Adaptation and Validation of the Combined Comorbidity Score for ICD-10-CM

Jenny W. Sun, SM,† James R. Rogers, MS,* Qoua Her, PharmD, MS, MSc,‡ Emily C. Welch, MPH,‡ Catherine A. Panozzo, PhD,‡ Sengwee Toh, ScD,†‡ and Joshua J. Gagne, PharmD, ScD*†*

Background: The combined comorbidity score, which merges the Charlson and Elixhauser comorbidity indices, uses the ninth revision of the International Classification of Diseases, Clinical Modification (ICD-9-CM). In October 2015, the United States adopted the 10th revision (ICD-10-CM).

Objective: The objective of this study is to examine different coding algorithms for the ICD-10-CM combined comorbidity score and compare their performance to the original ICD-9-CM score.

Methods: Four ICD-10-CM coding algorithms were defined: 2 using General Equivalence Mappings (GEMs), one based on ICD-10-CA (Canadian modification) codes for Charlson and Elixhauser measures, and one including codes from all 3 algorithms. We used claims data from the Clinfomatics Data Mart to identify 2 cohorts. The ICD-10-CM cohort comprised patients who had a hospitalization between January 1, 2016 and March 1, 2016. The ICD-9-CM cohort comprised patients who had a hospitalization between January 1, 2015 and March 1, 2015. We used logistic regression models to predict 30-day hospital readmission for the original score in the ICD-9-CM cohort and for each ICD-10-CM algorithm in the ICD-10-CM cohort.

Results: Distributions of each version of the score were similar. The algorithm based on ICD-10-CA codes [c-statistic, 0.646; 95% confidence interval (CI), 0.640–0.653] had the most similar discrimination for readmission to the ICD-9-CM version (c, 0.646; 95% CI, 0.639–0.653), but combining all identified ICD-10-CM codes had the highest c-statistic (c, 0.651; 95% CI, 0.644–0.657).

Conclusions: We propose an ICD-10-CM version of the combined comorbidity score that includes codes identified by ICD-10-CA and GEMs. Compared with the original score, it has similar performance in predicting readmission in a population of United States commercially insured individuals.

Key Words: ICD-10, ICD-9, comorbidity, claims data

(*Med Care* 2017;00: 000–000)

Comorbidity scores aggregate multiple medical conditions into a single number, which provides a standardized summary of individual-level and population-level comorbidity burden. These tools are widely used to increase statistical efficiency, simplify the variable selection process, and serve as preliminary guidance for confounding adjustment[1,2] in studies using large administrative databases that contain extensive health service utilization information but otherwise lack general measures of health status.[1] The Charlson index[3] and its adaptations for claims data and the Elixhauser comorbidity classification[4] are the most widely used comorbidity scores in studies using administrative data. The combined comorbidity score, which merges the Romano adaptation of the Charlson Index for use with claims data[5] and the Elixhauser single summary score modified by van Walraven,[6,7] outperforms either component index in predicting mortality in US claims databases. However, the score was created using the ninth revision of the International Classification of Diseases (ICD-9-CM).

The United States adopted the 10th revision of the International Classification of Diseases, Clinical Modification (ICD-10-CM) on October 1, 2015.[8] Since ICD-10-CM uses a new structure that does not directly map to ICD-9-CM codes in a one-to-one fashion, a new ICD-10-CM version of the combined comorbidity score is needed. Several coding algorithms have been developed to define Charlson and Elixhauser comorbidities using versions of ICD-10 codes available in other countries.[9–11] In Switzerland, Halfon et al[9] used clinical judgment to identify ICD-10 codes corresponding to the ICD-9-CM codes used to define conditions in the Deyo adaptation of the Charlson index. In Australia, Sundararajan et al[10] used a computerized algorithm to map ICD-9-CM to ICD-10-AM (Australian modification) codes for Charlson comorbidities. In Canada, Quan et al[11] used computerized algorithms to identify ICD-10-CA (Canadian modification) codes for both the Charlson and Elixhauser

From the *Division of Pharmacoepidemiology and Pharmacoeconomics, Department of Medicine, Brigham and Women's Hospital and Harvard Medical School; †Department of Epidemiology, Harvard T.H. Chan School of Public Health; and ‡Department of Population Medicine, Harvard Medical School and Harvard Pilgrim Health Care Institute, Boston, MA.

