A Modification of the Elixhauser Comorbidity Measures Into a Point System for Hospital Death Using Administrative Data

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Background: Comorbidity measures are necessary to describe patient populations and adjust for confounding. In direct comparisons, studies have found the Elixhauser comorbidity system to be statistically slightly superior to the Charlson comorbidity system at adjusting for comorbidity. However, the Elixhauser classification system requires 30 binary variables, making its use for reporting and analysis of comorbidity cumbersome.

Objective: Modify the Elixhauser classification system into a single numeric score for administrative data.

Methods: For all hospitalizations at the Ottawa Hospital, Canada, between 1996 and 2008, we determined if International Classification of Disease codes for chronic diagnoses were in any of the 30 Elixhauser comorbidity groups. We then used backward stepwise multivariate logistic regression to determine the independent association of each comorbidity group with death in hospital. Regression coefficients were modified into a scoring system that reflected the strength of each comorbidity group's independent association with hospital death.

Results: Hospitalizations that were included were 345,795 (derivation: 228,565; validation 117,230). Twenty-one of the 30 groups were independently associated with hospital mortality. The resulting comorbidity score had an equivalent discrimination in the derivation and validation groups (overall c-statistic 0.763, 95% CI: 0.759–0.766). This was similar to models having all Elixhauser groups (0.760, 95% CI: 0.756–0.764) or significant groups only (0.759, 95% CI: 0.754–0.762), but significantly exceeded discrimination when comorbidity was expressed using the Charlson score (0.745, 95% CI: 0.742–0.749).

Conclusion: When analyzing administrative data, the Elixhauser comorbidity system can be condensed to a single numeric score that summarizes disease burden and is adequately discriminative for death in hospital.

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Patient comorbidity must be measured in health services research. It is necessary to describe and compare patient populations. It is also necessary to adjust for potential confounding whenever chronic disease burden is associated with an outcome.

The Charlson et al[1] and Elixhauser et al[2] comorbidity classification systems are the 2 most commonly used in health research. Studies have found them to be significantly associated with various outcomes including in-hospital mortality,[3,4] postdischarge all-cause mortality,[1,5] and healthcare expenditures.[6] In direct comparisons, studies have found the Elixhauser comorbidity system to be statistically slightly superior to the Charlson system at adjusting for comorbidity.[7–9]

However, the Elixhauser comorbidity system has some disadvantages. It is measured as 30 dichotomous variables, each representing one of the comorbidity groups. Such a system makes it difficult to provide an overall description of a patient group since no single statistic is available to describe Elixhauser comorbidity. Also, requiring 30 binomial variables to adjust for comorbidity can jeopardize regression modeling with smaller datasets because of data overfitting or lack of convergence. In addition, modeling interactions between variables and comorbidity is cumbersome when the latter is expressed with a large number of variables. Finally, without a weighting system, the relative importance of each of the 30 comorbidities in the Elixhauser system cannot be gauged. Some Elixhauser comorbidity groups may not be importantly associated with some outcomes and may therefore be unnecessary in regression models. Because of these issues, we developed and validated an index that summarizes all 30 Elixhauser comorbidity groups as a single number to be used with administrative databases for predicting in-hospital mortality.

METHODS

Study Setting

This study took place at The Ottawa Hospital, Canada. This is a tertiary-care teaching center that averages 20,000 admissions annually during the study period. The study was approved by Ottawa Hospital Research Ethics Board.

Patients

The study included all admissions between 1996 and 2008. Similar to studies by Elixhauser et al[2] and Charlson et al,[1]

we excluded pediatric and obstetrical admissions, because these patient populations have very few chronic comorbidities and a very small chance of dying in hospital. We also excluded patients admitted solely for same-day surgeries and patients who were transferred to or from other hospitals, because their observation time was incomplete.

Index Derivation

For all admissions, medical records were reviewed by health professional coders to identify patient diagnoses that were documented by physicians. These diagnoses were coded using International Classification of Diseases (ICD)-9 (before April 2002) and ICD-10-CA systems (after April 2002). For each admission, we identified all preadmission diagnoses as those with "diagnosis type" variable values of "1" (indicating a preadmission comorbidity). We also identified all preadmission and postadmission comorbidities from previous hospital admissions for the patient. Postadmission comorbidities (diagnosis type "2") were not included for current hospitalizations since they were not present when patients were admitted to hospital. We used the ICD codes cited by Quan et al[10] to determine if each of these diagnoses were included in any of the 30 Elixhauser comorbidity groups. Only inpatient records were used. The total number of diagnostic codes per admission before and after 2002 was 16 and 25, respectively. The dataset extends back to 1996.

