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ORIGINAL ARTICLE – COLORECTAL CANCER

Assessment of the Value of Comorbidity Indices for Risk Adjustment in Colorectal Surgery Patients

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ABSTRACT

Background and Purpose. Comorbidity indices (CIs) are widely used in retrospective studies. We investigated the value of commonly used CIs in risk adjustment for postoperative complications after colorectal surgery.

Methods. Patients undergoing colectomy without stoma for colonic neoplasia at a single institution from 2009 to 2014 were included. Four CIs were calculated or obtained for each patient, using administrative data: Charlson–Deyo (CCI-D), Charlson–Romano (CCI-R), Elixhauser Comorbidity Score, and American Society of Anesthesiologists classification. Outcomes of interest in the 90-day postoperative period were any surgical complication, surgical site infection (SSI), Clavien–Dindo (CD) grade 3 or higher complication, anastomotic leak or abscess, and nonroutine discharge. Base models were created for each outcome based on significant bivariate associations. Logistic regression models were constructed for each outcome using base models alone, and each index as an additional covariate. Models were also compared using the DeLong and Clarke–Pearson method for receiver operating characteristic (ROC) curves, with the CCI-D as the reference.

Results. Overall, 1813 patients were included. Postoperative complications were reported in 756 (42%) patients. Only 9% of patients had a CD grade 3 or higher complication, and 22.8% of patients developed an SSI. Multivariable modeling showed equivalent performance of the base model and the base model augmented by the CIs for all outcomes. The ROC curves for the four indices were also similar.

Conclusions. The inclusion of CIs added little to the base models, and all CIs performed similarly well. Our study suggests that CIs do not adequately risk-adjust for complications after colorectal surgery.

Risk adjustment is commonly used to control for hospital-, procedure-, and patient-specific confounders when comparing outcomes between institutions and surgeons.[1] Several risk calculators have been developed and validated using information from clinical databases such as the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP).[1–6] However, their use to adjust for risk in observational research requires a manual chart review to collect the data, which can be prohibitively cumbersome when studying a large sample population.[7]

Patient comorbidity data documented in the electronic medical record (EMR) can be easily queried from administrative databases and used to calculate several validated comorbidity indices (CIs). These indices can be used for risk adjustment without the need for a manual chart review. The most widely used of these, the Charlson Comorbidity Index (CCI), was introduced in 1987 and has been validated as a predictor of 1-year all-cause mortality.[8,9] More recently, the CCI has been modified by Deyo et al.[10] and Romano et al.[11] for use with International Classification of

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Diseases, 9th revision (ICD-9) codes from administrative databases. These indices have been validated for a range of outcomes, from in-hospital mortality to readmissions and healthcare utilization.[10–15]

Few studies have addressed the use of CIs in risk adjustment for surgical endpoints and postoperative complications.[16–23] The indices were generally developed and validated for predicting 1-year mortality or in-hospital death, but complications such as wound infections and anastomotic leaks are more common and of greater relevance to colorectal surgery patients. No standardized methods for risk stratification have been developed specifically for these complications of colorectal surgery, although the CCI and other CIs have been used without validation.[18,21]

The objective of this study was to determine the value of CIs, calculated using data from EMRs, in risk adjustment for postoperative outcomes that may occur after colorectal surgery.

METHODS

Study Population

We conducted a retrospective analysis of colorectal surgery patients treated at Memorial Sloan Kettering Cancer Center from 1 January 2009 to 31 December 2014. Current Procedural Terminology (CPT) codes were used to identify patients who had undergone colon or rectal resection without a stoma. To minimize variability in surgical risk, we excluded patients on the basis of the following criteria: creation of a stoma prior to or at the time of surgery, prior history of colorectal resections, urgent surgery or transfer from another hospital, primary disease process not of colorectal origin (such as ovarian cancer), receiving hyperthermic intraperitoneal chemotherapy or intraoperative radiation therapy, undergoing a concurrent extra-abdominal procedure (such as video-assisted thoracic surgery), and undergoing treatment aimed at palliation. Patients for whom a stoma was created at the time of the index surgery were excluded because the presence of a stoma likely increases the risk for postoperative complications and nonroutine discharge.[24] Finally, patients with fewer than 90 days follow-up were excluded.