J.J.G.: is Principal Investigator of a grant from Novartis Pharmaceuticals Corporation to the Brigham and Women's Hospital and is a consultant to Aetion Inc. and to Optum Inc., all for unrelated work. J.R.R. is a consultant to Aetion Inc. for unrelated work. The remaining authors declare no conflict of interest.

Reprints: Joshua J. Gagne, PharmD, ScD, 1620 Tremont Street, Suite 3030, Boston, MA 02120. E-mail: jgagne1@partners.org.

Supplemental Digital Content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website, www.lww-medicalcare.com.

ISSN: 0025-7079/17/000-000

comorbidity scores and collaborated with the groups in Australia, Canada, and Switzerland to create a consensus approach. The World Health Organization (WHO) maintains a general standard for ICD-10, but allows for minor flexibility in adapting codes to a particular setting.[8,12] Therefore, each adaptation of ICD-10 may have slight differences in the definition or existence of specific codes. For example, the WHO 2015 version of ICD-10 includes code I64 for stroke, not specified as hemorrhage or infarction, but this code is not included in the ICD-10-CM version. Therefore, the US adaptation of ICD-10 (ICD-10-CM) differs slightly from modifications available in other countries.

Different mapping approaches based off the same ICD-9 codes can result in slightly different sets of ICD-10 codes. To facilitate the mapping of ICD-9-CM codes to ICD-10-CM codes, the US Centers for Medicare & Medicaid Services has developed General Equivalence Mappings (GEMs).[13] There are 2 mappings of GEMs: forward mapping and backward mapping. The forward direction maps all ICD-9-CM codes into ICD-10-CM codes, and the backward direction maps all ICD-10-CM codes into ICD-9-CM codes. Since the relationship between ICD-9-CM and ICD-10-CM is complex and not one-to-one, not all ICD-10-CM codes are represented in the forward map and not all ICD-9-CM codes are represented in the backward map.[14] Therefore, different applications of GEMs can lead to different sets of codes,[15] even when starting with the same source codes. Fung et al[15] provide a detailed explanation of the different GEMs and different matching methods.

The objective of this study was to evaluate different coding algorithms for the ICD-10-CM version of the combined comorbidity score and to compare the performance of each version to that of the original ICD-9-CM score. Performance of the ICD-10-CM version of the combined comorbidity score was also compared to ICD-10-CM versions of the Romano adaptation of the Charlson Index and the van Walraven modification of the Elixhauser system.

METHODS

Data Source and Study Cohorts

We used data from the Clinformatics Data Mart (OptumInsight, Eden Prairie, MN), which includes administrative pharmacy and medical claims for beneficiaries of UnitedHealthcare, a large commercial insurance provider in the United States as well as patients with a Medicare supplement plan. Approximately 10% of patients in the database are Medicare beneficiaries. The database comprises patients across the United States. Compared with the overall US population, the database covers slightly more patients in the South and slightly less in the Northeast. Data up to March 31, 2016 were available for analysis. We created 2 cohorts—one to examine the ICD-10-CM combined comorbidity score and one to assess the ICD-9-CM combined comorbidity score. To ensure independent cohorts, the initial study population was randomly divided in half before cohort identification. From the first half, we identified enrollees who had a hospitalization between January 1, 2016 and March 1, 2016 to comprise the ICD-10-CM cohort. The first hospitalization in this window was defined as the index hospitalization for each patient in the cohort. From the second half of the initial study population, the ICD-9-CM cohort was identified in parallel to the ICD-10-CM cohort as enrollees who had a hospitalization between January 1, 2015 and March 1, 2015. In both cohorts, patients with index hospitalization discharge dates after March 1 were excluded to ensure the opportunity for 30-day follow-up. We required patients to have at least 90 days of continuous enrollment before their index hospitalization.