Comorbidity groups whose tetrachoric correlation coefficients[11] exceeded 0.5 with a 95% CI exceeding 0 were considered strongly correlated. The tetrachoric correlation measures agreement for binary data as a correlation coefficient from -1 to $+1$.

The entire cohort was randomly divided into a derivation (66.7%) and validation (33.3%) group. The derivation set was used to determine the independent association of each Elixhauser comorbidity group with death in hospital. This was done using a multiple logistic regression model with death in hospital as the outcome variable and all 30 Elixhauser comorbidity groups as candidate predictor variables. We used backward variable elimination with an alpha inclusion criterion of 0.05 for variable retention to identify the Elixhauser comorbidity groups that were independently associated with death in hospital.

We then used the methods described by Sullivan et al[12] to modify the parameter estimates of this regression model into an index. The number of points assigned to each Elixhauser group equaled its regression coefficient divided by the coefficient in the model with the smallest absolute value. We rounded this quotient to the nearest whole number. These methods translate the model parameter estimates into units that are relative to the "weakest" variable in the model (ie, that with parameter estimate having the smallest absolute value). Therefore, the association of a variable assigned 2 points is twice as "strong" as that of a variable with 1 point but half as "strong" as that with 4 points.

Each person's "Elixhauser comorbidity score" was then calculated by summing up the points of all Elixhauser comorbidity groups for which they had been coded. The risk of hospital death for each possible Elixhauser comorbidity score was the inverse of $1 + e^{-(\text{intercept} + b * \text{point total})}$ where b is the value of the coefficient in the regression model with the smallest absolute value.

Index Assessment

In both the derivation and validation datasets, we determined the ability of the Elixhauser comorbidity score to discriminate between patients who did and did not die in hospital. This was measured using the c-statistic of a logistic model having "death in hospital" as the outcome variable and the Elixhauser comorbidity score as the predictor variable. We compared this discrimination to the c-statistic of the original logistic model having: all individual Elixhauser comorbidity groups; and only those individual Elixhauser comorbidity groups that were independently associated with death in hospital. We also compared the model using the Elixhauser comorbidity score with a logistic model using the total Charlson score. The Charlson score was determined using ICD-9 and ICD-10 diagnostic codes cited by Quan et al[10] using weights from Schneeweiss et al[13] The 95% CIs of all c-statistics were calculated in SAS using the %ROC macro from Gonen.[14]

We measured the calibration of the Elixhauser score by comparing the observed and expected death rates for Elixhauser scores containing at least 1% of study patients. Scores having fewer patients were aggregated with adjacent scores. Within each score, observed and expected death rates were deemed similar if the 95% CI around the observed death included the expected death rate. Ninety-five percent CIs for observed mortality rates were calculated using exact methods.[15] Overall calibration was summarized using the Hosmer Lemeshow statistic.[16] As a comparison, this process was repeated with the Charlson score. We also compared calibration of models using all 30 Elixhauser groups, the Elixhauser score, and the Elixhauser score expressed as a natural spline. The latter model was examined to capture any nonlinear associations between the Elixhauser score and death in hospital.

Finally, we determined construct validity for the Elixhauser comorbidity score by measuring its association with other measures influenced by comorbidity. These outcomes included patient age, hospital length of stay, admission service (ie, surgical vs. medical), admission urgency, and likelihood of intensive care unit admission. Intensive care unit admission was measured for all admissions after April 2002. The association between these measures and the Elixhauser comorbidity score was measured using multiple linear regression models with the score as the outcome variable and the other measures as the predictor variable.

RESULTS

Between January 1996 and September 2007, 345,795 adult admissions to the Ottawa Hospital met our inclusion criteria. Patients had a mean age of 58 years (SD = 19) and 50% were men. Sixty-eight percent of hospitalizations were emergent and 29% were under surgical services. Median length of stay was 4 days (interquartile range [IQR]: 2–9) and 5.3% of patients after April 2002 spent a portion of their hospitalization in the intensive care unit. Patients died in 17,484 (5.1%) of hospitalizations.

