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CLINICAL RESEARCH

The Application of Comorbidity Indices to Predict Early Postoperative Outcomes After Laparoscopic Roux-en-Y Gastric Bypass: A Nationwide Comparative Analysis of Over 70,000 Cases

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Abstract
Background Patients undergoing laparoscopic Roux-en-Y gastric bypass (LRYGB) often have substantial comorbidities, which must be taken into account to appropriately assess expected postoperative outcomes. The Charlson/-Deyo and Elixhauser indices are widely used comorbidity measures, both of which also have revised algorithms based on enhanced ICD-9-CM coding. It is currently unclear which of the existing comorbidity measures best predicts early postoperative outcomes following LRYGB.
Methods Using the Nationwide Inpatient Sample, patients 18 years or older undergoing LRYGB for obesity between 2001 and 2008 were identified. Comorbidities were assessed according to the original and enhanced Charlson/-Deyo and Elixhauser indices. Using multivariate logistic regression, the following early postoperative outcomes were assessed: overall postoperative complications, length of hospital stay, and conversion to open surgery. Model performance for the four comorbidity indices was assessed and compared using C-statistics and the Akaike's information criterion (AIC).
Results A total of 70,287 patients were included. Mean age was 43.1 years (SD, 10.8), 81.6 % were female and 60.3 % were White. Both the original and enhanced Elixhauser indices modestly outperformed the Charlson/Deyo in predicting the surgical outcomes. All four models had similar C-statistics, but the original Elixhauser index was associated with the smallest AIC for all of the surgical outcomes.
Conclusions The original Elixhauser index is the best predictor of early postoperative outcomes in our cohort of patients undergoing LRYGB. However, differences between the Charlson/Deyo and Elixhauser indices are modest, and each of these indices provides clinically relevant insight for predicting early postoperative outcomes in this high-risk patient population.

Keywords Laparoscopic Roux-en-Y gastric bypass · Comorbidity · Charlson/Deyo index · Elixhauser index · Postoperative outcomes

Introduction

Obesity is a major public health problem in the USA; the prevalence of obesity increased from 23 % in the early 1990s to almost 34 % in 2008 while obesity class III (BMI, >40 kg/m^2) increased from 2.9 to 5.7 % during the same time period [1]. The most obese patients have the greatest need for weight loss, yet standard treatments, such as behavior therapy and medical therapy are rarely successful [2, 3]. Given the beneficial long-term results after bariatric surgery in general and Roux-en-Y gastric bypass in particular [4–6], the use of these procedures have increased dramatically, and Roux-en-Y gastric bypass remains the most commonly performed operation in the United States, with most procedures performed laparoscopically [7, 8].

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With the increasing popularity of laparoscopic Roux-en-Y gastric bypass (LRYGB), the risks of the procedure make it important to measure risk factors for postoperative outcomes and risk-adjust patient groups for studies of outcomes [9–12].

Obese patients undergoing LRYGB often suffer from a substantial number of comorbidities including diabetes mellitus and cardiovascular disease [13]. Therefore, evaluations of postoperative outcomes after LRYGB have to adjust for these comorbidities due to the well-documented associated increase in postoperative complications and length of hospital stay (LOS) [10, 12, 14–16]. However, the complex and inconsistent interplay of diseases associated with adverse outcomes represents a challenge in developing risk-stratification models in bariatric surgery. The lack of standardized methods for comorbidty adjustment in this patient population may be at least partially responsible for the differences across previous studies.

A number of comorbidity measures have been developed and are often used in the analyses of both clinical and administrative data. They improve the evaluation of postoperative outcomes by accounting for differences in case-mix between patient groups. Different comorbidity measures have been validated in different patient groups including patients with hypertension [17] and colorectal cancer [18]. Two of the most widely used measures are the Charlson/Deyo and Elixhauser indices. The Charlson comorbidity index was originally developed to predict 1-year mortality and was based on 19 comorbidities, primarily for use with existing medical records [19]. The Charlson/Deyo index is an adaptation of the original Charlson index specifically for use when analyzing administrative databases where diseases are categorized based on the *International Classification of Disease, 9th revision, Clinical Modification* (ICD-9-CM). In its final version, the Charlson/Deyo index includes 17 comorbidities [20]. The Elixhauser comorbidity index, which was developed later, is based on 30 comorbidities also captured by the ICD-9-CM codes. This is almost twice the number of comorbidities included in the Charlson/Deyo index [21] and has been suggested to be a superior risk-adjustment measure in several studies comparing the two indices [22, 23]. Recently, enhanced versions of both comorbidity indices have been developed—these more completely cover all-important ICD-9-CM codes. In a Canadian study, both enhanced measures have been validated and shown to perform slightly better in predicting in-hospital mortality than the original versions based on administrative hospital discharge data [24, 25].

The ability of these comorbidity measures to predict early postoperative outcomes following LRYGB has not been investigated to date. We therefore aimed to compare the predictive performance of the original and enhanced Charlson/Deyo and Elixhauser indices, first with regards to overall in-hospital postoperative complications and second, to LOS, and conversion to open surgery during LRYGB. The identification of the best comorbidity measure can help to more uniformly risk adjust in the evaluation of surgical outcomes.