Defining Comorbidity Scores

In both cohorts, we used the 90 days before admission to the index hospitalization to measure conditions included in the combined comorbidity score. For the ICD-9-CM cohort, the ICD-9-CM combined comorbidity score was defined using the originally proposed coding algorithm.[7] For the ICD-10-CM cohort, each condition was defined using codes from 4 different algorithms. First, we used the forward-backward mapping method (FBM) of GEMs, which combines all codes identified from the forward and backward mappings. Fung et al[15] previously compared 4 applications of GEMs and found that the FBM outperformed other approaches to mapping with GEMs. Second, we examined the backward mapping method (BM) of GEMs, an approach that was not examined by Fung et al.[15] The BM of GEMs maps all available ICD-10-CM codes to ICD-9-CM codes. We then identified the ICD-10-CM codes that corresponded to the ICD-9-CM codes in the original combined comorbidity score. Both applications of GEMs used the 2016 version. Third, we used the ICD-10-CA codes previously identified by Quan et al[11] for the Charlson and Elixhauser comorbidity scores, removing those ICD-10-CA codes that do not exist in ICD-10-CM. Finally, the fourth and most comprehensive version of the ICD-10-CM combined score included all of the codes identified from the 3 approaches described above. All ICD-10-CM codes were manually reviewed to ensure each code description properly reflected the condition of interest. See Appendix 1 (Supplemental Digital Content 1, http://links.lww.com/MLR/B482) for codes used in each version.

These ICD-10-CM mappings were repeated for the Charlson and Elixhauser comorbidity scores using the same methods outlined for the combined comorbidity score. We identified 4 ICD-10-CM versions of the Romano adaptation of the Charlson Index using weights developed by Schneeweiss et al[16] and 4 ICD-10-CM versions of the van Walraven modification of the Elixhauser system, which were the specific adaptations that contributed to the combined comorbidity score.

Outcome and Analysis

For each patient, we applied the previously developed combined comorbidity score weights to each condition and summed the weights to calculate the patient's ICD-9-CM or ICD-10-CM combined comorbidity score. We followed patients for up to 30 days after their index hospitalization discharge date to assess 30-day all-cause hospital readmission. Although the original combined comorbidity score was developed with mortality as the outcome, data on mortality were not available for this study. To determine the association

between each version of the combined comorbidity score and readmission, we used multivariable logistic regression models that included each patient's combined comorbidity score as well as age (continuous variable) and sex as independent variables to estimate odds ratios (OR) and 95% confidence intervals (95% CI). We calculated the c-statistic and 95% CI to compare the discriminatory ability of each version of the combined comorbidity score. To provide a comparative assessment, we repeated this analysis for each version of the Charlson and Elixhauser comorbidity scores. The Schneeweiss and van Walraven weights were applied to calculate each patient's ICD-9-CM and ICD-10-CM Charlson and Elixhauser comorbidity score, respectively. We also assessed the association between 30-day readmission and each individual condition in the combined comorbidity score, defined according to each version of the score. For each version of the score, we fit a multivariable model that included each condition and age and sex as independent variables

RESULTS

We identified 76,166 eligible patients in the ICD-10-CM cohort and 69,835 eligible patients in the ICD-9-CM cohort (Table 1). On average at baseline, patients from both cohorts were 62 years old and 58% of patients in both cohorts were female. Compared with those in the ICD-9-CM cohort, patients in the ICD-10-CM cohort had the same mean number of physician visits (7.8), but a higher number of distinct ICD diagnoses [mean (SD), 19.6 (10.4) vs. 18.0 (9.1)] at baseline. In both cohorts, 10% of patients were readmitted within 30 days of index hospitalization discharge.

Table 2 displays distributions of the ICD-10-CM and ICD-9-CM versions of the combined, Charlson, and Elixhauser comorbidity scores. For the combined comorbidity score, distributions were similar among all versions of the score. The ICD-10-CM score that combined all codes identified from the three algorithms had the highest mean [mean (SD), 2.51 (2.78)] and the Quan and colleagues. adaptation of the ICD-10-CM score had the lowest mean [mean (SD), 2.09 (2.58)]. The mean (SD) of the ICD-9-CM score was 2.16 (2.60).

Descriptive statistics were also similar across all versions of the Charlson and Elixhauser comorbidity scores. With both scores, the version that combined all identified codes had the highest mean [mean (SD), 2.58 (2.79) for the Charlson score; 8.11 (9.59) for the Elixhauser score], which was consistent with the combined comorbidity score. The ICD-9-CM version of the Charlson and Elixhauser comorbidity scores had the lowest mean [mean (SD), 2.22 (2.56) for the Charlson score, 7.32 (8.36) for the Elixhauser score].