The prevalence of each Elixhauser comorbidity group is presented in Table 1. The most common comorbidities

TABLE 1. Prevalence of Elixhauser Comorbidity Groups and Their Association With Death in Hospital

Elixhauser Group	N (%)	Association With Death in Hospital Odds Ratio (95% CI)		Points
		Unadjusted	Adjusted	
Congestive heart failure	33 171 (9.6%)	3.37 (3.22, 3.53)	1.96 (1.85, 2.07)	7
Cardiac arrhythmias	38 604 (11.2%)	2.96 (2.83, 3.09)	1.71 (1.62, 1.80)	5
Valvular disease	10 237 (3.0%)	2.05 (1.88, 2.22)	0.91 (0.82, 0.99)	−1
Pulmonary circulation disorders	6688 (1.9%)	3.36 (3.09, 3.66)	1.48 (1.34, 1.62)	4
Peripheral vascular disorders	16 219 (4.7%)	2.19 (2.05, 2.34)	1.26 (1.17, 1.36)	2
Hypertension	69 737 (20.2%)	1.65 (1.58, 1.72)	—	0
Paralysis	7685 (2.2%)	2.51 (2.30, 2.74)	1.93 (1.75, 2.12)	7
Neurodegenerative disorders	15 770 (4.6%)	2.49 (2.33, 2.65)	1.83 (1.70, 1.96)	6
Chronic pulmonary disease	30 324 (8.8%)	2.24 (2.13, 2.36)	1.36 (1.29, 1.44)	3
Diabetes, uncomplicated	32 832 (9.5%)	1.63 (1.54, 1.72)	—	0
Diabetes, complicated	21 074 (6.1%)	2.00 (1.88, 2.12)	—	0
Hypothyroidism	8012 (2.3%)	1.73 (1.57, 1.91)	—	0
Renal failure	25 879 (7.5%)	3.00 (2.85, 3.15)	1.63 (1.54, 1.73)	5
Liver disease	7944 (2.3%)	4.04 (3.75, 4.35)	2.97 (2.73, 3.22)	11
Peptic ulcer disease, no bleeding	2512 (0.7%)	2.13 (1.81, 2.50)	—	0
AIDS/HIV	1600 (0.5%)	1.75 (1.41, 2.17)	—	0
Lymphoma	6760 (2.0%)	2.54 (2.31, 2.79)	2.55 (2.31, 2.81)	9
Metastatic cancer	25 491 (7.4%)	3.86 (3.68, 4.05)	3.30 (3.10, 3.52)	12
Solid tumour without metastasis	40 354 (11.7%)	2.89 (2.77, 3.02)	1.47 (1.39, 1.56)	4
Rheumatoid arthritis/collagen vascular diseases	7071 (2.0%)	1.38 (1.23, 1.55)	—	0
Coagulopathy	14 373 (4.2%)	3.05 (2.86, 3.25)	1.30 (1.22, 1.40)	3
Obesity	4425 (1.3%)	0.90 (0.76, 1.07)	0.64 (0.53, 0.77)	−4
Weight loss	5586 (1.6%)	3.64 (3.32, 3.98)	1.85 (1.67, 2.04)	6
Fluid and electrolyte disorders	42 791 (12.4%)	3.28 (3.15, 3.42)	1.61 (1.53, 1.69)	5
Blood loss anemia	3962 (1.1%)	1.92 (1.68, 2.20)	0.81 (0.70, 0.93)	−2
Deficiency anemia	6379 (1.8%)	1.84 (1.65, 2.05)	0.80 (0.71, 0.90)	−2
Alcohol abuse	10 859 (3.1%)	1.42 (1.29, 1.55)	—	0
Drug abuse	7414 (2.1%)	0.58 (0.50, 0.69)	0.50 (0.42, 0.60)	−7
Psychosis	9835 (2.8%)	1.28 (1.16, 1.42)	—	0
Depression	17 599 (5.1%)	1.02 (0.94, 1.11)	0.73 (0.67, 0.80)	−3

This is for the derivation population alone (n = 228.565).

The unadjusted odds ratio provides the association of the lone Elixhauser group with death in hospital.

The adjusted odds ratio provides the association of the Elixhauser group with death in hospital after adjusting for all other groups in the multivariate logistic model.

included hypertension (20.2%), fluid and electrolyte disorders (12.4%), and solid tumor without metastases (11.7%). Patients had between 0 and 17 Elixhauser comorbidities (median 1, IQR: 0–2) with 42% of patients having none.

Many of the comorbidity groups were notably correlated (Table 2). Congestive heart failure, cardiac arrythmias, and valvular disease were all strongly correlated with each other. Renal failure was strongly correlated with congestive heart failure and complicated diabetes, which itself was strongly correlated to peripheral vascular disorders and hypertension. Drug abuse was strongly correlated with many other comorbidity groups including AIDS, psychoses, depression, and alcohol abuse. As expected, alcohol abuse and liver disease were strongly correlated.

