				
Not Hispanic/Latinx				
Hispanic/Latinx	0.79	0.36, 1.45	0.62	0.73
Unspecified	0.62	0.36, 1.08	0.13	0.45
Insurance provider				
Private				
Medicare/Medicaid	1.02	0.79, 1.31	0.92	0.94
Other	0.88	0.19, 4.19	0.89	0.94
Dual-eligible Beneficiary	1.01	0.70, 1.47	0.96	0.96
Preferred language				
English				
Non-English	1.84	0.84, 3.76	0.22	0.47
Unspecified	2.34	0.71, 8.16	0.25	0.52
Health characteristics				
Comorbidities				
Myocardial Infarction	1.37	0.94, 1.90	0.19	0.45
Congestive Heart Failure	0.87	0.58, 1.16	0.57	0.73
Peripheral Vascular Disease	1.61	1.09, 2.44	0.059	0.32
Cerebrovasculer Disease	0.84	0.53, 1.33	0.53	0.73
Dementia	0.81	0.42, 1.53	0.60	0.73
Chronic Obstructive Pulmonary Disease	1.34	1.06, 1.75	0.065	0.32
Rheumatoid Disease	1.29	0.72, 2.69	0.50	0.73
Peptic Ulcer Disease	0.42	0.24, 0.81	0.023	0.22
Mild Liver Disease	0.42	0.22, 1.05	0.15	0.45
Diabetes without Complications	0.80	0.61, 1.05	0.20	0.45
Diabetes with Complications	1.36	0.86, 1.91	0.28	0.55
Hemiplegia or Paraplegia	1.17	0.34, 3.91	0.83	0.93
Renal Disease	0.65	0.46, 0.92	0.067	0.32
Cancer	0.74	0.53, 1.04	0.11	0.43
Moderate or Severe Liver Disease	1.74	0.49, 5.95	0.50	0.73
Metastatic Solid Tumor	0.72	0.50, 1.02	0.14	0.45
Operation characteristics				
Hospital Type				
Community Hospital				
Academic Hospital	0.64	0.44, 0.89	0.051	0.32
Admitting service				
Family/internal medicine				
Intensive Care	1.44	0.60, 3.58	0.52	0.73
Acute Care Surgery	22.5	7.75, 68.0	< 0.001	< 0.001
General Surgery	1.25	0.74, 2.28	0.52	0.73
Gynecology/Oncology	15.6	1.02, 168	0.073	0.32
Colon/Rectal Surgery	0.80	0.39, 1.54	0.55	0.73
Other	1.06	0.44, 2.34	0.90	0.94
Elective Surgery	2.20	0.58, 8.52	0.39	0.69
Urgent/Emergent Surgery	0.75	0.19, 2.55	0.75	0.87

Table 6 (continued)

	OR	90% CI	*p*-value	*q*-value
Transfer	1.27	0.62, 2.54	0.59	0.73
MS-DRG Diagnosis Weight	1.33	1.20, 1.48	< 0.001	< 0.001
Neoplasm	2.62	1.97, 3.63	< 0.001	< 0.001

CI credible interval, *IQR* interquartile range, *MIS* minimally invasive surgery, *MS-DRG* medicare severity-diagnosis-related group, *OR* odds ratio

pathways drive care of perioperative patients to ensure standardization of preoperative and postoperative care. While the MIS approach is the standard of care in many operations, it is generally recommended in colon surgery whenever surgeon skill set allows. The number of colectomies done with a minimally invasive approach is at least 50% and likely increasing as surgeons become more comfortable with laparoscopic and robotic platforms [27]. Open operation is more often performed for patient-specific factors or emergent surgery and more often results in increased complications [28, 29]. Enhanced recovery protocols have standardized perioperative care for patients overall. While individual protocols vary from hospital to hospital, there is a set of standard of care that includes early ambulation, optimization of non-narcotic pain control, and early alimentation. While formal protocols do not always eliminate rates of unfavorable postoperative occurrences [30], standardization of perioperative colectomy protocols may improve outcomes for all patients and minimize complications that initially were seen more commonly in open surgery. This has been demonstrated in vascular surgery, where endovascular and open repair of ruptured aortic aneurysm had similar incidences of PSIs [25]. This shift in postoperative management has potentially improved care for all patients, both those who have open surgery and MIS, and has minimized complications and PSI occurrences.