Among all versions of the combined comorbidity score, a 1-point increase in score was associated with a 17% greater odds of 30-day hospital readmission (OR, 1.17; 95% CI, 1.16–1.18 for all versions except Quan and colleagues, which had a 95% CI of 1.16–1.19; Table 3). The c-statistic for discriminating 30-day hospital readmission was nearly identical for all versions of the score. The estimate was 0.646 (95% CI, 0.639–0.653) for the ICD-9-CM combined score. The estimates for the ICD-10-CM versions ranged from 0.646 (95% CI, 0.640–0.653) for the Quan and colleagues version to 0.651 (95% CI, 0.644–0.657) for the approach that combined all identified ICD-10-CM codes.

ICD-10-CM versions of the combined comorbidity score consistently outperformed ICD-10-CM versions of the Charlson and Elixhauser scores in discriminating 30-day hospital readmission. For both the Charlson and Elixhauser comorbidity scores, c-statistics were also nearly identical across all versions of the scores. Among all ICD-10-CM versions, the Quan and colleagues adaptation had the highest c-statistic for the Charlson score (c-statistic, 0.637; 95% CI, 0.631–0.644) and the GEMs FBM and BM versions had the highest c-statistic for the Elixhauser score (c-statistic, 0.635; 95% CI, 0.628–0.641 for FBM and BM).

For each condition in the combined comorbidity score, the odds of 30-day hospital readmission were generally similar across all versions of the score (Table 4). The ORs were nearly identical for some conditions, such as alcohol abuse (OR ranging from 1.38–1.42) and renal failure (OR ranging from 1.64–1.66), but estimates varied more widely for other conditions, such as psychosis (OR ranging from 1.40–1.81) and liver disease (OR ranging from 1.53–1.69).

TABLE 1. Characteristics of 2 Populations in the ICD-9-CM Cohort and ICD-10-CM Cohort

Characteristics	ICD-9-CM Cohort	ICD-10-CM Cohort
N	69,835	76,166
Calendar period	January 2015 to March 2015	January 2016 to March 2016
Descriptive characteristics		
Age (y) [mean (SD)]	61.8 (21.7)	62.0 (21.5)
Female (%)	58.3	58.5
No. distinct prescription drugs [mean (SD)]	5.5 (5.3)	5.4 (5.3)
Any prescription drug (%)	78.14	76.32
No. distinct ICD diagnoses [mean (SD)]	18.0 (9.1)	19.6 (10.4)
No. physician visits [mean (SD)]	7.8 (11.6)	7.8 (11.7)
Any physician visit (%)	93.6	93.6
Nursing home residents (%)	7.2	6.9
Duration of index hospitalization (d) [mean (SD)]	5.2 (4.4)	5.0 (4.4)
30-day readmission (%)	9.7	10.0

ICD-10-CM indicates International Classification of Diseases, 10th Revision, Clinical Modification; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification.

DISCUSSION

We compared 4 approaches to defining ICD-10-CM codes for the combined comorbidity score. Compared with the previously developed ICD-9-CM version of the score, all 4 approaches had identical associations with and highly similar ability to discriminate 30-day hospital readmission. Descriptive distributions of the ICD-9-CM combined score and all versions of the ICD-10-CM score were similar. In the ICD-10-CM cohort, we identified slightly higher numbers of distinct ICD diagnoses at baseline as compared with the ICD-9-CM cohort, even though patients in each cohort had the

TABLE 2. Descriptive Statistics for Each Version the Comorbidity Scores

Characteristics	ICD-9-CM Score	ICD-10-CM Score 1: GEMs FBM	ICD-10-CM Score 2: GEMs BM	ICD-10-CM Score 3: Quan and Colleagues	ICD-10-CM Score 4: All
Combined score					
Mean (SD)	2.16 (2.60)	2.37 (2.71)	2.31 (2.69)	2.09 (2.58)	2.51 (2.78)
Median (IQR)	1 (3)	2 (4)	2 (4)	1 (3)	2 (4)
Percentage with score = 0	26.6	24.8	25.2	28.28	23.7
Range	−2, 18	−2, 20	−2, 19	−2, 18	−2, 20
Romano/Charlson score					
Mean (SD)	2.91 (3.18)	3.28 (3.44)	3.23 (3.40)	3.09 (3.31)	3.37 (3.49)
Median (IQR)	2 (5)	2 (5)	2 (5)	2 (5)	2 (5)
Percentage with score = 0	33.82	32.00	32.11	32.05	31.10
Range	0, 22	0, 24	0, 24	0, 24	0, 24
van Walraven/Elixhauser score					
Mean (SD)	7.32 (8.36)	7.66 (9.17)	7.66 (9.17)	8.07 (9.59)	8.11 (9.59)
Median (IQR)	5 (12)	5 (13)	5 (13)	6 (14)	6 (14)
Percentage with score = 0	25.55	21.50	21.50	21.17	19.53
Range	−12, 65	−14, 63	−14, 63	−15, 65	−15, 63