Most of the Elixhauser comorbidities influenced death in hospital (Table 1). At the univariate level, the odds ratio of the association with death in hospital was significant for all comorbidities except obesity and depression. Unadjusted odds ratios ranged from 0.58 for drug abuse to 4.04 for liver disease. Twenty-one of the comorbidities were retained in the final model and were independently associated with death in hospital (Table 1). Comorbidities most strongly associated with death in hospital included metastatic cancer (OR: 3.3, 95% CI: 3.1–3.5), liver disease (3.0, 2.7–3.2), and lymphoma (2.5, 2.3–2.8). Six comorbidity groups were independently associated with a decreased risk of death in hospital (Table 1). However, only one of these comorbidities (drug abuse) was also significantly associated with a decreased risk of death at the univariate level.

The points assigned to each comorbidity group ranged from −7 (for drug abuse) to +12 (for metastatic cancer) (Table 1). The range of possible Elixhauser comorbidity scores (calculated by separately summing all negatively and

TABLE 2. Correlation Between Elixhauser Comorbidity Groups

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Congestive heart failure	1	**0.64**	**0.60**	0.47	0.44	0.48	0.09	0.13	0.47	0.39	**0.52**	0.28	**0.57**	0.14	0.22	−0.19	0.05	−0.14	0.02	0.15	0.37	0.21	0.16	0.42	0.31	0.36	0.02	−0.09	0.09	0.12
Cardiac arrhythmias	—	1.00	**0.54**	0.38	0.34	0.43	0.18	0.19	0.33	0.25	0.34	0.25	0.39	0.10	0.18	−0.09	0.06	−0.03	0.09	0.11	0.41	0.05	0.18	0.34	0.23	0.29	0.05	−0.07	0.06	0.11
Valvular disease	—		1.00	0.47	0.30	0.35	0.06	0.07	0.21	0.16	0.27	0.21	0.33	0.13	0.14	−0.10	−0.03	−0.14	−0.01	0.12	0.36	0.01	0.08	0.19	0.25	0.26	−0.03	−0.06	−0.02	0.03
Pulmonary circulation disorders	—			1.00	0.17	0.21	0.08	0.11	0.37	0.19	0.21	0.23	0.29	0.17	0.15	0.08	0.09	0.15	0.19	0.22	0.35	0.26	0.21	0.31	0.20	0.32	0.06	0.07	0.10	0.15
Peripheral vascular disorders	—				1.00	0.48	0.14	0.10	0.31	0.25	**0.55**	0.15	0.47	0.05	0.22	−0.21	−0.07	−0.13	−0.01	0.11	0.28	0.10	0.16	0.28	0.18	0.24	0.03	−0.09	0.03	0.09
Hypertension	—					1.00	0.26	0.19	0.33	0.47	**0.53**	0.34	**0.53**	0.06	0.24	−0.23	−0.04	−0.08	0.03	0.19	0.24	0.26	0.13	0.35	0.19	0.30	−0.01	−0.10	0.03	0.13
Paralysis	—						1.00	0.50	0.05	0.15	0.13	0.10	0.06	−0.02	0.10	−0.01	−0.05	0.01	0.06	0.01	0.14	0.05	0.06	0.21	0.11	0.14	0.02	−0.02	0.08	0.15
Neurodegenerative disorders	—	—	—	—	—	—	—	1.00	0.14	0.13	0.13	0.20	0.14	0.19	0.15	0.22	0.01	−0.02	0.06	0.15	0.22	0.04	0.19	0.31	0.13	0.21	0.25	0.23	0.31	0.26
Chronic pulmonary disease	—	—	—	—	—	—	—	—	1.00	0.26	0.22	0.26	0.28	0.11	0.23	0.08	0.03	0.00	0.13	0.18	0.18	0.36	0.26	0.35	0.17	0.28	0.19	0.16	0.19	0.26
Diabetes, uncomplicated	—	—	—	—	—	—	—	—	—	1.00	**0.54**	0.23	0.31	0.21	0.19	−0.06	0.01	0.00	0.07	0.13	0.17	0.38	0.11	0.29	0.16	0.26	0.07	0.01	0.12	0.16
Diabetes, complicated	—	—	—	—	—	—	—	—	—	—	1.00	0.19	**0.67**	0.16	0.18	−0.12	−0.05	−0.16	−0.04	0.13	0.23	0.29	0.10	0.37	0.20	0.32	0.01	−0.05	0.06	0.15
Hypothyroidism	—	—	—	—	—	—	—	—	—	—	—	1.00	0.27	0.08	0.17	−0.08	0.05	−0.03	0.03	0.24	0.16	0.20	0.16	0.29	0.20	0.27	0.05	0.06	0.25	0.27
Renal failure	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.21	0.26	−0.10	0.11	−0.12	0.04	0.26	0.35	0.14	0.17	**0.51**	0.35	0.38	−0.02	−0.03	0.13	0.15
Liver disease	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.33	0.50	0.07	0.03	0.09	0.17	0.47	0.09	0.27	0.39	0.38	0.31	**0.52**	0.34	0.13	0.21
Peptic ulcer disease, no bleeding	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.14	−0.03	0.03	0.09	0.14	0.24	0.13	0.25	0.31	0.41	0.35	0.27	0.17	0.06	0.23
AIDS/HIV	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.31	−0.22	−0.01	0.07	0.32	−0.18	0.25	0.27	0.04	0.12	0.32	**0.53**	0.23	0.18
Lymphoma	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	−0.08	−0.06	0.05	0.28	−0.08	0.14	0.25	−0.01	−0.01	−0.16	−0.05	−0.03	0.00
Metastatic cancer	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	**0.83**	−0.09	0.07	−0.07	0.19	0.21	0.05	−0.02	−0.13	−0.21	−0.11	−0.09
Solid tumor without metastasis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	−0.03	0.14	0.01	0.21	0.27	0.16	0.08	−0.07	−0.15	−0.08	−0.02
Rheumatoid arthritis/ collagen vascular diseases				—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.24	0.09	0.19	0.28	0.18	0.25	0.08	0.12	0.06	0.18
Coagulopathy	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.07	0.22	0.44	0.31	0.29	0.18	0.10	0.08	0.17
Obesity	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	−0.09	0.17	0.09	0.12	0.04	0.14	0.16	0.28
Weight loss	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.49	0.21	0.35	0.22	0.15	0.16	0.34
Fluid and electrolyte disorders	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.36	0.43	0.27	0.17	0.25	0.30
Blood loss anemia	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.33	0.19	0.06	0.09	0.18
Deficiency anemia	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.22	0.15	0.16	0.25
Alcohol abuse	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	**0.64**	0.39	0.43
Drug abuse	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	**0.56**	**0.54**
Psychosis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00	0.43
Depression	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.00