Our results do not demonstrate a reduced rate of PSI in minimally invasive colorectal surgery, which has known clinical benefits, compared to open surgery. Thus, these data contribute to the body of literature questioning the reliability of PSI in representing postoperative quality outcomes. Previous literature has documented poor accuracy and representation of quality outcomes using the PSI definitions and parameters. PSI rates can vary significantly by operation being performed and may not be broadly useful. [2, 5, 6, 11, 31–33]. While the PSI 90 composite remains an important metric for quality reporting, hospital reimbursement, and financial penalties, it may not be the best quality surrogate measure based on AHRQ definitions. There are components of the PSI 90 that are not necessarily as important to general perioperative care, such as PSI 3 (pressure ulcer rate), PSI 6 (iatrogenic pneumothorax), and PSI 8 (postoperative hip fracture rate). Conversely, PSI 4 (death among surgical inpatients with serious treatable complication), PSI 5 (retained surgical item), and PSI 15 (accidental puncture or laceration), are more broadly applicable to an operation itself or the postoperative care [34, 35]. For these reasons, the PSI 90 could be better refined to specifically represent perioperative quality. To accurately measure surgical quality both the variable being measured and the measurement itself must be carefully considered.

Our research has several limitations. This was a retrospective review of a large dataset with a potential for misclassification of certain patient characteristics or errors in the data. ICD 10 codes were used to classify patients and there may have been variations in how coding was performed at individual sites. Procedure type was also not assigned, but rather recorded, which may include other laparoscopic-assisted operations, conversion to open operation, or robotic operations. Robotic operations are unable to be coded in the ICD 10 and cannot be specifically included. The diversity among the individual hospitals, while valuable at some levels, also results in possible inconsistent protocols for colon and rectal surgery. Most surgeons operate within 1 or 2 of the 5 hospitals, which could result in non-standardized pathways. Additionally, hospitals in the health system have different specialties performing colorectal surgery, including colorectal surgeons, general surgeons with MIS focus, and acute care surgeons, that could affect operative variables or surgical approach. Despite these limitations, we were able to demonstrate that rates of MIS and open colorectal surgery do not correlate with incidence of PSIs.

Conclusion

Patient Safety Indicators are important outcome measures that affect publicly reported data and reimbursement. Given their importance, they remain poorly described in the literature, especially in relation to specific types of surgical

Table 7 Bayesian logistic regressions relating numerator instances to non-numerator instances for patient safety indicators which significantly compose PSI 90 score across demographic, health, and operation variables with reported p-values and q-values