Patient demographics and operative details were collected from the EMRs through a query carried out by the institution's research and technology management division. The variables of interest were age, sex, smoking history (current, ever, never), insurance status (Medicaid/Medicare vs. private), preoperative chemotherapy and radiation, previous abdominal surgery, extraction site, American Joint Committee on Cancer (AJCC) stage, body mass index (BMI), preoperative American Society of Anesthesiologists (ASA) score, surgical procedure, surgical approach (open, robotic, or laparoscopic), surgeon, operative time, the use of a stapler for anastomosis, and concurrent procedures (such as liver resection). This study was approved by the Institutional Review Board of Memorial Sloan Kettering Cancer Center.

Complications

Data on complications that occurred up to 90 days after surgery were collected from patient charts by two of the authors. Inpatient notes, outpatient follow-up notes, and any correspondence from outside doctors or hospitals (including radiology reports) were thoroughly examined. Complications were scored according to the Clavien–Dindo (CD) classification system by one reviewer, and subsequently examined for accuracy by a second reviewer, with quality checks against two prospectively collected institutional databases that track surgical site infections (SSIs) and secondary surgical events. SSIs were diagnosed according to CDC-NSQIP criteria. Anastomotic leak was defined as extravasation of oral contrast on imaging, reoperation with confirmed compromise in anastomotic integrity, or documentation of leak by attending physician or radiologist. Abscess was defined as a rim-enhancing collection on imaging. Complications due to adjuvant chemotherapy or other medical treatments unrelated to surgery were deemed non-attributable and were excluded.

The five outcomes of interest in the 90-day period after surgery were any postoperative complication, SSI, a high-grade postoperative complication, a leak or intra-abdominal abscess, and nonroutine discharge of the patient. A high-grade complication was defined as a patient having a grade 3 or higher complication on the CD scale, and nonroutine discharge was defined as either discharge requiring home care services or transfer to a rehabilitation center.

Indices of Comorbidity and Physical Status

Comorbidity data were obtained by an electronic search of the hospital's administrative data. Only comorbidities present in these records within 6 months prior to and including the day of surgery were used for calculating CIs.

Three CIs were calculated for each patient: the Deyo modification of CCI (Charlson–Deyo), the Romano modification of CCI (Charlson–Romano), and the van Walraven modification of the Elixhauser comorbidity score (ECS).[9–11,15] The unmodified CCI was excluded as it was originally constructed for use with manually collected comorbidity data, while the Deyo and Romano adaptations of CCI are intended specifically for use with administrative

TABLE 1 Patient and treatment characteristics

Characteristic	No. of patients (n = 1813)
Age, years [median (IQR)]	61.7 (50.8–72.1)
Sex	
Female	928 (51)
Male	883 (49)
Race or ethnicity	
Hispanic	87 (5)
Black	110 (6)
Caucasian	1485 (82)
Other	129 (7)
BMI [median (IQR)]	27.9 (24.2–31.7)
Insurance	
Medicare/Medicaid	847 (47)
Private	966 (53)
Disease stage	
In situ/benign	247 (14)
I	357 (20)
II	476 (26)
III	433 (24)
IV	300 (17)
Smoking history[a]	
Current	190 (11)
Ever	618 (34)
Never	1003 (55)
Preoperative chemotherapy	245 (14)
Preoperative radiation therapy	26 (1)
Previous abdominal surgery	849 (47)
Surgical procedure	
Right colectomy	799 (44)
Left and sigmoid colectomies	402 (22)
Low anterior resection	529 (29)
Subtotal colectomy	83 (5)
Surgical approach	
Open	693 (38)
Laparoscopic	852 (47)
Robotic	268 (15)
Tumor type	
Adenocarcinoma	1541 (85)
Adenoma	120 (7)
Benign	77 (4)
Other neoplasia[b]	75 (4)
Extraction site	
Vertical midline	1614 (89)
Other	199 (11)
Comorbidity rate by index [mean (range)]	
Charlson–Deyo	1.26 (0–9)
Charlson–Romano	0.63 (0–9)
van Walraven	3.33 (−11 to 34)
ASA	2.64 (1–4)