The tetrachoric correlation coefficient between the Elixhauser comorbidity groups is presented.
The definition of numbers for the groups (top row) is given in the first column.
Correlation coefficients significantly exceeding 0.5 are presented in bold.

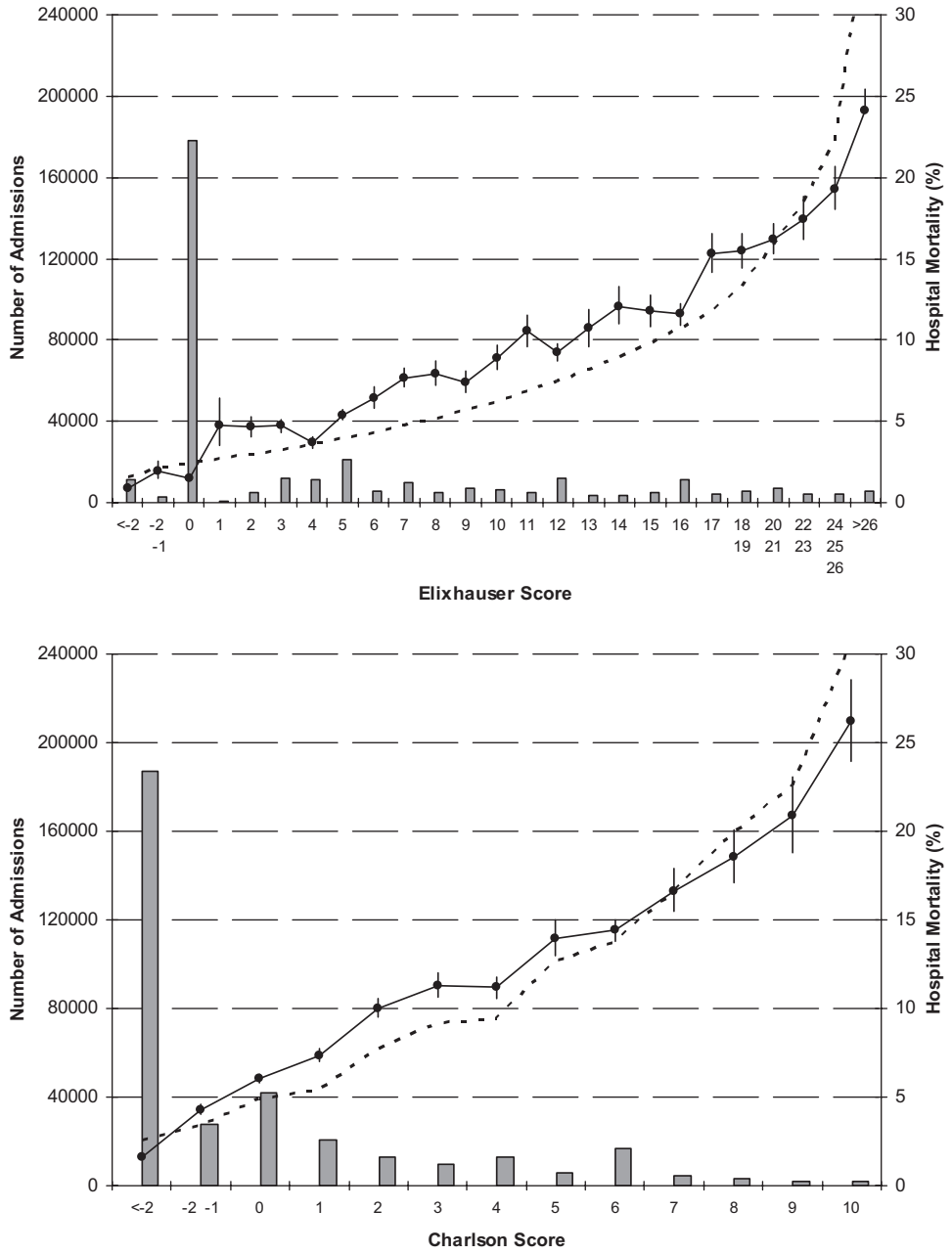

FIGURE 1. Calibration curve of Elixhauser and Charlson comorbidity indexes for predicting risk of hospital death. These graphs present the calibration of the Elixhauser (top) and Charlson (bottom) comorbidity scores for hospital death. Each plot presents the number of admissions having each score (columns, left vertical axis). For each score (horizontal axis), the graph presents the predicted hospital mortality (broken line, right vertical axis) and observed hospital mortality (solid line, right vertical axis) with 95% CIs.

positively scored groups from Table 1) was −19 to +89. The actual Elixhauser comorbidity scores in the study population ranged from −14 to +56 with a median score of 0 (IQR 0–8). Figure 1 illustrates the distribution of the Elixhauser comorbidity score for our study population.

Table 3 describes the association of Elixhauser comorbidity scores with other outcomes influenced by comorbidity. Each outcome was significantly associated with the Elixhauser score. The overall value of each outcome measure increased as the Elixhauser comorbidity score increased, but the association—with the exception of patient age—was nonlinear with the minimum of each measure occurring when the Elixhauser score was 0.