Methods

Data Source

The Institutional Review Board from Duke University approved the study protocol. We performed a cross-sectional study based on data from the Nationwide Inpatient Sample (NIS) including the years 2001 to 2008 [26]. The NIS is a hospital inpatient discharge database as part of the Healthcare Cost and Utilization Project, sponsored by the Agency for Healthcare Research and Quality [27]. The NIS comprises a 20 % stratified sample of all nonfederal, short-term, general, and other specialty hospitals in the USA and contains records for approximately eight million hospital stays each year. The dataset is a representative sample of all hospitals in the USA based on stratification over the following characteristics: geographic region, ownership (public or private), location (rural or urban), teaching status (teaching or non-teaching hospitals), and bed size (small, medium, or large). Each discharge record provides information on various patient characteristics, admission type (emergency, urgent, or elective), diagnoses and procedures, health insurance status, and LOS. NIS data compare favorably with the National Hospital Discharge Survey, supporting the validity of this database (Agency for Healthcare Research and Quality 2004) [28].

All patients age 18 or older undergoing LRYGB due to obesity between 2001 and 2008 were identified. ICD-9-CM procedure codes were used to identify LRYGB either through one specific procedure code (44.38) or through a combination of a procedure code for open gastric bypass (44.31, 44.39, and 44.3) together with an ICD-9-CM procedure code for laparoscopy (54.21) or an ICD-9-CM diagnosis code for conversion from laparoscopic to open surgery (V64.4 and V64.41). Obesity was identified using the following set of ICD-9 diagnosis codes: V85.3x (body mass index (BMI), 35.0–39.9 kg/m^2), V85.4 (BMI, >40 kg/m^2), V77.8 (obesity), 278.0 (overweight and obesity), 278.00 (obesity unspecified), 278.01 (morbid obesity), and 278.02 (overweight). Patients with gastrointestinal tract neoplasms (ICD-9 diagnosis codes, 150–159.9), adiposogenital dystrophy (253.8), obesity of endocrine origin (259.9), inflammatory bowel disease (555–556.9), noninfectious colitis (557.0–558.9), and patients admitted through the emergency department were excluded.

Measurement of Comorbidities

We assessed four comorbidity indices: the original and enhanced Charlson/Deyo indices and the original and enhanced Elixhauser indices. The Charlson/Deyo index consists of 17 different weighted diseases according to the disease severity as 1, 2, 3, or 6, which was originally derived from relative risk estimates of a proportional hazards regression model in the Charlson index among patients prospectively followed after admission to a medical service [19]. The Charlson/Deyo index represents the sum of the weights for all those conditions while the enhanced version covers more completely ICD-9-CM codes for the captured comorbidities. Both the original and enhanced Elixhauser indices were also used. The original Elixhauser method is based on 30 unweighted comorbidities identifiable by ICD-9-CM diagnosis codes. The Elixhauser index includes the following two comorbidities: obesity and weight loss. We excluded those two factors from the Index calculation to avoid collinearity in our analyses due to the close relationship of these variables to the patient population (obese patients) and the treatment (LRYGB) of interest. The remaining 28 diseases contributing to the Elixhauser index were identified and the Elixhauser index calculated. As for the enhanced Charlson/Deyo index, the original structure, scope, content, and definition of existing codes for the enhanced Elixhauser index are not altered, while a few more preexisting codes are added or deleted to better align with the current ICD-9-CM codes.

Outcomes

The early postoperative outcomes of interest were any postoperative complication, LOS, and conversion to open surgery. For the purpose of this study, the outcome variables were defined as dichotomous variables. Although standardized methods for reporting data on surgical complication or morbidity after bariatric surgery are needed, until recently, complications were frequently classified as being minor or major based on different definitions in previous studies [10–12, 14, 29]. We have used the concept of adverse events to represent undesirable outcomes following LRYGB because bariatric surgery is elective. [30]. Postoperative complications included in this study were identified and grouped as previously described by Guller et al. and widely used in surgical literature (Appendix) [31–34]: this approach allows identification of many complications. The ICD-9 diagnosis codes to identify postoperative complications which are used are distinct from those that identified comorbidites included in the four comorbidity indices. If any of these complications were present during postsurgical hospital stay, then postoperative complication was considered present, otherwise it was considered absent. For LOS, we defined prolonged LOS equal to or more than 5 days after LRYGB derived from the exceeding 95th percentile of the LOS distribution. Although the in-hospital mortality rate was also calculated, this measure was not analyzed further because of its extremely low occurrence (N=73, 0.1 %), which is consistent with previous studies, ranging from 0.1 to 0.2 % [12, 14].