Data are expressed as n (%) unless otherwise specified

IQR interquartile range, *BMI* body mass index, *ASA* American Society of Anesthesiologists

[a]Two patients had unknown smoking history

[b]Neuroendocrine tumor, leiomyoma, mucinous cystadenoma, gastrointestinal stromal tumor, or schwannoma

data. The ECS was developed from a set of 30 comorbidities defined by ICD-9-Clinical Modification (ICD-9-CM) codes used in administrative data. The van Walraven modification of the ECS adds weighting to all binary elements by using coefficients from a multivariate logistic regression model for in-hospital mortality. In addition to the three CIs, the ASA physical status score for each subject was collected from anesthesia records. Cancer-related comorbidity categories were removed from comorbidity score calculations and controlled for separately.[25]

Models and Statistical Analyses

Bivariate associations between patient or treatment variables and the outcomes of interest were examined using simple logistic regression. Covariates with a significant association ($p < 0.05$) were included in the base models. A base model was created for each of the five outcomes. The variables surgeon and age of patient were included in all models regardless of significance.

Logistic regression models were constructed for each outcome using the base model alone and augmented base models with one of the three CIs or ASA score as an additional covariate. The predictive power of the augmented models was compared with that of the base model by using c-statistics. A difference of ≥ 0.02 in predictive power was considered significant.[8]

TABLE 2 Postoperative complications

Complication	No. of patients (n = 1813)
Any	756 (42)
High grade	164 (9)
Surgical site infection[a]	414 (23)
Superficial	258 (14)
Deep	40 (2)
Organ space	116 (6)
Anastomotic leak/intra-abdominal abscess	113 (6)
Nonroutine discharge	582 (32)

Data are expressed as n (%)

[a]Categorized according to the guidelines of the Centers for Disease Control and Prevention

The Clarke–Pearson method developed by DeLong et al.[26] was used to compare the unadjusted predictive power of the Charlson–Deyo score with those of the other two CIs and the ASA score. Receiver operating characteristic curves were created for each outcome, with the Charlson–Deyo score as the reference since it is the most widely used CI.[12]

RESULTS

A total of 1813 patients met the inclusion criteria. The median patient age at the time of surgery was 62 years, and 50% of patients had AJCC stage II or III adenocarcinoma of the colon (Table 1). Over the 6-year period of the study, seven surgeons performed a median of 222 colectomies each. Approximately 38% of the colectomies were performed with an open approach, and 62% were performed with a minimally invasive approach.

Depending on the index, 38–85% of patients had at least one recorded comorbidity aside from their cancer-associated diagnoses (Table 1). On the basis of the Charlson–Deyo and Charlson–Romano indices, 73% and 94% of patients, respectively, had fewer than three comorbidities.

The rates of postoperative complications are shown in Table 2. The overall complication rate within 90 days of surgery was 42%. Four (< 1%) patients died within 30 days after surgery, and a total of nine (< 1%) patients died within 90 days after surgery.

Surgical approach, tumor stage, and preoperative chemotherapy had significant ($p < 0.05$) associations with all five outcomes and were included in the five base models (Table 3). Insurance status, BMI, smoking history, and specimen extraction site were included in the base models for any complication, SSI, and nonroutine discharge; year of surgery and patient's sex were included in the model for SSI; history of abdominal surgery was included in the model for nonroutine discharge; and surgical procedure was included in the base models for any complication, high-grade complication, and anastomotic leak or intra-abdominal abscess.

