ORIGINAL CONTRIBUTION

Key Factors Associated With Postoperative Complications in Patients Undergoing Colorectal Surgery

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BACKGROUND: Surgical outcomes are determined by complex interactions among a variety of factors including patient characteristics, diagnosis, and type of procedure.

OBJECTIVE: The aim of this study was to prioritize the effect and relative importance of the surgeon (in terms of identity of a surgeon and surgeon volume), patient characteristics, and the intraoperative details on complications of colorectal surgery including readmission, reoperation, sepsis, anastomotic leak, small-bowel obstruction, surgical site infection, abscess, need for transfusion, and portal and deep vein thrombosis.

DESIGN: This study uses a novel classification methodology to measure the influence of various risk factors on postoperative complications in a large outcomes database.

METHODS: Using prospectively collected information from the departmental outcomes database from 2010 to 2011, we examined the records of 3552 patients who underwent colorectal surgery. Instead of traditional statistical methods, we used a family of 7000 bootstrap classification models to examine and quantify the impact of various factors on the most common serious surgical complications. For each complication, an ensemble of multivariate classification models was designed to determine the relative importance of potential factors that may influence outcomes of surgery. This is a new technique for analyzing outcomes data that produces more accurate results and a more reliable ranking of study variables in order of their importance in producing complications.

PATIENTS: Patients who underwent colorectal surgery in 2010 and 2011 were included.

SETTINGS: This study was conducted at a tertiary referral department at a major medical center.

MAIN OUTCOME: Postoperative complications were the primary outcomes measured.

RESULTS: Factors sorted themselves into 2 groups: a highly important group (operative time, BMI, age, identity of the surgeon, type of surgery) and a group of low importance (sex, comorbidity, laparoscopy, and emergency). ASA score and diagnosis were of intermediate importance. The outcomes most influenced by variations in the highly important factors included readmission, transfusion, surgical site infection, and abscesses.

LIMITATIONS: This study was limited by the use of data from a single tertiary referral department at a major medical center.

CONCLUSIONS: Body mass index, operative time, and the surgeon who performed the operation are the 3 most important factors influencing readmission rates, rates of transfusions, and surgical site infection. Identification of these contributing factors can help minimize complications.

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KEY WORDS: Colorectal, Surgery, Complications, Outcomes, Risk factors.

The outcome of colorectal surgical procedures is influenced by a variety of factors, including the quality of care, patient characteristics, preoperative risk factors, and operative details. Outcomes can be measured across a variety of dimensions, and different risk factors

may have differential relative impact on a specific complication. Sorting out the determinants of surgical outcomes is important, because the identification of adjustable risk factors underlies attempts to improve outcomes.

Numerous studies have explored the association between outcomes and risk factors for surgical procedures. One recent study determined the most important predictors of complications that need to be included in models for adequate risk adjustment. This study used a large database of patients who underwent 5 core general surgery operations.[1] Another recent study evaluated risk factors associated with readmission after colorectal surgeries among a nationwide cohort of patients.[2] The relative importance of the experience of the operating surgeon on operative mortality in patients who underwent cardiovascular procedures or cancer resections was observed in 1 earlier study.[3] This work demonstrated that the outcome of a surgical procedure may depend as much on patient characteristics and preoperative factors as on intraoperative details and the surgeon's skill. Another study evaluated the impact of surgeon caseload among other factors as an independent predictor of mortality, readmission, and length of stay after restorative proctocolectomy.[4] In that study, surgeon volume was inversely related to complications.

These studies, and many others like them, focus on 1 or 2 risk factors but do not examine the complex interrelationships between multiple risk factors. In fact, little is known about the relative contribution of various risk factors on different outcomes of interest to colorectal surgeons. To address these deficiencies, we undertook a comprehensive evaluation of the potential risk factors associated with the most serious complications of major colorectal surgical procedures by using data from an institution-based outcomes registry. We hypothesized that a data-driven approach to the analysis of common serious complications in patients who undergo colorectal surgery would allow us to estimate the magnitude of the influence of risk factors on any particular complication.