BM indicates backward mapping; FBM, forward-backward mapping; GEMs, general equivalence mappings; ICD-10-CM, International Classification of Diseases, 10th Revision, Clinical Modification; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; IQR, interquartile range.

same number of physician visits on average. This may be because of the larger number of ICD-10-CM codes available and their greater specificity.

The mean for all versions of the ICD-10-CM combined comorbidity score was slightly higher than the mean ICD-9-CM comorbidity score, except the one that used codes proposed by Quan and colleagues. Although the OR for the association between a 1-point change in score and 30-day readmission were identical, the small differences in c-statistic across ICD-10-CM versions were consistent with the differences in mean scores. The lower mean score based on the Quan and colleagues codes may reflect the fact that this approach does not take advantage of relevant codes that may be in ICD-10-CM but not available in ICD-10-CA. For example, this algorithm did not include several ICD-10-CM codes for peripheral vascular disease and any tumor that were identified using GEMs. Indeed, the comprehensive version that included codes identified by the 3 other approaches had the highest mean score. Although the coding algorithm proposed by Quan and colleagues had a c-statistic that was the most comparable to that obtained from the ICD-9-CM version, it was slightly lower than that of the other methods that used the GEMs. Therefore, we recommend using the comprehensive algorithm since it had the highest c-statistic. However, we recognize that the differences in c-statistics were very small and not statistically significantly different.

TABLE 3. Comorbidity Score Odds Ratios and Discrimination for 30-day Hospital Readmission

30-day Hospital Readmission	ICD-9-CM Cohort	ICD-10-CM Cohort 1: GEMs FBM	ICD-10-CM Cohort 2: GEMs BM	ICD-10-CM Cohort 3: Quan and Colleagues	ICD-10-CM Cohort 4: All
Combined score					
OR (95% CI) for score	1.17 (1.16, 1.18)	1.17 (1.16, 1.18)	1.17 (1.16, 1.18)	1.17 (1.16, 1.19)	1.17 (1.16, 1.18)
c-statistic (95% CI)	0.646 (0.639, 0.653)	0.649 (0.643, 0.656)	0.650 (0.644, 0.656)	0.646 (0.640, 0.653)	0.651 (0.644, 0.657)
Romano/Charlson score					
OR (95% CI) for score	1.13 (1.12, 1.14)	1.13 (1.12, 1.14)	1.13 (1.12, 1.14)	1.13 (1.12, 1.14)	1.13 (1.12, 1.14)
c-statistic (95% CI)	0.636 (0.629, 0.643)	0.637 (0.630, 0.643)	0.637 (0.630, 0.643)	0.638 (0.631, 0.644)	0.638 (0.631, 0.645)
van Walraven/Elixhauser score					
OR (95% CI) for score	1.05 (1.04, 1.05)	1.05 (1.04, 1.05)	1.05 (1.04, 1.05)	1.05 (1.04, 1.05)	1.05 (1.04, 1.05)
c-statistic (95% CI)	0.631 (0.624, 0.638)	0.635 (0.628, 0.641)	0.635 (0.628, 0.641)	0.634 (0.628, 0.641)	0.632 (0.626, 0.639)

Models adjusted for age and sex.

Measures represent a 1-unit increase in each score.

BM indicates backward mapping; FBM, forward-backward mapping; GEMs, General Equivalence Mappings; ICD-10-CM, International Classification of Diseases, 10th Revision, Clinical Modification; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; OR, odds ratio.