Several base model covariates remained significant in multivariable analysis. Patients with private insurance had a lower risk of any complication, SSI, or nonroutine discharge (odds ratio [OR] 0.63, 0.69, and 0.63, respectively) when compared with those with Medicare or Medicaid insurance. Patients who had preoperative chemotherapy

TABLE 3 Variables included in the base models

Any complication	High-grade complication	Surgical site infection	Leak/intra-abdominal abscess	Nonroutine discharge
Age[a]	Age	Age	Age	Age[a]
Surgeon[a]	Surgeon	Surgeon	Surgeon	Surgeon
Stage	Stage[a]	Stage[a]	Stage[a]	Stage[a]
Surgical procedure[a]	Surgical procedure		Surgical procedure[a]	
Surgical approach[a]	Surgical approach	Surgical approach[a]	Surgical approach	Surgical approach[a]
Preop. chemotherapy[a,b]	Preop. chemotherapy[b]	Preop. chemotherapy[b]	Preop. chemotherapy[b]	Preop. chemotherapy[b]
BMI[a]		BMI[a]		BMI[a]
Insurance type[a]		Insurance type[a]		Insurance type[a]
Smoking history		Smoking history		Smoking history
Extraction site		Extraction site		Extraction site
		Year of surgery		Prior abdominal surgery
		Sex[a]		

Preop. preoperative chemotherapy, *BMI* body mass index

[a]Remained significant in multivariable analysis

[b]Preoperative chemotherapy

TABLE 4 C-Statistics of the base models and augmented models

Model	C-Statistic				
	Any complication	High-grade complication	Surgical site infection	Leak/intra-abdominal abscess	Nonroutine discharge
Base model	0.69	0.70	0.72	0.71	0.76
Augmented models					
Charlson–Deyo	0.69	0.71	0.72	0.72	0.76
Charlson–Romano	0.70	0.70	0.72	0.72	0.76
van Walraven	0.70	0.70	0.72	0.72	0.76
ASA	0.70	0.70	0.72	0.71	0.76

ASA American Society of Anesthesiologists

had a higher risk of any complication compared with those with no preoperative chemotherapy (OR 1.6, 95% confidence interval 1.1–2.3). Laparoscopic and robotic surgical approaches were associated with a lower risk of any complication, nonroutine discharge, and SSI compared with open surgery. Patients with stage III or IV disease undergoing surgery had a significantly higher risk of high-grade complications compared with those with stage in situ or benign disease (OR 2.70 and 2.76, respectively). Patients undergoing left and sigmoid colectomies had a lower risk of anastomotic leak or intra-abdominal abscess compared with those undergoing low anterior resections (OR 0.45, 95% confidence interval 0.23–0.86). Those who had subtotal colectomies or right colectomies were more likely to have any complication compared with those who had low anterior resections (OR 2.19, 95% confidence interval 1.27–3.77; OR 1.41, 95% confidence interval 1.08–1.84, respectively). Table 4 shows the results of the primary analysis comparing the c-statistics of the base models alone with the c-statistics of the augmented models. A c-statistic of 0.50 signifies that a model is no better at predicting an outcome than random chance. The c-statistics for the base models ranged from 0.686 for the outcome of any complication, to 0.759 for the outcome of nonroutine discharge. In the primary analyses for all outcomes, the c-statistics of the base models did not differ significantly from the c-statistics for the augmented models.

Figure 1 shows the secondary analyses using the Clarke–Pearson method for the five outcomes. In all cases, the Charlson–Romano index, van Walraven index, and ASA score did not differ significantly from the Charlson–Deyo score (the reference). In addition, the calculated areas under the curve showed poor predictive power between the indices and all outcomes. Models are typically considered reasonable when the c-statistic is higher than 0.7, and strong when the c-statistic exceeds 0.8.

DISCUSSION

Our base models had acceptable predictive powers (c-statistic 0.69–0.76) for all five outcomes. The addition of the individual CIs added no predictive power to the base models. The three CIs performed equally poorly when modeled individually apart from the base models, and the performance of each was equivalent to that of the ASA score. The c-statistics of the CIs and ASA score were $<$ 0.65 for all five outcomes in univariate analyses.