Covariates

The following patient characteristics were extracted from the NIS and categorized as follows: age (18–30, 31–45, 45–64, and ≥65 years), gender, race/ethnicity (White, Black, Hispanic, and others), primary expected payer (private including health maintenance organization, Medicare, Medicaid, and others), and median household income based on Zip code levels (<$34,999, $35,000 to $44,999, and ≥45,000). Hospital characteristics included hospital location (South, Northeast, Midwest and West), hospital setting/-teaching status (rural, urban/nonteaching, and urban/teaching) and hospital volume categorized by quintiles (≤58, 59–114, 115–173, 174–289, and ≥290). A teaching hospital was defined by the NIS as a hospital having residents in any specialty while hospital volume was based on the number of annual procedures.

Statistical Analyses

Descriptive statistics including Chi-square test for categorical (count, in percent) and t test for continuous data (mean, SD) were used to present the characteristics of the sample. The frequency of individual comorbidites was calculated for each of the four comorbidity indices.

Thereafter, four separate univariate and multivariate logistic regression models, each using a different comorbidity index (original and enhanced Charlson/Deyo or Elixhauser indices) as a predictor variable, were developed to predict the three surgical outcome variables (any postoperative complication, LOS, and conversion to open surgery). For this analysis, the original and the enhanced Charlson/Deyo indices were categorized into four groups: 0, 1, 2, and ≥3. Because the Elixhauser index does not have its own weighted scoring system, we also summed all of the comorbid disease to create total Elixhauser score groups (0, 1, 2, and ≥3)—this is similar to what has been done by others [35, 36]. Each logistic regression model was adjusted by the following covariates: age, gender, race, household income, insurance status, geographic region, hospital setting/teaching status, hospital volume, and year of operation. Since LOS was substantially skewed and 5 days defined in our study were relatively longer than mean day (2.6±3.1 days), we performed sensitivity analyses for the multivariate regression analyses with 3 and 5 days in the model. All estimates were similar between the two models; therefore, only the model with 5 days is presented.

Model selection methods were used to identify the comorbidity index most predictive of each of the surgical outcomes. The Akaike's information criterion (AIC) is computed based on the log-likelihood of a model and the number of parameters (K) included in that model [37].

$$\mathrm{AIC} = -2(\text{log-likelihood}) + 2K$$

The AIC provides an objective way of determining which model among a set of model is most parsimonious and information on the strength of evidence for each model; thus, the concept of significance become superfluous with the AIC. The AIC was applied to the four distinct models for each outcome, and the model with the lowest AIC was deemed to be the best model. In general, the rule of thumb for identifying a model or set of models as " better " is a difference in AIC values of >4 between models and the magnitude of AIC has little meaning [38]. We also examined the fit of the four models using C-statistics for logistic regression models. The C-statistic is equivalent to the area under the receiver operation characteristic curve, measuring the model's ability to discriminate between those subjects who experience the outcome of interest versus those who do not, and its typical values range from 0.5 (no discrimination beyond chance) to 1.0 (perfect discrimination); the bigger the C-statistic, the better the discrimination [39–41].

Statistical significance was set at an alpha level of less than 0.05 (two tailed). All analyses were conducted using SPSS for Windows, version 17 (SPSS Inc., Chicago, IL).

Results

A total of 70,287 patients undergoing LRYGB were identified for the study period 2001 to 2008. The mean age (SD) was 43.1 (±10.8) years, 81.6 % were female, and 60.3 % were White (Table 1). Most had private health insurance (78.3 %) and a ZIP-code-related household income over $45,000 (52.6 %).

Overall, at least one postoperative complication was found in 5.2 % of the patients (n=3,633): the most common were gastrointestinal (e.g., vomiting, ileus/obstruction, and anastomotic complications; 1.8 %, n=1,265) and pulmonary complications (e.g., pulmonary edema, respiratory distress, and pneumonia; 1.8 %, n=1,237) (Table 2). The mean LOS (SD) was 2.6 (±3.1) days: 5.6 % of patients stayed longer than 5 days which represents the 95th percentile. The overall conversion to open surgery was 2.0 % (n=1,015).

The proportion of patients presenting with a specific comorbidity according to each of the four comorbidity indices was shown in Table 3. The most common comorbidities in the original/enhanced Charlson/Deyo indices were uncomplicated diabetes mellitus and chronic pulmonary disease. In contrast, in the original/enhanced Elixhauser indices, uncomplicated hypertension, uncomplicated diabetes mellitus, depression, chronic pulmonary disease, and

Table 1 Patient characteristics

Variable	No. (%) of patients (70,287)
Age	
18–30 years	9,433 (13.4)
31–45 years	30,650 (43.6)
45–64 years	28,979 (41.2)
≥65 years	1,101 (1.6)
Missing	124 (0.2)
Gender	
Female	57,332 (81.6)
Male	12,636 (18.0)
Missing	319 (0.4)
Race	
White	42,356 (60.3)
Black	6,184 (8.8)
Hispanic	5,045 (7.2)
Others	2,437 (3.5)
Missing	14,265 (20.2)
Household income	
<34,999	13,508 (19.2)
35,000 to 44,999	17,740 (25.2)
≥45,000	36,999 (52.6)
Missing	2,040 (2.9)
Insurance	
Private/HMO	55,068 (78.3)
Medicare	4,856 (6.9)
Medicaid	3,539 (5.0)
Other	6,524 (9.3)
Missing	300 (0.5)
Hospital geographic region	
Northeast	15,584 (22.2)
Mid-west	11,182 (15.9)
South	22,186 (31.6)
West	21,335 (30.4)
Hospital location/teaching status	
Rural	1,606 (2.3)
Urban/nonteaching	32,918 (46.8)
Urban/teaching	35,763 (50.9)
Hospital volume	
Quintile 1	14,230 (20.2)
Quintile 2	14,104 (20.1)
Quintile 3	14,194 (20.2)
Quintile 4	13,989 (19.9)
Quintile 5	13,770 (19.6)
Operation year	
2001–2004	16,885 (24.0)
2005	14,847 (21.1)
2006	12,508 (17.8)
2007	10,486 (14.9)
2008	15,561 (22.1)