TABLE 4. Odds Ratios for 30-day Hospital Readmission for Each Condition in the Combined Comorbidity Score

Condition Odds Ratio (95% Confidence Interval)	ICD-9-CM Cohort	ICD-10-CM Cohort 1: GEMs FBM	ICD-10-CM Cohort 2: GEMs BM	ICD-10-CM Cohort 3: Quan and Colleagues	ICD-10-CM Cohort 4: All
Alcohol abuse	1.38 (1.21, 1.57)	1.42 (1.27, 1.59)	1.42 (1.26, 1.59)	1.40 (1.25, 1.56)	1.40 (1.25, 1.57)
Any tumor	1.63 (1.53, 1.74)	1.63 (1.53, 1.74)	1.63 (1.53, 1.73)	1.48 (1.38, 1.58)	1.62 (1.52, 1.72)
Cardiac arrhythmias	1.34 (1.27, 1.42)	1.41 (1.34, 1.49)	1.41 (1.34, 1.49)	1.39 (1.32, 1.46)	1.40 (1.32, 1.47)
Chronic pulmonary disease	1.46 (1.39, 1.55)	1.51 (1.43, 1.59)	1.51 (1.43, 1.59)	1.50 (1.43, 1.58)	1.50 (1.43, 1.58)
Coagulopathy	1.77 (1.62, 1.93)	1.65 (1.51, 1.79)	1.65 (1.51, 1.79)	1.63 (1.50, 1.77)	1.63 (1.50, 1.77)
Complicated diabetes	1.48 (1.38, 1.60)	1.51 (1.42, 1.60)	1.60 (1.50, 1.71)	1.51 (1.43, 1.60)	1.51 (1.42, 1.60)
Congestive heart failure	1.72 (1.62, 1.82)	1.68 (1.59, 1.77)	1.68 (1.59, 1.77)	1.69 (1.60, 1.78)	1.68 (1.59, 1.78)
Deficiency anemia	1.66 (1.56, 1.76)	1.65 (1.56, 1.74)	1.65 (1.56, 1.74)	1.70 (1.57, 1.84)	1.65 (1.56, 1.74)
Dementia	1.00 (0.89, 1.14)	1.03 (0.95, 1.12)	0.98 (0.90, 1.07)	0.89 (0.78, 1.00)	1.04 (0.95, 1.13)
Fluid and electrolyte disorders	1.57 (1.49, 1.65)	1.67 (1.58, 1.75)	1.67 (1.58, 1.75)	1.67 (1.58, 1.75)	1.67 (1.58, 1.75)
Hemiplegia	1.11 (0.94, 1.30)	1.27 (1.11, 1.46)	1.27 (1.11, 1.46)	1.28 (1.12, 1.47)	1.27 (1.11, 1.46)
HIV/AIDS	1.89 (1.30, 2.75)	1.85 (1.32, 2.58)	1.85 (1.32, 2.58)	1.85 (1.32, 2.58)	1.85 (1.32, 2.58)
Hypertension	1.29 (1.22, 1.36)	1.31 (1.24, 1.38)	1.31 (1.24, 1.38)	1.38 (1.31, 1.46)	1.38 (1.31, 1.46)
Liver disease	1.53 (1.37, 1.71)	1.66 (1.52, 1.82)	1.68 (1.54, 1.83)	1.65 (1.52, 1.80)	1.69 (1.55, 1.83)
Metastatic cancer	2.06 (1.86, 2.27)	2.10 (1.92, 2.30)	2.10 (1.92, 2.31)	2.10 (1.92, 2.30)	2.10 (1.92, 2.30)
Peripheral vascular disease	1.30 (1.21, 1.40)	1.38 (1.29, 1.47)	1.38 (1.29, 1.47)	1.38 (1.30, 1.47)	1.38 (1.29, 1.47)
Psychosis	1.54 (1.44, 1.66)	1.40 (1.32, 1.49)	1.40 (1.32, 1.49)	1.81 (1.60, 2.06)	1.40 (1.32, 1.49)
Pulmonary circulation disorders	1.73 (1.56, 1.93)	1.74 (1.58, 1.92)	1.74 (1.58, 1.92)	1.62 (1.49, 1.76)	1.62 (1.49, 1.76)
Renal failure	1.64 (1.54, 1.74)	1.65 (1.56, 1.75)	1.64 (1.54, 1.74)	1.66 (1.56, 1.76)	1.66 (1.56, 1.76)
Weight loss	1.83 (1.65, 2.02)	1.94 (1.77, 2.12)	1.94 (1.78, 2.12)	1.82 (1.69, 1.97)	1.82 (1.69, 1.97)

Models adjusted for age and sex.