PATIENTS AND DATABASES

With the use of information from a prospectively collected outcomes database, we examined the records of 3552 patients who underwent major abdominal or transanal colorectal surgery in 2010 and 2011, performed by 15 surgeons in the Department of Colorectal Surgery at the Cleveland Clinic. We included all surgical cases performed by the study surgeons if inpatient admission was required. Outpatient surgical cases were not included in the analysis. The departmental clinical database was created to collect risk-adjusted outcomes for all colorectal procedures, to provide feedback to surgeons, and to give surgeons a better understanding of their performance. The complication data are collected by a dedicated research assistant and monitored by surgeons at the department. The data collection process was optimized with a number of automatic feeds from electronic medical records, and data integrity was ensured by auditing and computerized quality control. The goals of the registry and data collection process are closely modeled after the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) database in terms of standard definitions and adherence to 30-day follow-up period for outcomes collection. In addition, we also included colorectal-specific outcome variables. The research assistant conducted a 30-day follow-up via a letter or phone call, and periodic death searches in public records are obtained to complete follow-up data. In addition, representative study surgeons participate in regular audits to test data quality.

More than 200 patient and operative variables are recorded in the registry, including patient demographics, preoperative risk factors, laboratory values, intraoperative details, and postoperative complications. The characteristics of the patients for which we adjusted the analyses included age (a continuous variable), BMI (a continuous variable), and comorbidity (yes or no). We adjusted the analyses for the type of surgical procedure and operative time (continuous variable). To perform meaningful modeling, surgical procedures were grouped into 10 major categories (Table 1) that were likely to represent procedures of similar complexity and similar technical skills required by a surgeon. Laparoscopic approach was presented as another variable. For all procedures, we identified the operating surgeon. To characterize surgeon volume, we determined the number of procedures in each major category that a surgeon performed in 2 years. As opposed to previous studies that analyzed volume as the average number of any procedures performed by a surgeon, we used a refined definition of volume that we believe would better reflect the level of technical skills achieved by a colorectal surgeon. We used the colorectal surgical procedure as the unit of analysis, with volume measured at the level of the surgeon and the specific procedure. The database includes laboratory values and also many patient characteristics that are limited to a small minority. For example, cirrhosis is a variable we record, but because of the low numbers of patients with this condition, it was excluded from the analysis. In the end, we chose to include variables that are known to affect outcome (ASA, BMI, diagnosis, etc) and the variables that pertained to the majority of our patients.

We focused on the most meaningful complications of colorectal procedures including readmission, reoperation, sepsis, anastomotic leak, small-bowel obstruction, surgical site infection (SSI), abscess, need for transfusion, and venous thromboembolism. Into the analysis of anastomotic leaks we excluded surgeries in which an anastomosis was not created. Our definition of SSI is based on the NSQIP definition but is less inclusive. For example,