HMO health maintenance organization

Table 2 Incidence of postoperative complications

Complications	No. (%) of patients
Cardiovascular complications	699 (1)
Pulmonary complications	1,237 (1.8)
Gastrointestinal complications	1,265 (1.8)
Urinary/renal complications	244 (0.3)
Infections	315 (0.4)
Mechanical wound complications	350 (0.5)
Systemic complications	335 (0.5)
Overall, at least one complication	3,633 (5.2)

hypothyroidism were most common, respectively. Most of the comorbidity prevalences were similar for the original and enhanced Charlson/Deyo indices, except for mild liver disease, which was more commonly captured by the enhanced index. Most of the comorbidities had a prevalence of less than or equal to 1 % for both Charlson/Deyo indices. For the Elixhauser indices, the captured comorbidities ranged from <1 to 9.3 %. Differences greater than 1 % between the original and enhanced Elixhauser indices were seen for arrhythmias, deficiency anemia, and psychosis.

Tables 4, 5, and 6 provide the frequency and odds ratios for each of the three surgical outcomes by comorbidity score. In univariate analysis, an increasing comorbidity score in all four indices increased the probability of postoperative complication; even after controlling for multiple confounding variables, the associations remained statistically significant except comparing between 0 and 1 comorbidity. For postoperative complications, C-statistics were higher in the original and enhanced Elixhauser indices (0.67 (95 % CI, 0.66 to 0.68)) than in the original and enhanced Charlson/Deyo indices (0.63 (95 % CI, 0.61 to 0.64) and 0.62 (95 % CI, 0.61 to 0.64), respectively). Consistent with this result, the AICs were lower for both Elixhauser indices than those for both Charlson/Deyo indices (Table 4).

LOS was dichotomized as exceeding the 95th percentile of LOS distribution (5 days or more) versus less than 5 days. An increasing comorbidity score was also associated with increased LOS in both univariate and multivariate analyses. For LOS, C-statistics were higher in the original and enhanced Elixhauser indices (0.69 (95 % CI, 0.68 to 0.70)) than in the original and enhanced Charlson/Deyo indices (0.66 (95 % CI, 0.64 to 0.66) and 0.65 (95 % CI, 0.64 to 0.65), respectively). The AIC was lowest for the original Elixhauser index (Table 5).

Conversion to open surgery increased slightly with an increasing comorbidity score for all four indices. Unlike postoperative complication and LOS, some of the effects became nonsignificant in multivariate analyses. For conversion to open surgery, C-statistics were similar in the four models (the original Charlson/Deyo index, 0.62 (95 % CI, 0.61 to 0.64); the enhanced Charlson/Deyo index, 0.63 (95 % CI, 0.61 to 0.64); and the original and enhanced Elixhauser indices, 0.64 (95 % CI, 0.62 to 0.66) and 0.64 (95 % CI, 0.64 to 0.65), respectively); however, the AIC was the lowest for the original Elixhauser index (Table 6).

Discussion

In this study, we compared the ability of the four comorbidity measurements, the original Charlson/Deyo index, the enhanced Charlson/Deyo index, the original Elixhauser index, and the enhanced Elixhauser index to predict early postoperative outcomes in patients undergoing LRYGB.

The original/enhanced Elixhauser indices performed slightly better than the original/enhanced Charlson/Deyo indices. Similar findings have been reported in other studies of patients e.g. with myocardial infarction, hepatic cirrhosis, and those undergoing complex gastrointestinal surgery [23, 35, 42]. Furthermore, the original Elixhauser index was superior to the enhanced version.