Similar results have been reported by Dekker et al.[27] who used the Leiden Cancer Registry (a subset of the Netherlands Cancer Registry) to compare the CCI, sum of diseased organ systems, and ASA score in risk adjustment for postoperative mortality, prolonged ($>$ 14-day) length of stay, and any surgical complication among 2204 colorectal cancer patients. Those authors found that no single measure of comorbidity or physical status examined outperformed the other measures. Our study confirmed the results of Dekker et al., while further evaluating the most commonly used CIs derived from administrative data. The findings of our study are applicable to researchers in any institution, especially those who do not have access to a pre-existing database.

Several studies have evaluated the use of CIs for risk stratification in relation to morbidity and mortality in surgery patients.[18,19,23,28] Depending on the study population and outcome of interest, the predictive abilities ranged from poor to excellent. Few studies have focused on specific short-term surgical outcomes. In one such study, Tan et al.[18] compared the CCI and ASA score in predicting anastomotic leak after colorectal surgery. Those authors found an association between higher ASA or CCI scores and anastomotic leak, but they did not calculate c-statistics to demonstrate the validity of using these scores for risk adjustment. An association between a comorbidity or physical status score and a specific outcome does not

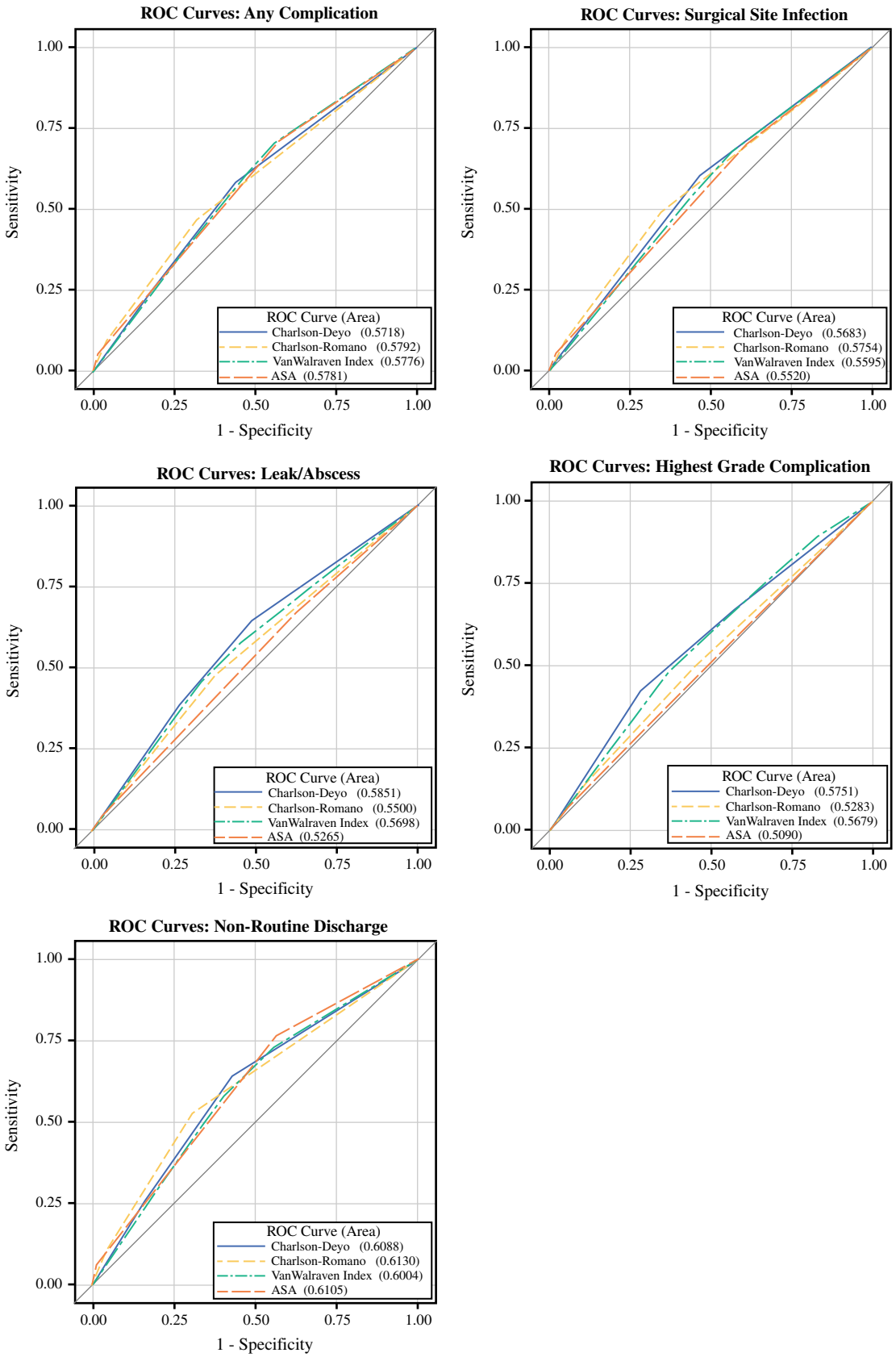

FIG. 1 ROC curve analyses for the five outcomes. *ROC* receiver operating characteristic, *ASA* American Society of Anesthesiologists

necessarily indicate that inclusion of that score would improve risk stratification. Our analyses specifically address this issue by calculating c-statistics, which indicate that the addition of CIs provides minimal additional predictive power.

The indices' lack of predictive power in our study may be due to several factors. First, and most importantly, none of the indices examined were designed to be used in risk adjustment for surgical complications. Since they were originally designed for other endpoints of interest (such as 1-year mortality after hospitalization), they include comorbidities that may have no impact on the risk of postoperative complications. Finally, a considerable proportion (15–62%) of patients had no comorbidities aside from their cancer-associated diagnoses.