TABLE 1. Characteristics of the patients

Characteristics	
Total number of patients	3552
Age at surgery, mean ± SD	50.7 ± 17.1
Female sex, n (%)	1747 (49.2)
BMI (kg/m^2)	26.6 ± 6.1
ASA class, n (%)	
I	50 (1.4)
II	1880 (52.9)
III	1493(42.0)
IV/V	129 (3.6)
Indication for surgery, n (%)	
Cancer	577 (16.2)
Mucosal ulcerative colitis	547 (15.4)
Crohn's disease	468 (13.2)
Ostomy	415 (11.7)
Fistula	252 (7.1)
Diverticulitis	190 (5.3)
Polyp	117 (3.3)
Bowel obstruction	113 (3.2)
Hernia	83 (2.3)
Other	790 (22.2)
Comorbidity, n (%)	
No. of patients with any comorbidity	973 (27.4)
No. of patients with >1 comorbidity	408 (11.5)
Surgical procedures, n (%)	
Abdominoperineal resection, Hartmann procedures	191 (5.4)
Ileal pouch operation	255 (7.2)
Segmental colon resection	631 (17.8)
Multisegmental colon resection	286 (8.1)
Small-bowel operations	199 (5.6)
Proctectomy with anastomosis or end ileostomy	252 (7.1)
Transanal and prolapse procedure	523 (14.7)
K-pouch and enterocutaneous fistula	171 (4.8)
Ostomy creation or closure (isolated procedure)	807 (22.7)
Other	237 (6.7)
Estimated blood loss, mL, median; mean (IQR)	100; 201 (30–250)
Laparoscopic, n (%)	740 (20.8)
Emergency, n (%)	84 (2.4)
Surgeon volume: No. of procedures per surgeon in 2 y, medium (range)	
Abdominoperineal resection, Hartmann procedures	14 (8–28)
Ileal pouch operation	18 (7–61)
Segmental colon resection	51 (19–86)
Multisegmental colon resection	22 (4–38)
Small-bowel operations	15 (7–33)
Proctectomy with anastomosis or end ileostomy	19 (6–39)
Transanal and prolapse procedure	32 (18–52)
K-pouch and enterocutaneous fistula	10 (1–40)
Ostomy creation or closure (isolated procedure)	53 (28–133)
Other	19 (6–52)
Complications (within 30 days), n (%)	
Operative mortality	25 (0.7)
Incisional surgical site infection	300 (8.4)
Readmission	430 (12.1)
Reoperation	184 (5.2)
Transfusion	343 (9.7)
Anastomotic leak	80 (3.8)[a]
Abscess	191 (5.4)
Sepsis	86 (2.4)
Portal and deep vein thrombosis	125 (3.5)
Small-bowel obstruction	112 (3.2)
No. of patients with any complication	1064 (30.0)
No. of patients with >1 complication	518 (14.6)

IQR = interquartile range.
[a]Percentage from the number of cases with anastomoses (n = 2105).

in regard to superficial SSI, we do not include all wounds that have redness or localized swelling and are opened by the surgeon unless there is also purulence or other gross signs of infection. In this study, the term surgical site infection (SSI) applied to infection of the superficial or deep tissues of the surgical incision. Abscess was defined as an infected abdominal or pelvic fluid collection not involving incision. Postoperative mortality was not analyzed because of the small number of cases.

Patient characteristics, preoperative clinical data, and intraoperative details are presented in Table 1.

Statistical Methods

We developed a family of random forest models: sophisticated prognostic models that capture complex relationships among many risk factors to predict outcomes of patients.[5] Several characteristics of random forest have made it an excellent classifier. Random forest is a nonlinear model that makes no assumption about data distribution. Random forest methodology is based on a nonparametric model that can simultaneously analyze and explore interactions between many competing and interrelated variables. Random forest predictions are based on an ensemble of classification trees; each tree is constructed from a bootstrap sample (random subset of data) with replacement and uses randomly selected covariates at each split. The random forest algorithm can handle a mix of categorical and continuous predictors. To evaluate the impurity function and decide how to split a tree node based on a numeric variable, the algorithm evaluates each randomly selected numeric variable in sorted order. For categorical unordered variables, random forest algorithm evaluates a split at each category. The use of bootstrap samples and restricted subsets of attributes makes it more powerful than simple ensembles of trees and leads to virtually unbiased estimation of prediction error. It was shown to build models with high accuracy when tested on high-dimensional datasets.