One possible explanation for this finding is that the Elixhauser indices identify a much larger portion of patients with a comorbidity and higher numbers of comorbidities than the Charlson/Deyo index. The Elixhauser indices include almost twice the number of comorbidity categories. In particular, hypertension (>50 %), depression (>21 %), and hypothyroidism (10 %) were included in the Elixhauser indices but not in the Charlson/Deyo indices; these comorbidities are very common among obese patients [43–45]. Furthermore, hypertension and depression are known to increase the risk of serious complications after bariatric surgery [46–48]. Another possible explanation is that there are large numbers of each of 0, 1, 2, and ≥3 score subgroups in the Elixhauser indices. Although each surgical outcome rate was higher for patients with the highest score in the Charlson/Deyo indices, this subgroup had a relative small number of patients. For example, as shown in Table 3, postoperative complication rate was higher with increasing original Charlson/Deyo score (4.8 % with 0 comorbidity, 5.2 % with 1 comorbidity, 6.9 % with 2 comorbidity, and 11.3 % with ≥3 comorbidity), while the number of patients decreased dramatically in the higher score groups (1,934 with 0 comorbidity, 1,271 with 1 comorbidity, 349 with 2 comorbidity, and 79 with ≥3 comorbidity). However, those of the original Elixhauser index rose with the increasing number of patients: 4.0 %, 587 patients with 0 comorbidity; 4.4 %, 949 patients with 1 comorbidity; 5.2 %, 1,020 patients with 2 comorbidity, and 7.5 %, 1,077 patients with ≥3 comorbidity.

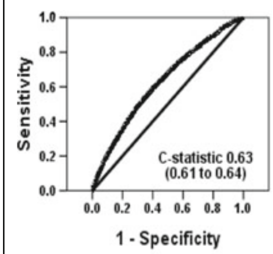
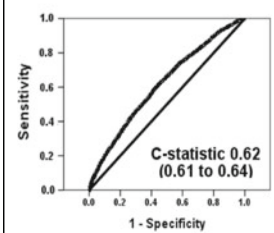
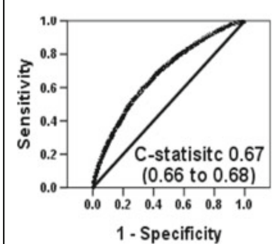
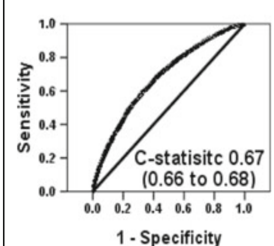
We anticipated that the new coding systems would perform better than the original version since adding additional

Table 3 Prevalence of individual disease indicators for comorbidity measures

Disease category	Deyo		Elixhauser	
	ICD-9-CM	Enhanced ICD-9-CM	ICD-9-CM	Enhanced ICD-9-CM
Cancer				
Lymphoma			20 (0.0)	20 (0.0)
Malignancies	69 (0.1)	69 (0.1)	–	–
Solid tumor without metastasis	–	–	32 (0.0)	32 (0.0)
Metastatic cancer	4 (0.0)	4 (0.0)	4 (0.0)	4 (0.0)
Cardiovascular				
Coagulopathy	–	–	234 (0.3)	234 (0.3)
Arrhythmias	–	–	2,107 (3.0)	2,777 (4.0)
Valvular disease	–	–	816 (1.2)	816 (1.2)
Cerebrovascular	87 (0.1)	87 (0.1)	–	–
CHF	797 (1.1)	980 (1.4)	802 (1.1)	980 (1.4)
HTN (uncomplicated)	–	–	36,044 (51.3)	36,069 (51.3)
HTN (complicated)	–	–	147 (0.2)	516 (0.7)
MI	535 (0.8)	535 (0.8)	–	–
Peripheral vascular disease	188 (0.3)	231 (0.3)	231 (0.3)	232 (0.3)
Pulmonary				
Pulmonary circulation disorder	–	–	264 (0.4)	264 (0.4)
Chronic pulmonary disease	12,224 (17.4)	12,393 (17.6)	12,198 (17.4)	12,393 (17.6)
Endocrine				
Diabetes (uncomplicated)	19,593 (27.9)	19,681 (28.0)	19,589 (27.9)	19,589 (27.9)
Diabetes (complicated)	761 (1.1)	827 (1.2)	849 (1.2)	906 (1.3)
Hypothyroidism	–	–	7,238 (10.3)	7,300 (10.4)
Gastrointestinal				
Liver disease(mild)	373 (0.5)	6,481 (9.2)	6,260 (8.9)	6,509 (9.3)
Liver disease(severe) or failure	48 (0.1)	48 (0.1)	–	–
Peptic ulcer disease	192 (0.3)	192 (0.3)	167 (0.2)	167 (0.2)
Neurologic				
Dementia	2 (0)	2 (0)	–	–
Paralysis	–	–	36 (0.1)	37 (0.1)
Paraplegia	9 (0.0)	37 (0.1)		
Other neurologic disorder			296 (0.4)	296 (0.4)
Nutritional				
Blood loss anemia	–	–	168 (0.2)	168 (0.2)
Deficiency anemia	–	–	2,220 (3.2)	846 (1.2)
Fluid and electrolyte disorder	–	–	1,993 (2.8)	1,996 (2.8)
Psychological				
Alcohol abuse/dependence	–	–	41 (0.1)	46 (0.1)
Depression	–	–	14,917 (21.2)	15,192 (21.6)
Drug abuse	–	–	87 (0.1)	127 (0.2)
Psychotic illness/psychosis	–	–	1,093 (1.6)	73 (0.1)
Renal				
Renal disease/failure	308 (0.4)	377 (0.5)	370 (0.5)	371 (0.5)
Musculoskeletal				
Rheumatologic/collagen vascular disease	676 (1.0)	699 (1.0)	732 (1.0)	755 (1.1)
HIV/AIDS	5 (0.0)	5 (0.0)	5 (0.0)	5 (0.0)