The regression models containing patient comorbidity discriminated adequately between those who survived and those who died in hospital (Table 4). The c-statistic when all

TABLE 3. Association of Elixhauser Comorbidity Score With Other Measures Influenced by Comorbidity

Outcome	Unit	Measure	Elixhauser Score <0 (4%)	0 (52%)	1–5 (14%)	6–13 (15%)	14+ (15%)	Expected Change in Elixhauser Score With 1-Unit Change of Outcome Measure (*P*)
Patient age	Year	Mean	45.6	53.6	63.4	65.1	66.5	0.12 (<0.0001)
		Median	43	54	66	68	69	
Length of stay	Day	Mean	11.6	5.8	9.6	12.7	13.6	0.07 (<0.0001)
		Median	6	3	5	7	8	
Medicine service	%	—	85.0	62.8	71.5	76.4	84.0	0.03 (<0.0001)
Intensive care unit*	%	—	5.0	2.8	6.5	8.1	9.0	0.04 (<0.0001)

*Includes patients admitted after 1 April 2002.
The proportion of the study cohort within each Elixhauser Score category is given.

TABLE 4. Comorbidity Measures and Their Discrimination for Hospital Mortality

Comorbidity Measure	C Statistic (95% CI) Derivation Group	Validation Group	All Patients
All Elixhauser groups	0.760 (0.756–0.765)	0.761 (0.754–0.767)	0.760 (0.756–0.764)
Significant Elixhauser groups	0.758 (0.753–0.763)	0.758 (0.751–0.764)	0.759 (0.754–0.762)
Elixhauser comorbidity score	0.763 (0.758–0.767)	0.763 (0.757–0.769)	0.763 (0.759–0.766)
Charlson comorbidity score	0.747 (0.742–0.751)	0.742 (0.736–0.748)	0.745 (0.742–0.749)

"All Elixhauser Groups" consists of all comorbidity groups cited in Table 1.
"Significant Elixhauser Groups" consists of the Elixhauser groups in Table 1 that were independently associated with death in hospital.