The main advantage of a random forest classifier is its explanatory power: it uses a variable importance, one of the advanced properties of this model, to measure impact of each factor on a predicted class label. In our analyses, we used a variable importance measure to assess the relative impact of

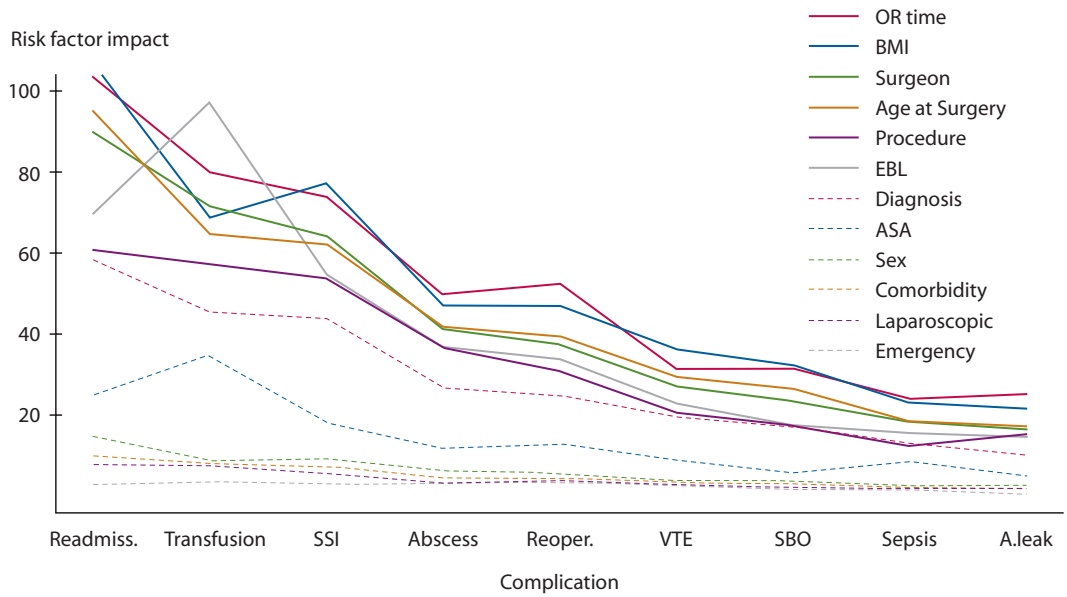

FIGURE 1. Plots of relative importance of various factors related to major complications of colorectal surgeries. As an example, surgeon identity, represented by the red line, has a higher impact on readmission, transfusion, and SSI, and has lesser implication on sepsis and anastomotic leak complications. As another example, readmission rates (first entry on the *x* axis) influenced most by patient BMI, operative time, and the identity of the surgeon. The relative importance of the type of procedure (laparoscopic or not), patient comorbid conditions, and timing of surgery (emergency) play a lesser role for readmission and all other complications. OR TIME = length of surgery; EBL = estimated blood loss; READMISS. = readmission; SSI = surgical site infection; REOPER. = reoperation; VTE = venous thromboembolism; SBO = small-bowel obstruction; A. LEAK = anastomotic leak.

each risk factor on the observed association with an outcome by first excluding and then including a variable. The variable importance value measures how much misclassification increases or decreases if a given variable is not available. In other words, random forest explains how well the variable discriminates between a "bad" and a "good" outcome after adjusting for all other variables included in a model.

Separate random forest models were built for each complication to identify and rank important risk factors that maximize prediction. A mix of categorical (eg, surgical procedure, indication for surgery) and continuous variables (eg, BMI, age at surgery, estimated blood loss) were analyzed at each split of a tree. Each of the classification trees in a model was constructed from about two thirds of the data; the remaining one third of the data is used to estimate error rates and produce variable importance values. Each model, comprising of a forest of 3000 classification trees, yielded a rank ordering of all variables, which reflects how strongly each risk factor is associated with an outcome variable. To assess the relative contribution of a risk factor on each type of complication, we then combined variable importance values from all models and presented in a single graph.

To better understand the predictive value of the most informative variables selected by the random forest models, a series of traditional logistic regression models, one for each complication, was generated. A p value of less than 5% was considered to indicate statistical significance, and all tests were 2 sided.