All data are number and percentage

Table 4 Incidence, odds ratios, and performance for postoperative complication stratified by comorbidity index score

	Incidence, % (No) Total No= 3,633	OR (95% CI)		AIC	C-statistic (95% CI)
		Unadjusted	Adjusted		
Deyo's ICD-9-CM (score)				21403.68	
0	4.8 (1,934)	Ref.	Ref.		
1	5.2 (1,271)	1.10 (1.01 to 1.18)	1.04 (0.96 to 1.14)		
2	6.9 (349)	1.47 (1.31 to 1.66)	1.33 (1.16 to 1.53)		
≥3	11.3 (79)	2.53 (1.99 to 3.21)	2.18 (1.66 to 2.88)		
Enhanced Deyo's ICD-9-CM (score)				21420.32	
0	4.8 (1,781)	Ref.	Ref.		
1	5.2 (1,313)	1.01 (1.00 to 1.16)	1.03 (0.95 to 1.12)		
2	6.2 (431)	1.30 (1.16 to 1.45)	1.22 (1.08 to 1.38)		
≥3	8.5 (108)	1.83 (1.50 to 2.24)	1.62 (1.29 to 2.05)		
Elixhauser's ICD-9-CM (score)				21305.25	
0	4.0 (587)	Ref.	Ref.		
1	4.4 (949)	1.10 (0.99 to 1.22)	1.09 (0.96 to 1.23)		
2	5.2 (1,020)	1.32 (1.19 to 1.46)	1.26 (1.11 to 1.43)		
≥3	7.5 (1,077)	1.95 (1.76 to 2.16)	1.90 (1.67 to 2.16)		
Enhanced Elixhauser's ICD-9-CM (score)				21306. 37	
0	3.8 (570)	Ref.	Ref.		
1	4.5 (976)	1.17 (1.05 to 1.30)	1.13 (0.99 to 1.28)		
2	5.2 (1,023)	1.38 (1.24 to 1.53)	1.31 (1.16 to 1.49)		
≥3	7.6 (1,064)	2.06 (1.85 to 2.28)	1.94 (1.71 to 2.21)		

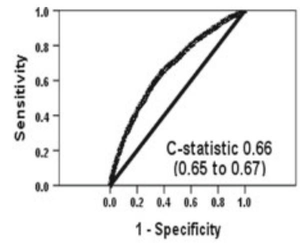
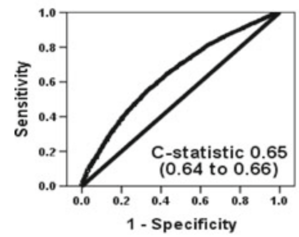
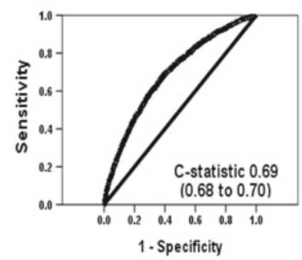
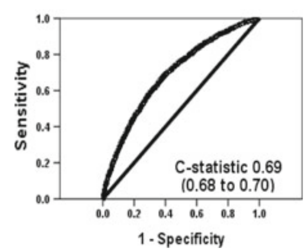
All p values of OR, AIC, and C-statistic, <0.01

AIC akaike information criterion, adjusted for age, gender, race, household income, insurance status, geographic region, hospital setting/teaching status, hospital volume, and year of operation

disease codes may enhance the accuracy and completeness of disease identification. However, the differences in predictive ability between the original and the enhanced versions were small, giving no clear advantage to the original version which is in contrast to others studies [24, 25]. It is possible that most comorbidities studied had similar frequencies across the original and enhanced measures in Charlson/Deyo and Elixhauser although variations were observed for a limited number of comorbidities. The main exception for the Charlson/Deyo index, where the prevalence of mild liver disease, was almost 9 % higher when using the enhanced compared with the original algorithm. For the Elixhauser measure, the differences of most comorbidites between the original and enhanced algorithms were less than 2 %.

With increasing use of LRYGB, concern has been expressed regarding the outcomes of these procedures. Since low surgical morbidity and mortality have been reported in early studies of bariatric surgery, administrative data including thousands of patients could be used to evaluate outcomes by patient and provider characteristics but also to process of care that is related to these outcomes. The

Table 5 Incidence, odds ratios, and performance for length of hospital stay stratified by comorbidity index score