	PSI 03				PSI 06				PSI 08				PSI 09				PSI 10			
	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value
Approach Method																				
Laparoscopy/MIS																				
Open	1.00	0.02, 40.0	> 0.9	> 0.9	1.66	0.06, 21.8	0.8	> 0.9	1.00	0.02, 14.3	> 0.9	> 0.9	2.71	0.18, 27.1	0.6	> 0.9	1.35	0.15, 9.49	0.8	> 0.9
Demographic Information																				
Age, yrs	1.00	0.90, 1.12	> 0.9	> 0.9	1.01	0.91, 1.12	0.8	> 0.9	1.00	0.87, 1.12	> 0.9	> 0.9	1.02	0.96, 1.09	0.7	> 0.9	1.00	0.92, 1.08	> 0.9	> 0.9
Racial Identity																				
White																				
Black	1.00	0.03, 52.0	> 0.9	> 0.9	0.78	0.03, 21.6	> 0.9	> 0.9	1.00	0.03, 29.0	> 0.9	> 0.9	0.66	0.11, 6.72	0.8	> 0.9	0.41	0.01, 5.06	0.6	> 0.9
Other	1.00	0.03, 103	> 0.9	> 0.9	0.98	0.04, 53.3	> 0.9	> 0.9	1.00	0.02, 44.9	> 0.9	> 0.9	0.86	0.05, 57.9	> 0.9	> 0.9	0.95	0.03, 40.1	> 0.9	> 0.9
Unspecified	1.00	0.02, 39.9	> 0.9	> 0.9	0.93	0.02, 57.1	> 0.9	> 0.9	1.00	0.03, 57.3	> 0.9	> 0.9	0.82	0.02, 50.5	> 0.9	> 0.9	0.93	0.02, 59.2	> 0.9	> 0.9
Ethnicity																				
Not Hispanic/Latinx																				
Hispanic/Latinx	1.00	0.01, 42.1	> 0.9	> 0.9	0.99	0.01, 38.8	> 0.9	> 0.9	1.00	0.03, 103	> 0.9	> 0.9	0.86	0.01, 17.9	> 0.9	> 0.9	0.97	0.02, 259	> 0.9	> 0.9
Unspecified	1.00	0.02, 32.0	> 0.9	> 0.9	0.92	0.03, 48.4	> 0.9	> 0.9	1.00	0.03, 48.4	> 0.9	> 0.9	0.64	0.02, 11.6	0.8	> 0.9	0.93	0.04, 18.4	> 0.9	> 0.9
Insurance Provider																				
Private																				
Medicare/Medicaid	1.00	0.03, 51.6	> 0.9	> 0.9	1.33	0.08, 41.6	0.9	> 0.9	1.00	0.03, 22.7	> 0.9	> 0.9	3.68	0.28, 71.1	0.4	> 0.9	1.91	0.23, 30.9	0.7	> 0.9
Other	1.00	0.02, 81.7	> 0.9	> 0.9	1.00	0.03, 57.1	> 0.9	> 0.9	1.00	0.01, 53.8	> 0.9	> 0.9	1.00	0.02, 41.5	> 0.9	> 0.9	1.00	0.03, 116	> 0.9	> 0.9
Dual-eligible Beneficiary	1.00	0.03, 48.7	> 0.9	> 0.9	0.72	0.06, 29.4	0.9	> 0.9	1.00	0.02, 59.0	> 0.9	> 0.9	1.94	0.19, 28.4	0.6	> 0.9	0.76	0.02, 63.9	0.9	> 0.9
Preferred Language																				
English																				

Table 7 (continued)