Computation was performed by the use of random forest implementation in the R statistical software package version 2.10.0.[5,6] Optimal parameters for the algorithm (number of cases in a bootstrap sample, number of variables considered for the split, and number of trees) were selected according to a general principle of random forest methodology.

RESULTS

Our primary analyses focused on the relationships between risk factors and each type of complication defined as a complication before hospital discharge or within 30 days of the index surgery. We used classification models to examine these relationships with adjustment for patient characteristics and intraoperative details. We used the colorectal surgical procedure, defined as an abdominal or anal/perineal procedure, that required anesthesia and in-hospital stay, as the unit of analysis.

A family of classification models revealed the strength of associations between various risk factors and complications. Figure 1 shows risk factors that are sorted in descending order of importance in generating each of a series of postoperative complications. Factors sort themselves into 2 groups: a highly important group (length of surgery, BMI, identity of the surgeon, patient age, type of procedure, and estimated blood loss) and a group of low importance (sex, comorbidity, laparoscopy, and

TABLE 2. Rank ordering or relative impact of top 7 risk factors on complication rates

Rank	*Readmission*	*Transfusion*	*SSI*	*Abscess*	*Reoperation*	*VTE/DVT*	*SBO*	*Sepsis*	*Anastomotic leak*
1	OR time	EBL[a]	OR time	OR time	OR time	BMI	BMI	OR time	OR time
2	BMI	OR time	BMI	BMI	BMI	OR time	OR time	BMI	BMI
3	Surgeon	Surgeon	Surgeon	Surgeon	Surgeon	Age at surgery	Age at surgery	Surgeon	Surgeon
4	Age at surgery	BMI	Age at surgery	Age at surgery	Age at surgery	Surgeon	Surgeon	Age at surgery	Age at surgery
5	EBL	Age at surgery	Procedure	Procedure	Procedure	EBL	Procedure	EBL	Procedure
6	Procedure	Procedure	EBL	EBL	EBL	Procedure	EBL	Diagnosis	EBL
7	Diagnosis	Diagnosis	Diagnosis	Diagnosis	Diagnosis	Diagnosis	Diagnosis	Procedure	Diagnosis

OR time = length of surgery; EBL = estimated blood loss; SSI = surgical site infection; VTE = venous thromboembolism; DVT = deep vein thrombosis; SBO = small-bowel obstruction.

[a]EBL was included in the analysis to predict transfusion as a validation point and for consistency.

emergency). ASA score and diagnosis are of intermediate importance. Our analyses suggest that BMI, length of surgery, and identity of the surgeon are the 3 risk factors that dominate the majority of complications. However, the strength of the associations between risk factors and outcomes varied markedly across all complications. Based on variable importance values, the 3 risk factors (BMI, length of surgery, and identity of the surgeon) are the top predictors for all complications, but they had greater impact on readmission, transfusion, and SSI rates than that on small-bowel obstruction, sepsis, and anastomotic leak complications. Contributions of risk factors to each postoperative complication in the group of low importance display less variation.

Table 2 demonstrates the relative impact of all predictors on each of a series of postoperative complications. To simplify the presentation of our results, we show here the analyses for the top 7 risk factors for which we have found a strong association with outcomes; we ranked the impact of risk factors on each type of complication. Our analyses suggest that BMI is the top predictor for SSI, venous thromboembolism, and small-bowel obstruction, whereas length of surgery dominates readmission, transfusion, abscess, reoperation, sepsis, and anastomotic leak. Identity of the surgeon and patient age are the next 2 important predictors of all complications followed by procedure type, estimated blood loss, and diagnosis.