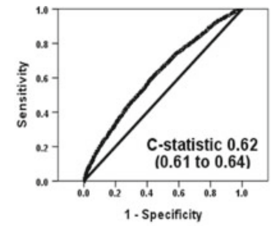
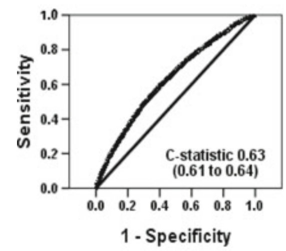
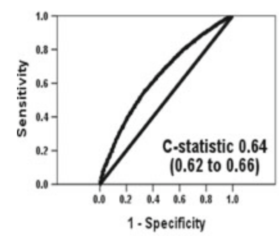
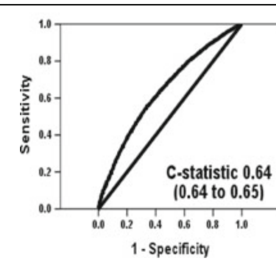
	Incidence, % (No) No=3,915	OR (95% CI)		AIC	C-statistic (95%CI)
		Unadjusted	Adjusted		
Deyo's ICD-9-CM (score)					
0	4.8 (1,924)				
1	5.8 (1,399)	1.22 (1.14 to 1.31)	1.12 (1.03 to 1.22)	22019.44	
2	9.6 (482)	2.11 (1.90 to 2.34)	1.70 (1.50 to 1.93)		
≥3	15.7 (110)	3.72 (3.02 to 4.59)	2.58 (2.00 to 3.32)		
Enhanced Deyo's ICD-9-CM (score)					
0	4.8 (1757)				
1	5.6 (1421)	1.19 (1.11 to 1.28)	1.10 (1.01 to 1.20)	21873.81	
2	8.3 (579)	1.81 (1.64 to 1.99)	1.44 (1.44 to 1.81)		
≥3	12.5 (158)	2.84 (2.39 to 3.38)	1.72 (1.72 to 2.61)		
Elixhauser's ICD-9-CM (score)					
0	3.9 (571)				
1	4.4 (947)	1.13 (1.01 to 1.25)	1.10 (0.97 to 1.25)	21713.10	
2	5.4 (1,065)	1.42 (1.29 to 1.57)	1.33 (1.18 to 1.51)		
≥3	9.3 (1,332)	2.53 (2.29 to 2.80)	2.29 (2.02 to 2.60)		
Enhanced Elixhauser's ICD-9-CM (score)					
0	3.9 (580)				
1	4.4 (970)	1.14 (1.03 to 1.27)	1.08 (0.96 to 1.22)	21744.43	
2	5.5 (1,076)	1.43 (1.29 to 1.59)	1.33 (1.17 to 1.50)		
≥3	9.2 (1,289)	2.49 (2.25 to 2.76)	2.14 (1.92 to 2.46)		

All *p* values of OR, AIC, and C-statistic, <0.01. Adjusted for age, gender, race, household income, insurance status, geographic region, hospital setting/teaching status, hospital volume, and year of operation

AIC akaike information criterion

ability of administrative databases to provide meaningful results depends on appropriate risk adjustment for case mix. Although numerous studies have shown the importance of comorbid disease in evaluating patient outcomes after surgery, many studies have reported surgical outcomes in patients undergoing bariatric surgery based on the presence of single comorbid conditions but not based on more comprehensive comorbidity scores [12, 46, 48]. This is important since many obese patients have multiple comorbid diseases, which may impact surgical outcomes. In addition, generalizability of results from earlier studies is limited due to lack of standardized comorbidity measurement. Some studies applied the Charlson/Deyo index [34, 49–51], while others used the Elixhauser index [52–54] even if they used the same administrative dataset. Particular measures often seem to be chosen for convenience rather than performance. The Charlson/Deyo index has been widely validated and investigators may still prefer to use this measure given its simplicity, however, our findings suggest that the Elixhauser measure performed better than the

Table 6 Incidence, odds ratios, and performance for conversion to open surgery stratified by comorbidity index score

	Incidence, % (No) No=1,391	OR (95% CI)		AIC	C-statistic (95% CI)
		Unadjusted	Adjusted		
Deyo's ICD-9-CM (score)				9278.92	
0	1.8 (742)	Ref.	Ref.		
1	2.1 (511)	1.15 (1.02 to 1.28)	1.22 (1.06 to 1.39)		
2	2.3 (117)	1.27 (1.04 to 1.54)	1.16 (0.91 to 1.48)		
≥3	3.1 (21)	1.65 (1.06 to 2.56)	1.17 (0.65 to 2.11)		
Enhanced Deyo's ICD-9-CM (score)				9275.71	
0	1.8 (627)	Ref.	Ref.		
1	2.1 (519)	1.13 (1.01 to 1.27)	1.23 (1.07 to 1.41)		
2	2.4 (168)	1.33 (1.12 to 1.58)	1.31 (1.06 to 1.62)		
≥3	2.5 (32)	1.39 (0.97 to 1.99)	1.23 (0.79 to 1.92)		
Elixhauser's ICD-9-CM (score)				9261.75	
0	1.8 (258)	Ref.	Ref.		
1	1.8 (382)	0.99 (0.85 to 1.17)	0.98 (0.81 to 1.18)		
2	2.0 (389)	1.13 (0.96 to 1.33)	1.08 (0.89 to 1.31)		
≥3	2.5 (362)	1.45 (1.23 to 1.70)	1.49 (1.22 to 1.83)		
Enhanced Elixhauser's ICD-9-CM (score)				9263.05	
0	1.8 (263)	Ref.	Ref.		
1	1.8 (386)	0.99 (0.85 to 1.17)	0.96 (0.79 to 1.16)		
2	2.0 (392)	1.13 (0.97 to 1.33)	1.07 (0.88 to 1.30)		
≥3	2.5 (350)	1.42 (1.21 to 1.67)	1.46 (1.19 to 1.79)		