	PSI 03				PSI 06				PSI 08				PSI 09				PSI 10			
	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value
Non-English	1.00	0.02, 47.1	> 0.9	> 0.9	0.96	0.02, 19.2	> 0.9	> 0.9	1.00	0.03, 28.8	> 0.9	> 0.9	0.83	0.02, 49.3	> 0.9	> 0.9	0.99	0.02, 22.0	> 0.9	> 0.9
Unspecified	1.00	0.02, 106	> 0.9	> 0.9	0.98	0.01, 76.4	> 0.9	> 0.9	1.00	0.01, 43.4	> 0.9	> 0.9	0.92	0.02, 38.6	> 0.9	> 0.9	0.99	0.01, 80.6	> 0.9	> 0.9
Health Characteristics																				
Comorbidities																				
Myocardial Infarction	1.00	0.01, 136	> 0.9	> 0.9	1.47	0.05, 27.1	0.8	> 0.9	1.00	0.03, 51.0	> 0.9	> 0.9	2.54	0.19, 31.0	0.6	> 0.9	2.77	0.13, 70.5	0.6	> 0.9
Congestive Heart Failure	1.00	0.04, 47.2	> 0.9	> 0.9	1.69	0.08, 41.7	0.8	> 0.9	1.00	0.02, 56.0	> 0.9	> 0.9	0.59	0.04, 5.15	0.7	> 0.9	0.01	0.00, 0.33	0.030	> 0.9
Peripheral Vascular Disease	1.00	0.03, 64.7	> 0.9	> 0.9	1.54	0.12, 37.3	0.8	> 0.9	1.00	0.01, 21.9	> 0.9	> 0.9	2.52	0.17, 38.9	0.6	> 0.9	3.84	0.23, 56.1	0.4	> 0.9
Cerebrovasculer Disease	1.00	0.02, 27.5	> 0.9	> 0.9	2.70	0.10, 31.2	0.6	> 0.9	1.00	0.03, 89.9	> 0.9	> 0.9	0.35	0.03, 3.41	0.5	> 0.9	1.60	0.12, 60.4	0.8	> 0.9
Dementia	1.00	0.05, 40.2	> 0.9	> 0.9	1.23	0.02, 44.7	> 0.9	> 0.9	1.00	0.02, 67.2	> 0.9	> 0.9	1.50	0.11, 27.0	0.8	> 0.9	0.42	0.02, 7.02	0.6	> 0.9
Chronic Obstructive Pulmonary Disease	1.00	0.03, 64.7	> 0.9	> 0.9	0.37	0.03, 8.78	0.6	> 0.9	1.00	0.03, 43.3	> 0.9	> 0.9	2.53	0.13, 34.2	0.6	> 0.9	0.88	0.19, 12.6	> 0.9	> 0.9
Rheumatoid Disease	1.00	0.03, 43.1	> 0.9	> 0.9	1.17	0.03, 43.2	> 0.9	> 0.9	1.00	0.02, 99.3	> 0.9	> 0.9	1.17	0.06, 51.5	> 0.9	> 0.9	1.07	0.02, 64.9	> 0.9	> 0.9
Peptic Ulcer Disease	1.00	0.01, 27.5	> 0.9	> 0.9	1.10	0.03, 23.3	> 0.9	> 0.9	1.00	0.01, 57.8	> 0.9	> 0.9	1.34	0.04, 38.3	0.9	> 0.9	1.17	0.05, 27.9	> 0.9	> 0.9
Mild Liver Disease	1.00	0.03, 26.1	> 0.9	> 0.9	1.14	0.07, 53.7	> 0.9	> 0.9	1.00	0.02, 48.9	> 0.9	> 0.9	0.09	0.01, 1.43	0.2	> 0.9	0.31	0.01, 2.62	0.5	> 0.9
Diabetes without Complications	1.00	0.01, 48.2	> 0.9	> 0.9	1.51	0.11, 55.7	0.8	> 0.9	1.00	0.03, 51.8	> 0.9	> 0.9	1.01	0.10, 14.2	> 0.9	> 0.9	3.81	0.17, 66.3	0.5	> 0.9
Diabetes with Complications	1.00	0.01, 27.1	> 0.9	> 0.9	1.29	0.09, 22.3	> 0.9	> 0.9	1.00	0.02, 49.1	> 0.9	> 0.9	0.52	0.02, 9.46	0.7	> 0.9	1.69	0.07, 50.2	0.8	> 0.9
Hemiplegia or Paraplegia	1.00	0.01, 66.6	> 0.9	> 0.9	1.01	0.04, 43.3	> 0.9	> 0.9	1.00	0.02, 122	> 0.9	> 0.9	1.62	0.09, 37.9	0.8	> 0.9	1.27	0.08, 39.6	> 0.9	> 0.9

Table 7 (continued)