individual Elixhauser comorbidity groups were included in the model was 0.760 (95% CI: 0.756–0.764) with similar measures in both the derivation and validation groups. Discrimination did not change when statistically insignificant Elixhauser groups were excluded (Table 4). Discrimination was also similar when the statistically significant Elixhauser groups were substituted with the Elixhauser comorbidity score (0.763, 95% CI: 0.759–0.766). Discrimination of this model was statistically similar in both derivation and validation groups, and was the same when the Elixhauser score was expressed as a natural spline. Discrimination of the model with the Elixhauser score was significantly better than the Charlson score (0.745, 95% CI: 0.742–0.749) (Table 4).

Figure 2 presents the estimated risk of in-hospital death for each Elixhauser comorbidity score. This ranged from a risk of 0.37% for the minimum Elixhauser score of −19 to a risk of 99.41% for the maximum Elixhauser score of 89. Like the expected hospital mortality, the observed mortality rate increased as the Elixhauser score increased (Fig. 1). With the exception of 4 Elixhauser score strata, the expected mortality rate based on the Elixhauser score differed significantly from the observed mortality rate. For most Elixhauser scores, the expected mortality rate was lower than the observed mortality rate (Fig. 1). The difference between observed mortality rates and those based on the Elixhauser score was significant (Hosmer-Lemeshow statistic 2041, $df = 23$, $P < 0.0001$). Calibration of the Charlson score was also poor (Fig. 1) (Hosmer Lemeshow statistic 1269, $df = 11$, $P < 0.0001$). The Hosmer-Lemeshow statistic (calculated using expected risk by deciles) significantly decreased for model using all 30 Elixhauser groups, the Elixhauser score, and the Elixhauser score expressed as a natural spline (Hosmer Lemeshow statistic values [degrees of freedom] of 1797 [8], 1564 [7], and 324 [7], respectively). This suggests that the association between the Elixhauser score and death in hospital is best expressed as a nonlinear term.

DISCUSSION

We derived and internally validated a comorbidity index based on the Elixhauser classification system. This comorbidity score was significantly associated with in-hospital mortality and health services measures associated with burden of illness. The score adequately discriminated between patients who survived and succumbed in hospital. Although the score did not accurately predict risk of death in hospital, it can be used to describe and adjust for patient comorbidity when working with administrative data.

The Elixhauser comorbidity score expands the capability of researchers to describe and adjust for disease burden in patients. In contrast to the 30 binary variables of the original Elixhauser comorbidity system, this score facilitates the summary of comorbidities in patients. This is especially relevant in regression models where the need for 30 additional variables could result in problems with over-fitting or model convergence. This could be especially pertinent to single hospitals or small hospital groups. In addition, the Elixhauser comorbidity score was significantly better discrimination for hospital death than the Charlson score.

It is not surprising that the Elixhauser comorbidity score poorly predicted hospital mortality rates. Patient comorbidity is but one factor that significantly influences hos-