All *p* values of OR, AIC, and C-statistic, <0.01. Adjustment performed for age, gender, race, household income, insurance status, geographic region, hospital setting/teaching status, hospital volume, and year of operation

AIC akaike information criterion

Charlson/Deyo index for predicting overall adverse short-term outcomes. On the other hand, the enhanced algorithms did not outperform the original Charlson/Deyo or Elixhauser Indices. This is relevant to researchers involved in the field of outcomes research after LRYGB. The discrimination of our prediction model (i.e., the ability to separate cases from no cases) was only moderate, with a C-statistic of 0.68, which is just below the cutoff value of 0.7 usually needed for acceptable discrimination. To some extent, this may be due to the relative homogeneity of the patients' comorbid diseases. Another possible reason for the limited discrimination between the models is that factors other than patient comorbid diseases may influence surgical outcomes, and these factors are not captured in this dataset.

Administrative databases can provide important information on the practice of surgery at a population level; however, these datasets have inherent limitations. First, since our results are based on a large, complex survey sample, but not on a national bariatric surgery registry, there is a potential for an unmeasured confounder. Due to the constraints of NIS, we are unable to include other well-established surgical risk factors such as preoperative albumin level or poor nutrition status. We did not validate the quality of the administrative database comparing to clinical data (gold standard) for patients undergoing LRYGB; we were only able to compare the four comorbitiy indices relative to each other. Second, accuracy and completeness of coding are also potential concerns when using administrative data. Since a unique ICD-9 procedure code was not assigned to LRYGB until 2005, a combination of the code for open gastric bypass together with laparoscopic surgery had to be used to identify LRYGB. However, while including open gastric bypass to the analysis would have biased our results, miscoding at this early time has rather excluded some of the LRYGB than included open gastric bypass patients to the study cohort. In addition, to account for coding differences across years as well as for technical changes in LRYGB over time, we adjusted the regression models with year of surgery. Third, because the database is compiled from discharge abstracts, only in-hospital complications, LOS and conversion to open surgery can be assessed; the data presumably underestimate total postoperative outcomes and readmissions are not captured. Finally, we did not include in-hospital mortality because this was a very rare outcome.

Our study is the first to directly compare the Charlson/-Deyo and the Elixhauser indices for surgical outcomes prediction in patients undergoing LRYGB. In conclusion, the Elixhauser index outperforms the Charlson/Deyo index in predicting early postoperative outcomes in patients undergoing LRYGB. These results indicate that researchers should now consider shifting away from the Charlson/Deyo index to the Elixhauser index as the comorbidity measurement method of choice for administrative data. Standardized and comprehensive risk-adjustment protocols to control for differences will have important future applications in LRYGB outcome studies based on administrative data and will allow for better comparison between studies.

Conflicts of Interest All contributing authors, including Jin Hee Shin, Mathias Worni, Anthony W. Castleberry, Ricardo Pietrobon, Philip A. Omotosho, Mina Silberberg, and Truls Østbye, declare that they have no conflicts of interest in relation to this manuscript.

Appendix

	ICD-9-CM code
Postoperative complications	
Mechanical wound complications	
Postoperative hematoma	998.12
Postoperative seroma (noninfected)	998.13
Disruption of operative wound	998.3
Disruption of wound unspecified	998.30
Disruption of internal operation (surgical) wound	998.31
Disruption of external operation (surgical) wound	998.32
Persistent postoperative fistula	998.6
Delayed wound healing	998.83
Infections	
Postoperative infection	998.5
Postoperative infected seroma	998.51
Postoperative skin abscess/infection	998.59
Postoperative septic wound complications	998.59
Postoperative intraabdominal/subdiaphragmatic abscess	998.59
Urinary/renal complications	
Postoperative urinary retention	997.5
Postoperative urinary tract infection	997.5
Acute renal failure	997.5
Pulmonary complications	
Postoperative acute pneumothorax	512.1
Postoperative pulmonary edema	518.4
Adult respiratory distress syndrome following surgery	518.5
Transfusion-related acute lung injury	518.7
Postoperative atelectasis/pneumonia	997.3
Mendelson syndrome resulting from a procedure	997.3
Gastrointestinal complications	
Postoperative vomiting	564.3
Diarrhea following gastrointestinal surgery	564.4
Postoperative small bowel obstruction/ileus (requiring nasogastric tube)	997.4
Complication of anastomosis of gastrointestinal tract	997.4
Cardiovascular complications	
Postoperative hypotension	458.29
Postoperative stroke	997.02
Cardiac arrest/insufficiency during or resulting from a procedure	997.1
Phlebitis or thrombophlebitis from procedure	997.2
Systemic complications	
Postoperative shock	998.0
Postoperative fever	998.89
Unspecified complication of procedure, not elsewhere classified	998.9

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