	PSI 03				PSI 06				PSI 08				PSI 09				PSI 10			
	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value
Renal Disease	1.00	0.04, 94.7	> 0.9	> 0.9	1.51	0.08, 33.1	0.8	> 0.9	1.00	0.01, 22.1	> 0.9	> 0.9	0.84	0.05, 5.84	> 0.9	> 0.9	0.56	0.06, 4.68	0.7	> 0.9
Cancer	1.00	0.02, 38.9	> 0.9	> 0.9	0.34	0.01, 10.1	0.6	> 0.9	1.00	0.03, 12.6	> 0.9	> 0.9	0.91	0.06, 8.69	> 0.9	> 0.9	2.73	0.09, 56.7	0.6	> 0.9
Moderate or Severe Liver Disease	1.00	0.01, 35.7	> 0.9	> 0.9	1.00	0.02, 89.2	> 0.9	> 0.9	1.00	0.02, 46.9	> 0.9	> 0.9	1.97	0.12, 32.1	0.7	> 0.9	0.29	0.01, 5.39	0.5	> 0.9
Metastatic Solid Tumor	1.00	0.04, 25.7	> 0.9	> 0.9	1.39	0.06, 50.6	0.9	> 0.9	1.00	0.03, 23.2	> 0.9	> 0.9	1.69	0.15, 17.6	0.8	> 0.9	1.05	0.03, 52.6	> 0.9	> 0.9
Operation Charac-teristics																				
Hospital Type																				
Community Hospital																				
Academic Hospital	1.00	0.04, 23.7	> 0.9	> 0.9	0.71	0.06, 17.8	0.9	> 0.9	1.00	0.04, 56.4	> 0.9	> 0.9	6.53	0.26, 70.4	0.3	> 0.9	3.44	0.47, 55.2	0.5	> 0.9
Admitting Service																				
Family/ Internal Medicine																				
Intensive Care	1.00	0.02, 26.8	> 0.9	> 0.9	21.0	1.24, 1,112	0.14	> 0.9	1.00	0.02, 61.9	> 0.9	> 0.9	0.87	0.02, 27.9	> 0.9	> 0.9	1.43	0.12, 9.93	0.8	> 0.9
Acute Care Surgery	1.00	0.01, 41.0	> 0.9	> 0.9	0.82	0.02, 26.3	> 0.9	> 0.9	1.00	0.01, 51.0	> 0.9	> 0.9	2.72	0.20, 54.5	0.5	> 0.9	0.66	0.04, 17.8	0.8	> 0.9
General Surgery	1.00	0.03, 56.4	> 0.9	> 0.9	0.60	0.02, 10.1	0.8	> 0.9	1.00	0.02, 31.4	> 0.9	> 0.9	0.62	0.01, 23.0	0.8	> 0.9	0.90	0.07, 13.3	> 0.9	> 0.9
Gynecol-ogy/ Oncology	1.00	0.02, 31.8	> 0.9	> 0.9	0.99	0.04, 77.2	> 0.9	> 0.9	1.00	0.01, 69.0	> 0.9	> 0.9	0.95	0.02, 31.0	> 0.9	> 0.9	1.00	0.02, 69.8	> 0.9	> 0.9
Colon/ Rectal Surgery	1.00	0.02, 32.5	> 0.9	> 0.9	0.73	0.03, 20.2	0.9	> 0.9	1.00	0.03, 34.4	> 0.9	> 0.9	0.96	0.06, 22.3	> 0.9	> 0.9	1.19	0.11, 24.2	> 0.9	> 0.9
Other	1.00	0.01, 66.4	> 0.9	> 0.9	0.91	0.04, 31.3	> 0.9	> 0.9	1.00	0.01, 83.2	> 0.9	> 0.9	0.84	0.02, 29.2	> 0.9	> 0.9	0.98	0.04, 88.8	> 0.9	> 0.9
Elective Surgery	1.00	0.04, 46.0	> 0.9	> 0.9	1.89	0.18, 23.4	0.8	> 0.9	1.00	0.03, 19.9	> 0.9	> 0.9	1.27	0.06, 15.7	0.9	> 0.9	1.00	0.03, 28.5	> 0.9	> 0.9
Urgent/ Emergent Surgery	1.00	0.02, 37.8	> 0.9	> 0.9	0.53	0.02, 5.71	0.7	> 0.9	1.00	0.03, 39.1	> 0.9	> 0.9	0.78	0.07, 13.3	0.9	> 0.9				

Table 7 (continued)