To better explain the results of the analyses, we present univariate analyses and a series of traditional logistic regression models with adjustment for the most informative predictors selected by the random forest. To simplify the presentation, we included here only the top 4 predictors selected by the random forest. In univariate and multivariate analyses, predictors were analyzed in relation to each complication. Overall, operative time is associated with increased complication rates in colorectal surgical procedures. The first predictor listed in Table 3 shows differences in operative times for patients who did not have a specific complication in comparison with patients who had a complication. Operative time for patients who were not readmitted was significantly shorter than for patients who required readmission (131.1 minutes vs 144.6 minutes, $p = 0.0083$) and operative time for cases without blood transfusion was 126.8 minutes vs 188.4 minutes for cases with transfusion ($p < 00001$). The strength of association between length of surgery and the outcome varied according to the type of complication in terms of both the absolute complication rates (Table 3) and the adjusted odds ratio (Table 4). The adjusted odds ratio for cases lasting more than 200 minutes as compared with cases with shorter operative time ranged from 1.12 for small-bowel obstruction to 2.79 for transfusion. The observed effect of the length of surgery may be explained by the experience of the operating surgeon. In fact, with adjustment for surgeon volume, operative time has been found to be an independent predictor for a number of complications including readmission, transfusion, SSI, abscess, reoperation, and anastomotic leak.

When the surgeon volume was assessed as a continuous variable, defined as the total number of each type of procedure that a surgeon performed during the 2 years, it was inversely related to all complications. In multiple logistic regression analyses, we categorized surgeon volume as a binary variable: 20 or more procedures vs fewer than 20. The adjusted odds ratio for cases performed by a low-volume surgeon vs those performed by a high-volume surgeon varied widely according to the complication type, from 1.02 for sepsis to 2.17 for anastomotic leak. Irrespective of other factors, surgeon volume was a significant predictor for 4 complications (SSI, abscess, reoperation, and anastomotic leak).

Increased BMI was independently associated with SSI, portal and deep vein thrombosis; higher BMI was related to decreased small-bowel obstruction. Patient age (>75 years) was independently and directly linked to transfusion and reoperation.

TABLE 3. Univariate analyses of the most important risk factors selected by the random forest models across all complications

	No	*Yes*	*p*
Comparison of operative times in minutes (mean ± SD) for patients without (no) and with complications (yes)			
Readmission	131.1 ± 97.9	144.6 ± 98.7	0.008
Transfusion	126.8 ± 91.0	188.4 ± 136.7	<0.001
Surgical site infection	130.0 ± 96.8	162.9 ± 106.9	<0.001
Abscess	130.8 ± 97.2	167.4 ± 106.9	<0.001
Reoperation	131.1 ± 97.0	163.7 ± 111.6	0.001
VTE	132.0 ± 98.3	153.3 ± 88.9	0.010
Small-bowel obstruction	132.8 ± 98.6	131.3 ± 80.6	0.845
Sepsis	132.6 ± 98.1	140.3 ± 97.7	0.472
Anastomotic leak	131.5 ± 97.3	189.2 ± 116.1	<0.001
Comparison of surgeon volume,[a] number of procedures (mean ± SD) for patients without (no) and with (yes) complications			
Readmission	54.5 ± 40.3	49.3 ± 39.4	0.005
Transfusion	55.0 ± 40.4	43.3 ± 36.9	<0.001
Surgical site infection	54.8 ± 40.3	43.7 ± 37.8	<0.001
Abscess	54.70 ± 40.30	39.02 ± 35.91	< .001
Reoperation	54.1 ± 40.1	49.3 ± 41.8	0.362
VTE	54.3 ± 40.3	40.9 ± 36.0	0.001
Small-bowel obstruction	54.0 ± 40.2	50.8 ± 42.2	0.211
Sepsis	53.9 ± 40.3	53.0 ± 39.6	0.541
Anastomotic leak	54.37 ± 40.2	31.62 ± 34.6	<0.001
Comparison of BMI (mean ± SD) for patients without (no) and with (yes) complications			
Readmission	26.5 ± 6.2	26.8 ± 5.9	0.071
Transfusion	26.6 ± 6.1	26.8 ± 6.1	0.177
Surgical site infection	26.5 ± 6.1	27.6 ± 6.2	0.007
Abscess	26.56 ± 6.20	26.61 ± 5.14	0.903
Reoperation	26.5 ± 6.1	27.1 ± 6.3	0.112
VTE	26.5 ± 6.1	28.4 ± 6.8	0.007
Small-bowel obstruction	26.6 ± 6.2	25.4 ± 4.7	0.017
Sepsis	26.6 ± 6.1	27.1 ± 7.2	0.149
Anastomotic leak	26.6 ± 6.2	27.1 ± 5.6	0.427
Comparison of age at surgery, years (mean ± SD) for patients without (no) and with (yes) complications			
Readmission	50.87 ± 17.06	49.07 ± 17.29	0.043
Transfusion	50.0 ± 16.99	56.7 ± 16.94	<0.001
Surgical site infection	50.54 ± 17.14	51.81 ± 16.61	0.209
Abscess	50.70 ± 17.13	49.82 ± 16.56	0.477
Reoperation	50.59 ± 17.11	51.76 ± 16.91	0.361
VTE	50.59 ± 17.10	52.28 ± 17.05	0.278
Small-bowel obstruction	50.62 ± 17.11	51.64 ± 16.61	0.521
Sepsis	50.53 ± 17.08	55.55 ± 17.15	0.009
Anastomotic leak	50.69 ± 17.12	48.90 ± 15.90	0.324