BM indicates backward mapping; FBM, forward-backward mapping; GEMs, General Equivalence Mappings; ICD-10-CM, International Classification of Diseases, 10th Revision, Clinical Modification; ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification.

All ICD-10-CM versions of the combined comorbidity score outperformed all ICD-10-CM versions of the Charlson and Elixhauser scores in discriminating 30-day readmission. This is consistent with the results observed in the ICD-9-CM setting for mortality.[7] Descriptive statistics and ability to discriminate 30-day readmission were similar with the ICD-9-CM score and all versions of the ICD-10-CM score for both the Charlson and Elixhauser scores. Distributions varied slightly more in the Elixhauser score, which were likely due to the wider range in possible values of the score.

Although the comprehensive algorithm yielded the highest c-statistic among all ICD-10-CM versions of the combined comorbidity score, other algorithms provided the best discrimination for the Charlson and Elixhauser comorbidity scores. The Quan and colleagues and comprehensive adaptations both had the highest c-statistic for the Charlson score and the GEMs FBM and BM both had the highest c-statistic for the Elixhauser score; however, the differences in c-statistics were small. Preferred mapping strategies for different settings and conditions should continue to be investigated.

Our study has several limitations. The combined comorbidity score was originally evaluated for predicting mortality. However, mortality data were not available for this analysis. We examined readmission as an outcome because only data through March 2016 were available and ICD-10-CM was implemented in the United States in October 2015. A mortality outcome could have provided better discrimination compared with a readmission outcome,[17,18] and subsequent validations with longer follow-up should consider mortality as an outcome. Also, given the data available, we used 90-day covariate assessment periods which may not be long enough to ascertain chronic conditions that may not be frequently coded. Although this could lead to an under capture of certain conditions, it should not differentially affect the study cohorts. In addition, we assessed the combined comorbidity scores in a commercially insured population in the United States, whereas the combined comorbidity score was originally developed in Medicare beneficiaries. Whether our results hold in older and in other populations needs to be confirmed.

As the United States adjusts to the ICD-10-CM system, the quality and consistency of ICD-10-CM coded data may be a concern. Coding errors might impact data quality and the performance of the ICD-10-CM algorithms. Nevertheless, results were very similar between ICD-9-CM and ICD-10-CM versions of the score and covariates defined using ICD-9-CM and ICD-10-CM codes generally had similar associations with the outcome of 30-day readmission. There are also seasonal variations in hospital admissions and outcomes. Although only 1 season was examined, the comparability of our results should not be affected because all versions of the score were assessed during the same calendar months. Finally, potential changes in coding practices may occur. In particular, GEMs are under constant review and important revisions to the GEMs database will be updated annually for at least 3 years beyond October 1, 2015.[19] Important changes would limit the generalizability of our results and may necessitate changes to the codes sets used for the combined comorbidity score.

In this study, we created 2 mutually exclusive cohorts of patients with 90-day look back periods during which only ICD-9-CM or ICD-10-CM codes were being used. Some studies may seek to use the combined comorbidity score across the transition from ICD-9-CM to ICD-10-CM. As such, both ICD-9-CM and ICD-10-CM codes will be needed to define covariates for some patients. Although our study did not explicitly examine this setting, we found that the distributions and performances of the ICD-9-CM and ICD-10-CM combined comorbidity scores were similar, so defining conditions according to whether patients meet criteria for either ICD-9-CM or ICD-10-CM definitions or both should provide similar results.

Our study also provides insights into ICD-10-CM mapping and coding practices that go beyond their use for calculating the combined comorbidity score. In general, the prevalence of each condition in the combined comorbidity score was similar across ICD-9-CM and ICD-10-CM definitions, with a few exceptions. For example, the baseline prevalence of chronic pulmonary disease was 23% to 24% across definitions, but the prevalence of both dementia and psychosis varied widely (Appendix 2, Supplemental Digital Content 1, http://links.lww.com/MLR/B483). The associations between readmission and the individual conditions were generally similar across the definitions used in the different versions of the score. In particular, the ICD-10-CM versions had very similar ORs for all conditions except dementia and psychosis. The ORs for conditions defined using ICD-9-CM codes were also similar, with few exceptions, despite being based on an independent cohort. For example, peripheral vascular disease was associated with an OR of 1.38 across all ICD-10-CM versions and an OR of 1.30 for the ICD-9-CM version. These results may help investigators in selecting preferred mapping strategies for individual conditions.