	PSI 03				PSI 06				PSI 08				PSI 09				PSI 10			
	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value
Transfer	1.00	0.04, 40.6	> 0.9	> 0.9	0.81	0.02, 15.9	> 0.9	> 0.9	1.00	0.02, 107	> 0.9	> 0.9	0.52	0.05, 6.82	0.7	> 0.9	1.00	0.02, 41.6	> 0.9	> 0.9
MS-DRG Diagnosis Weight	1.00	0.39, 2.86	> 0.9	> 0.9	1.40	0.36, 3.59	0.6	> 0.9	1.00	0.33, 2.93	> 0.9	> 0.9	0.96	0.43, 2.20	> 0.9	> 0.9	1.74	1.10, 3.21	0.080	> 0.9
Neoplasm	1.00	0.07, 21.2	> 0.9	> 0.9	0.21	0.01, 7.19	0.4	> 0.9	1.00	0.02, 47.7	> 0.9	> 0.9	0.78	0.06, 5.57	0.9	> 0.9	7.13	0.66, 158	0.3	> 0.9

	PSI 12				PSI 13				PSI 14				PSI 15		
	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value
Approach Method															
Laparoscopy/MIS															
Open	0.74, 125	0.13	> 0.9	1.98	0.27, 10.5	0.6	> 0.9	1.43	0.08, 29.1	0.9	> 0.9	3.68	0.25, 38.7	0.4	> 0.9
Demographic Information															
Age, yrs	1.00, 1.09	0.2	> 0.9	1.00	0.95, 1.09	> 0.9	> 0.9	0.97	0.91, 1.07	0.5	> 0.9	1.03	0.98, 1.08	0.5	> 0.9
Racial Identity															
White															
Black	0.13, 2.87	0.6	> 0.9	0.08	0.00, 2.62	0.3	> 0.9	0.51	0.03, 4.67	0.7	> 0.9	2.31	0.27, 16.8	0.5	> 0.9
Other	0.04, 9.16	0.7	> 0.9	0.86	0.04, 26.8	> 0.9	> 0.9	0.93	0.02, 41.4	> 0.9	> 0.9	0.76	0.05, 29.8	0.9	> 0.9
Unspecified	0.02, 12.2	0.7	> 0.9	0.44	0.01, 5.79	0.6	> 0.9	0.71	0.02, 15.7	0.9	> 0.9	0.76	0.03, 19.2	0.9	> 0.9
Ethnicity															
Not Hispanic/Latinx															
Hispanic/Latinx	0.03, 16.8	0.8	> 0.9	0.87	0.02, 25.5	> 0.9	> 0.9	0.95	0.03, 209	> 0.9	> 0.9	0.80	0.04, 22.2	> 0.9	> 0.9
Unspecified	0.03, 4.36	0.7	> 0.9	10.4	0.99, 163	0.13	> 0.9	0.60	0.03, 22.3	0.8	> 0.9	0.71	0.06, 20.4	0.9	> 0.9
Insurance Provider															
Private															
Medicare/Medicaid	0.30, 4.31	0.8	> 0.9	5.02	0.54, 41.1	0.3	> 0.9	2.92	0.26, 29.3	0.5	> 0.9	0.74	0.10, 5.04	0.8	> 0.9
Other	0.02, 79.3	> 0.9	> 0.9	1.00	0.01, 64.7	> 0.9	> 0.9	0.98	0.01, 38.7	> 0.9	> 0.9	0.98	0.01, 123	> 0.9	> 0.9
Dual-eligible Beneficiary	0.62, 11.0	0.3	> 0.9	0.51	0.03, 5.75	0.7	> 0.9	0.72	0.04, 43.7	0.9	> 0.9	5.80	0.92, 60.3	0.2	> 0.9
Preferred Language															
English															
Non-English	1.00, 80.1	0.13	> 0.9	0.95	0.10, 21.6	> 0.9	> 0.9	0.96	0.02, 56.5	> 0.9	> 0.9	0.72	0.05, 20.0	0.9	> 0.9
Unspecified	0.02, 20.1	> 0.9	> 0.9	0.81	0.01, 81.9	> 0.9	> 0.9	0.91	0.01, 53.3	> 0.9	> 0.9	0.96	0.02, 39.9	> 0.9	> 0.9
Health Characteristics															
Comorbidities															
Myocardial Infarction	0.27, 7.50	0.7	> 0.9	8.46	0.39, 209	0.4	> 0.9	1.46	0.06, 50.5	0.8	> 0.9	2.03	0.15, 27.3	0.7	> 0.9
Congestive Heart Failure	0.69, 11.5	0.3	> 0.9	0.15	0.01, 1.57	0.14	> 0.9	1.15	0.06, 43.2	> 0.9	> 0.9	2.65	0.17, 25.8	0.6	> 0.9
Peripheral Vascular Disease	0.24, 6.60	0.8	> 0.9	4.52	0.28, 67.6	0.4	> 0.9	1.24	0.03, 49.4	> 0.9	> 0.9	1.70	0.06, 18.9	0.8	> 0.9
Cerebrovasculer Disease	0.17, 4.69	0.9	> 0.9	1.64	0.11, 39.7	0.8	> 0.9	1.35	0.07, 39.1	0.9	> 0.9	1.88	0.07, 25.7	0.7	> 0.9