VTE = venous thromboembolism.
[a]Surgeon volume was measured at the level of surgeon and each procedure, 10 surgical procedure groups listed in Table 1.

DISCUSSION

A systematic approach to the collection of outcomes data can reveal the most important variables that impact risk prediction and explain variations in risk-adjusted outcomes. The NSQIP and the American College of Surgeons Case Log System have shown that this approach has practical value for quality improvement. The NSQIP database provides surgeons with a uniform format for collecting outcomes data and uses sophisticated statistical techniques for risk adjustment.[7,8] Although the NSQIP records a spectrum of clinical details, it does not include some colorectal-specific outcomes and colorectal-specific variables that can be used for optimal risk adjustment, such as the number of anastomoses created, anastomotic leak, and small-bowel obstruction. In addition, the NSQIP dataset is limited to a select group of surgical procedures. Our dataset includes all surgical procedures performed by our colorectal surgeons.

A study by Cohen et al[9] identified the most important predictors of outcomes for colorectal operations based on the NSQIP data. A colorectal-specific risk calculator, a 15-variable predictor model, was constructed for mortality,

TABLE 4. Adjusted OR for 9 complications according to length of surgery, surgeon volume, BMI, and patient age

	Adjusted OR (95% CI)			
Complication	*Length of surgery (>200 min)*	*Surgeon volume (<20 procedures)*	*BMI (>30)*	*Age at Surgery (>75)*
Readmission	1.45 (1.17–1.80) ***	1.16 (0.92–1.46)	1.02 (0.80–1.29)	1.00(0.68–1.43)
Transfusion	2.79 (2.17–3.60) ***	1.26 (0.98–1.61)	1.10 (0.85–1.43)	2.15 (1.51–2.99) ***
Surgical site infection	2.11 (1.63–2.75) ***	1.38 (1.06–1.79) *	1.34 (1.02–1.74) *	1.08 (0.69–1.64)
Abscess	2.11 (1.53–2.94)***	1.76 (1.28–2.40)***	0.79 (0.55–1.13)	0.83 (0.44–1.42)
Reoperation	1.41 (1.03–1.95) *	1.57 (1.13–2.18)**	1.28 (0.91–1.78)	1.65 (1.01–2.57) *
VTE/DVT	1.58 (1.08–2.34)*	1.43 (0.96–2.11)	1.63 (1.10–2.37) *	1.16 (0.58–2.08)
Small-bowel obstruction	1.12 (0.75–1.67)	1.31 (0.84–2.00)	0.50 (0.28–0.84) *	1.51 (0.80–2.64)
Sepsis	1.35 (0.86–2.14)	1.02 (0.61–1.66)	1.41 (0.87–2.24)	1.40 (0.65–2.67)
Anastomotic leak	2.42 (1.45–4.16)***	2.17 (1.36–3.48)**	1.12 (0.67–1.83)	0.81 (0.11–1.21)