In conclusion, we propose an ICD-10-CM version of the combined comorbidity score that includes codes previously identified by Quan et al[11] for the Charlson Index and the Elixhauser system as well as additional codes identified using the backward mapping and forward-backward mapping applications of GEMs. Compared to the original ICD-9-CM combined comorbidity score, the ICD-10-CM version has a similar performance in predicting 30-day hospital readmission in a population of commercially insured individuals in the United States in the early transition period of the coding system.

ACKNOWLEDGMENTS

The authors thank Joan E. Landon for her assistance in preparing the analytic dataset.

REFERENCES

1. Schneeweiss S, Maclure M. Use of comorbidity scores for control of confounding in studies using administrative databases. *Int J Epidemiol*. 2000;29:891–898.
2. Schneeweiss S, Seeger JD, Maclure M, et al. Performance of comorbidity scores to control for confounding in epidemiologic studies using claims data. *Am J Epidemiol*. 2001;154:854–864.
3. Charlson ME, Pompei P, Ales KL, et al. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis*. 1987;40:373–383.
4. Elixhauser A, Steiner C, Harris DR, et al. Comorbidity measures for use with administrative data. *Med Care*. 1998;36:8–27.
5. Romano PS, Roos LL, Jollis JG. Adapting a clinical comorbidity index for use with ICD-9-CM administrative data: differing perspectives. *J Clin Epidemiol*. 1993;46:1075–1079; discussion 1081–1090.
6. van Walraven C, Austin PC, Jennings A, et al. A modification of the Elixhauser comorbidity measures into a point system for hospital death using administrative data. *Med Care*. 2009;47:626–633.
7. Gagne JJ, Glynn RJ, Avorn J, et al. A combined comorbidity score predicted mortality in elderly patients better than existing scores. *J Clin Epidemiol*. 2011;64:749–759.
8. International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM). Centers for Disease Control and Prevention; 2016.
9. Halfon P, Eggli Y, van Melle G, et al. Measuring potentially avoidable hospital readmissions. *J Clin Epidemiol*. 2002;55:573–587.
10. Sundararajan V, Henderson T, Perry C, et al. New ICD-10 version of the Charlson comorbidity index predicted in-hospital mortality. *J Clin Epidemiol*. 2004;57:1288–1294.
11. Quan H, Sundararajan V, Halfon P, et al. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. *Med Care*. 2005;43:1130–1139.
12. International Statistical Classification of Disease and Related Health Problems, Tenth Revision. World Health Organization; 2004.
13. 2016 ICD-10 CM and GEMs. 2015. Available at: https://www.cms.gov/Medicare/Coding/ICD10/2016-ICD-10-CM-and-GEMs.html. Accessed November 30, 2016.
14. Wollman J. ICD -10: A master data challenge. *Health Manag Technol*. 2011;32:16. 20–11.
15. Fung KW, Richesson R, Smerek M, et al. Preparing for the ICD-10-CM transition: automated methods for translating ICD codes in clinical phenotype definitions. *EGEMS (Wash DC)*. 2016;4:1211.
16. Schneeweiss S, Wang PS, Avorn J, et al. Improved comorbidity adjustment for predicting mortality in Medicare populations. *Health Serv Res*. 2003;38:1103–1120.
17. Mehta HB, Dimou F, Adhikari D, et al. Comparison of comorbidity scores in predicting surgical outcomes. *Med Care*. 2016;54:180–187.
18. Moore BJ, White S, Washington R, et al. Identifying increased risk of readmission and in-hospital mortality using hospital administrative data: the AHRQ Elixhauser Comorbidity Index. *Med Care*. 2017;55:698–705.
19. General Equivalence Mappings Frequently Asked Questions. 2016. Available at: https://www.cms.gov/medicare/coding/icd10/downloads/gems-crosswalksbasicfaq.pdf. Accessed March 13, 2017.