We confirmed an association of higher BMI with any complication, risk of SSI, and nonroutine discharge.[29–31] In addition to confirming the previously described association between minimally invasive surgery and a lower likelihood of SSI, our models showed that minimally invasive surgery was associated with a lower likelihood of nonroutine discharge.[32] Since our study was not aimed at validating these risk factors, their specific effects need to be further investigated in a dedicated analysis.

The limitations of our study include its retrospective nature and potential for missed complications. We captured as many complications of interest as possible by checking the data against two prospective institutional databases, as well as all patient correspondence and outside medical records. Another potential limitation lies in the nature of administrative databases themselves. Previous studies have produced conflicting results on concordance between CIs derived from administrative data and those derived from manually collected data.[12,33] We used administrative data because of its increasing use in surgical outcomes research since it minimizes the need for manual chart review. Lastly, since the study was conducted at a comprehensive cancer center, where patients may be more likely to have advanced disease or undergo complex treatment, the high risk associated with the disease itself may have diluted the contribution of the indices in predicting outcomes. However, our study's distribution of patients by disease stage closely matched the distribution reported by the American Joint Committee on Cancer for the general population of colorectal cancer patients.[34]

One of the strengths of this study lies in the fact that it was conducted at a single institution, allowing for thorough chart review and manual collection of data on common postoperative complications. Another important strength is the composition of the patient population investigated. The average age in our cohort was 62 years, which is significantly younger than in many studies of CIs. Many of the patients had no comorbidities apart from cancer-associated diagnoses, and 93% of patients had fewer than three comorbidities. Given the increasing incidence of colorectal cancer among younger patients, the findings of our study are particularly relevant to the changing population of patients who undergo colorectal cancer surgery.[35]

CONCLUSION

The inclusion of the Charlson–Deyo, Charlson–Romano, van Walraven adaptation, and ASA indices did not improve the ability of base models to predict postoperative complications in colorectal surgery patients, nor did any index perform better than the others. Inclusion of these CIs alone does not guarantee adequate risk adjustment in colorectal surgery patients, and it is likely that patient and treatment data from the EMRs may suffice.

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