Significant *p*-value codes: ***0.0001; **0.001; *0.01; $p = 0.05$.
VTE = venous thromboembolism; DVT = deep vein thrombosis.

overall morbidity, and serious mortality. Application of the variable selection process in stepwise regression models ranked variables according to the selection order. However, an outcome was defined as a group of complications, and a relationship between risk factors and a particular complication was not identified. More recently, the relative importance of variables to predict morbidity and mortality for 5 core general surgery operations in the procedure-specific NSQIP was analyzed.[1] In this work, stepwise logistic regression models were used to identify the most important variables that predict outcomes. The focus of this work was mortality and morbidity, defined as the presence of at least 1 complication. The study showed that a small set of variables can be used to predict patient risk without compromising risk adjustment. Once again, relative importance of each variable was not linked to a specific complication in this study.

Numerous studies have investigated the association between potential risk factors and outcomes in colorectal surgical procedures. However, relatively few of these studies have simultaneously analyzed a series of major complications in relation to a broad range of potential confounding factors and characterized the relative influence of these factors on specific outcomes. To address this issue, we undertook a comprehensive evaluation of the operative risk factors associated with colorectal surgical procedures. We had 2 primary aims: to assess the association between risk factors and various complications and to achieve a better understanding of the extent to which risk factors influence specific outcomes.

For all complications we studied, complication rates increased with prolonged operative time. The association of operative time with SSI across a broad range of procedures has been reported in several studies.[10–12] Operative time was also reported as a risk factor for anastomotic leak following colorectal surgery.[13–15] Determinates of operative time are multifactorial and may include complexity of the case or previous abdominal operations. Specifically, more complex cases would require longer operative time and may also result in poorer outcomes. Our definition of a complex case is not limited to, but can relate to, the type of procedure, patient BMI, or diagnosis. Our models were adjusted for all of these factors. Still, operative time remained one of the major predictors for all complications. Another explanation for the observed relation between the operative time and the outcome may be that surgeons who are more experienced with a specific procedure tend to achieve better technical skills and perform operations faster. As suggested by our analyses, factors related to both operative time and surgeon volume seem to be important for all complications. Our findings, however, indicate that the relative importance of surgeon and operative time varies according to the complication. In the case of SSI, abscess, venous thrombosis, and anastomotic leak, surgeon volume is a significant and independent risk factor irrespective of the operative time. The importance of experience of the surgeon has been recognized in several studies.[3]

Obesity is known to lead to higher complication rates across a wide variety of surgical procedures. It is not surprising that, in our study, increasing BMI was associated with increased postoperative complication rates, with 1 exception: patients with lower BMI were more likely to have small-bowel obstruction. Previous studies have reported similar findings and have indicated that this finding may be related to an impaired wound-healing process in patients who are obese.[16,17]

This present study is limited by the inability to adjust for patient differences such as previous abdominal surgeries, level of complexity of a surgical procedure, or variations in specific processes of care that might have influenced the results. Our study was conducted at a single high-volume referral center for colorectal surgery. Our result may not apply to colorectal surgery performed in other settings. A better understanding of the described associations between outcomes and risk factors using a larger series of data from various institutions will be required.

CONCLUSION

We have shown that patient BMI, operative time, and the identity of the surgeon who performed the operation are the 3 most important factors influencing readmission rates, rates of transfusions, and SSI in colorectal surgery. An understanding of these results may be useful to colorectal surgeons who are making an effort to improve their surgical outcomes.

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