Table 7 (continued)

	PSI 12				PSI 13				PSI 14				PSI 15		
	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value	OR	90% CI	*p*-value	*q*-value
Dementia	0.10, 3.52	0.7	> 0.9	0.37	0.03, 10.1	0.5	> 0.9	1.03	0.01, 104	> 0.9	> 0.9	1.88	0.13, 75.0	0.7	> 0.9
Chronic Obstructive Pulmonary Disease	0.09, 0.92	0.10	> 0.9	0.52	0.10, 5.46	0.6	> 0.9	1.54	0.06, 16.1	0.8	> 0.9	5.20	0.80, 64.5	0.3	> 0.9
Rheumatoid Disease	0.17, 39.7	0.7	> 0.9	1.30	0.04, 23.7	0.9	> 0.9	1.13	0.02, 56.2	> 0.9	> 0.9	1.39	0.05, 27.1	0.9	> 0.9
Peptic Ulcer Disease	0.17, 71.1	0.5	> 0.9	1.84	0.07, 31.0	0.7	> 0.9	1.15	0.06, 27.5	> 0.9	> 0.9	1.46	0.08, 54.6	0.8	> 0.9
Mild Liver Disease	0.09, 33.2	0.8	> 0.9	0.38	0.01, 10.1	0.6	> 0.9	1.01	0.02, 51.6	> 0.9	> 0.9	0.36	0.02, 3.58	0.5	> 0.9
Diabetes without Complications	0.78, 13.1	0.2	> 0.9	17.1	0.13, 420	0.2	> 0.9	1.93	0.10, 18.8	0.7	> 0.9	4.12	0.26, 46.4	0.4	> 0.9
Diabetes with Complications	0.60, 83.8	0.3	> 0.9	1.44	0.05, 49.7	0.9	> 0.9	1.04	0.01, 19.0	> 0.9	> 0.9	1.29	0.04, 23.5	> 0.9	> 0.9
Hemiplegia or Paraplegia	0.10, 25.6	0.7	> 0.9	1.01	0.03, 112	> 0.9	> 0.9	1.29	0.05, 64.6	> 0.9	> 0.9	1.11	0.01, 22.7	> 0.9	> 0.9
Renal Disease	0.09, 1.87	0.3	> 0.9	0.91	0.13, 5.54	> 0.9	> 0.9	1.08	0.03, 36.2	> 0.9	> 0.9	3.57	0.32, 81.7	0.4	> 0.9
Cancer	0.29, 4.46	> 0.9	> 0.9	1.56	0.18, 12.8	0.7	> 0.9	1.34	0.06, 24.6	0.9	> 0.9	0.89	0.07, 5.43	> 0.9	> 0.9
Moderate or Severe Liver Disease	0.04, 52.0	> 0.9	> 0.9	0.34	0.01, 7.82	0.6	> 0.9	1.00	0.01, 59.0	> 0.9	> 0.9	0.06	0.00, 2.33	0.2	> 0.9
Metastatic Solid Tumor	0.28, 45.1	0.3	> 0.9	0.21	0.01, 2.05	0.3	> 0.9	1.20	0.05, 54.8	> 0.9	> 0.9	2.00	0.17, 43.5	0.7	> 0.9
Operation Characteristics															
Hospital Type															
Community Hospital															
Academic Hospital	0.13, 2.79	0.8	> 0.9	2.87	0.17, 17.3	0.5	> 0.9	2.19	0.07, 43.2	0.7	> 0.9	0.71	0.07, 7.03	0.8	> 0.9
Admitting Service															
Family/Internal Medicine															
Intensive Care	0.13, 9.73	0.9	> 0.9	1.36	0.11, 21.0	0.9	> 0.9	0.98	0.02, 64.1	> 0.9	> 0.9	6.44	0.61, 79.7	0.2	> 0.9