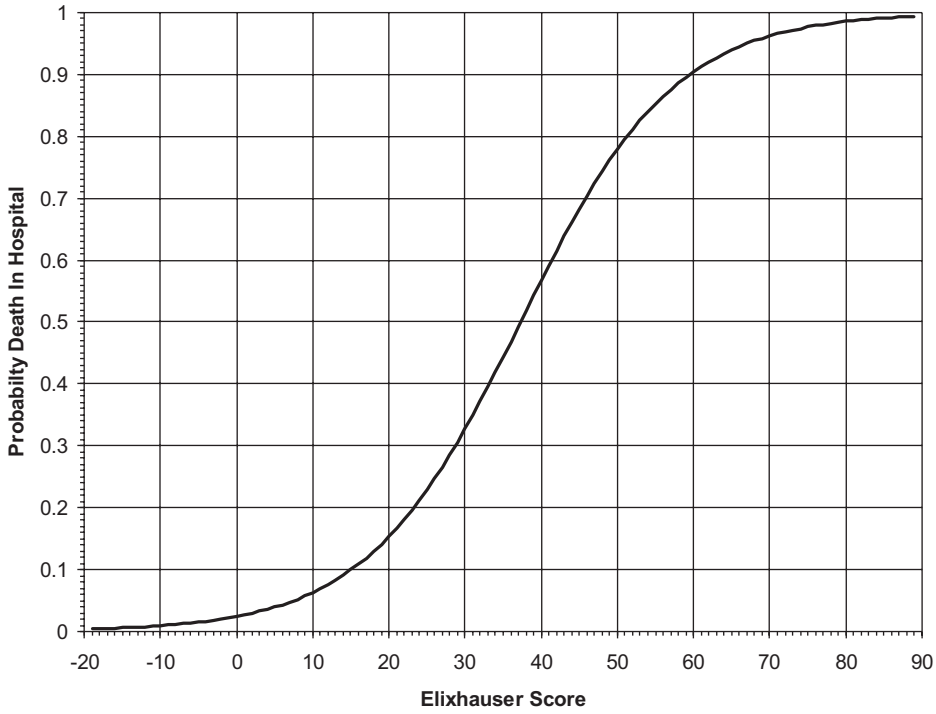

FIGURE 2. Expected risk of hospital death by total Elixhauser comorbidity score. This figure presents all possible Elixhauser comorbidity scores (horizontal axis) along with their expected probability of death in hospital (vertical axis).

pital death risk. Escobar et al[17] found that 4 other factors, including admission urgency and service, patient age, laboratory abnormalities, and admission diagnosis, had the same or greater influence on predicting risk of hospital death than patient comorbidity. This shows that patient comorbidity alone is inadequate for accurately predicting in-hospital mortality. Therefore, the poor prediction of hospital death risk by the Elixhauser and Charlson score is expected.

We found both expected and notable results. Similar to our findings, previous indexes (including those by Charlson et al[1] and Escobar et al[17]) have prioritized metastatic cancer when comorbidity is ranked by importance. Like our system, these other indexes also heavily weighted paralysis, lymphoma, and heart, liver, and renal failure. However, we were surprised to find that 6 comorbidities were independently associated with a decreased risk of in-hospital morbidity. Four of these 6 groups (including valvular disease, blood loss anemia, obesity, and depression) were also found by Elixhauser et al[2] to be independently associated with a decreased risk of hospital death. In an administrative study of intensive care patients, Johnston et al[18] also found that hypertension, complicated diabetes, and drug abuse were significantly associated with a decreased risk of death.

Elixhauser et al[2] hypothesized that the decreased risk of hospital death associated with some comorbidity groups reflects a bias in coding in which the severity of overall patient illness inversely affects the likelihood that nonthreatening conditions are coded. Seriously ill patients have so many diagnoses that acutely immaterial diagnoses are not coded. In contrast, a healthy patient is more likely to have such diagnoses coded in the absence of other ominous diseases. As a result, the presence of codes for nonthreatening diseases is a surrogate for a relatively healthy patient with a low risk of hospital death. This is reflected in the results of our multivariate model. These findings highlight that research using administrative databases reveal information about diagnostic codes that may or not reflect the condition they purportedly represent.

One strength of our analysis is its use of point of admission diagnoses to predict outcome in hospital. Restricting the analysis to point of admission diagnoses ensures that all data required to calculate the index are available when the patient is admitted to the hospital. Analyses in which the onset of diagnosis is unclear would also include complications in hospital. Since these would have significant prognostic importance, the predictive capabilities of an index using such data would likely biased upward since it would contain in-hospital information.

Our study has several other strengths. First, our study methods resulted in a reliable regression model and scoring system. We used standard regression methodology and internally validated our models. We also used accepted methods to modify our final model into a scoring system.[12] Explicit tests of discrimination show that our comorbidity score reliably gauges patient comorbidity and its effect on in-hospital mortality. Second, our study used a large sample size from over a decade of patient encounters. Finally, our methods were explicit and can be duplicated by other researchers who need to describe or control for patient comorbidity with administrative databases.

Our study also has some limitations. First, it involved only 1 hospital; externally validating this index in other hospital systems will be important to ensure its utility. Second, our scoring system was derived with, and created for, administrative data. Idiosyncrasies of administrative data—such as those resulting in negative points for some comor-

bidities—likely influenced the final scoring system. If these idiosyncrasies exist in all administrative systems, our index should—after external validation—be applicable for administrative database research elsewhere. However, a point system derived from primary data is required for studies having primary data collection. Finally, our index is based on comorbidities that are coded in administrative databases. The accuracy of such codes is highly variable between both diagnoses and institutions and can often be poor.[19] In addition, the capture of these comorbidities is influenced by factors other than their existence in patients. These factors include physician documentation, accuracy of code assignment, and possibly financial pressures that could influence the capture of comorbidities based on how well they are remunerated.

Despite these potential coding issues, however, we were still able to derive and internally validate an adequately discriminative comorbidity index for risk adjustment using administrative data. Further research is needed to determine if this index is valid elsewhere and can be combined with other influential factors to accurately predict risk of hospital death and post hospital death.

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