Acute Care Surgery	0.04, 2.39	0.4	> 0.9	0.54	0.03, 8.79	0.7	> 0.9	3.31	0.18, 34.7	0.5	> 0.9	0.79	0.08, 7.51	0.9	> 0.9
General Surgery	0.16, 3.01	0.7	> 0.9	2.10	0.18, 21.3	0.6	> 0.9	0.73	0.03, 10.8	0.9	> 0.9	2.51	0.23, 11.4	0.5	> 0.9
Gynecology/Oncology	0.05, 18.2	> 0.9	> 0.9	0.70	0.03, 12.4	0.9	> 0.9	0.91	0.03, 14.3	> 0.9	> 0.9	0.96	0.02, 37.4	> 0.9	> 0.9
Colon/Rectal Surgery	0.21, 9.37	> 0.9	> 0.9	0.98	0.12, 17.9	> 0.9	> 0.9	0.58	0.02, 7.64	0.8	> 0.9	0.36	0.03, 6.34	0.6	> 0.9
Other	0.95, 28.2	0.13	> 0.9	0.97	0.04, 36.7	> 0.9	> 0.9	0.97	0.01, 31.6	> 0.9	> 0.9	0.69	0.03, 14.2	0.8	> 0.9
Elective Surgery	0.05, 10.5	> 0.9	> 0.9	1.00	0.03, 39.2	> 0.9	> 0.9	1.78	0.11, 57.0	0.8	> 0.9	1.53	0.10, 18.8	0.8	> 0.9
Urgent/Emergent Surgery	0.07, 12.9	> 0.9	> 0.9					0.56	0.03, 17.0	0.8	> 0.9	0.65	0.03, 6.76	0.8	> 0.9
Transfer	2.62, 69.6	0.007	0.3	0.98	0.02, 30.1	> 0.9	> 0.9	14.5	0.87, 543	0.2	> 0.9	0.64	0.02, 17.8	0.8	> 0.9
MS-DRG Diagnosis Weight	0.98, 1.49	0.14	> 0.9	2.11	1.42, 3.02	0.009	0.4	0.57	0.22, 1.36	0.3	> 0.9	1.15	0.61, 1.76	0.6	> 0.9
Neoplasm	0.21, 4.57	0.9	> 0.9	6.42	1.15, 49.1	0.2	> 0.9	1.29	0.06, 46.2	0.9	> 0.9	0.93	0.10, 13.8	> 0.9	> 0.9

CI credible interval, *IQR* interquartile range, *MIS* minimally invasive surgery, *MS-DRG* medicare severity-diagnosis related group, *OR* odds ratio, *PSI* patient safety indicator approaches. Comparison of open and minimally invasive colon and rectal surgeries at a large 5-hospital health system showed no significant differences between surgical approaches regarding acuity of care, patient race, patient insurance status, or teaching status of the hospital. Despite the established clinical benefits of MIS, this surgical approach did not show significant differences in PSI rates for MIS compared to open surgery. Further work must be done to better understand modifiable risks to PSI occurrences or if the PSI 90 could be further refined.

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Declarations

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