Coding Algorithms for Defining Comorbidities in ICD-9-CM and ICD-10 Administrative Data

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Objectives: Implementation of the International Statistical Classification of Disease and Related Health Problems, 10th Revision (ICD-10) coding system presents challenges for using administrative data. Recognizing this, we conducted a multistep process to develop ICD-10 coding algorithms to define Charlson and Elixhauser comorbidities in administrative data and assess the performance of the resulting algorithms.

Methods: ICD-10 coding algorithms were developed by "translation" of the ICD-9-CM codes constituting Deyo's (for Charlson comorbidities) and Elixhauser's coding algorithms and by physicians' assessment of the face-validity of selected ICD-10 codes. The process of carefully developing ICD-10 algorithms also produced modified and enhanced ICD-9-CM coding algorithms for the Charlson and Elixhauser comorbidities. We then used data on in-patients aged 18 years and older in ICD-9-CM and ICD-10 administrative hospital discharge data from a Canadian health region to assess the comorbidity frequencies and mortality prediction achieved by the original ICD-9-CM algorithms, the enhanced ICD-9-CM algorithms, and the new ICD-10 coding algorithms.

Results: Among 56,585 patients in the ICD-9-CM data and 58,805 patients in the ICD-10 data, frequencies of the 17 Charlson comorbidities and the 30 Elixhauser comorbidities remained generally similar across algorithms. The new ICD-10 and enhanced ICD-9-CM coding algorithms either matched or outperformed the original Deyo and Elixhauser ICD-9-CM coding algorithms in predicting in-hospital mortality. The C-statistic was 0.842 for Deyo's ICD-9-CM coding algorithm, 0.860 for the ICD-10 coding algorithm, and 0.859 for the enhanced ICD-9-CM coding algorithm, 0.868 for the original Elixhauser ICD-9-CM coding algorithm, 0.870 for the ICD-10 coding algorithm and 0.878 for the enhanced ICD-9-CM coding algorithm.

Conclusions: These newly developed ICD-10 and ICD-9-CM comorbidity coding algorithms produce similar estimates of comorbidity prevalence in administrative data, and may outperform existing ICD-9-CM coding algorithms.

Key Words: ICD-9, ICD-10, comorbidity, risk adjustment outcome, administrative data

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Patient clinical characteristics usually are measured and controlled in clinical outcomes research. Similarly, when administrative data are used for such research, comorbidity coding algorithms are essential for defining comorbidities. Two comorbidity measurement tools developed by Charlson et al[1] and Elixhauser et al[2] are used widely to measure burden of disease or case-mix with administrative data. Charlson et al[1] defined 17 comorbidities using clinical conditions recorded in charts. Deyo et al,[3] Romano et al,[4] and D'Hoore et al[5,6] independently developed International Classification of Disease, 9th Revision, Clinical Modification (ICD-9-CM) coding algorithms for the Charlson comorbidities. Deyo's coding algorithm[1] and the Dartmouth-Manitoba coding algorithm developed by Romano et al[3] are similar in generating Charlson index scores and in their ability to predict outcomes.[7–9] D'Hoore et al[5,6] only used the first 3 characters of ICD-9-CM codes and did not distinguish subgroups of certain clinical conditions (such as diabetes with or without complications). Elixhauser et al[2] defined 30 comorbidities using distinctive ICD-9-CM codes as a starting point. The original Elixhauser ICD-9-CM coding algorithm has been revised

twice, and the most recent revision (version 3.0) was posted on the website of the Agency for Healthcare Research and Quality (we refer to this as the Elixhauser AHRQ-Web ICD-9-CM coding algorithm).[10] This revised algorithm contains more ICD-9-CM codes than the original Elixhauser ICD-9-CM coding algorithm, but excludes cardiac arrhythmias from the list of comorbidities.

In 1992, the 10th Revision of ICD (ICD-10)[11] was introduced by the World Health Organization as a potential enhancement to ICD-9-CM. An obvious merit of ICD-10 is that it contains more codes than ICD-9-CM, allowing for the richer coding of clinical information.[12] ICD-10 coding uses a new alphanumeric system and many codes are not directly convertible to corresponding ICD-9-CM codes. Therefore, ICD-10 coding algorithms to define comorbidities must be developed.

Recently, Halfon et al[13] in Switzerland and Sundararajan et al[14] in Australia independently developed ICD-10 coding algorithms to define Charlson comorbidities. Although many of the ICD-10 codes are similar, there are discrepancies between the 2 coding algorithms, which may relate to the different approaches used to developing the algorithms. Halfon et al[13] used clinical judgment surrounding individual ICD-9-CM codes following Charlson's clinical definitions for comorbidities. In contrast, Sundararajan et al[14] employed a computerized ICD-9-CM and ICD-10 mapping file to translate the ICD-9-CM codes to ICD-10 codes. An ICD-10 coding algorithm has not yet been reported for Elixhauser comorbidities.

The objectives of this study were: (1) to develop ICD-10 coding algorithms for Charlson and Elixhauser comorbidities by a consensual approach among 3 international research groups in Switzerland, Australia and Canada, (2) to back-translate the newly developed ICD-10 coding algorithms into ICD-9-CM codes to improve the original Deyo (for Charlson comorbidities) and Elixhauser ICD-9-CM coding algorithms, (3) to use administrative data from a Canadian health region to demonstrate the degree of consistency between ICD-9-CM and ICD-10 coding algorithms in defining these comorbidities, and (4) to assess the performance of the coding algorithms for predicting in-hospital mortality.

METHODS

Development of ICD-10 Coding Algorithms for Charlson Comorbidities

Step 1

Three lists of ICD-10 codes were generated for the ICD-10 Charlson comorbidities. List 1 contained all codes in the ICD-10 coding algorithms for defining Charlson comorbidities developed by Halfon et al[13] and Sundararajan et al.[14] For List 2, 2 coders with clinical and coding experience in ICD-9-CM and ICD-10 independently coded the 17 Charlson comorbidities using the ICD-10 Canadian version (International Statistical Classification of Disease and Related Health Problems, Tenth Revision, Canada [ICD-10-CA]) computerized code finder.[15] We provided the coders with 1 clinical term per comorbidity (such as myocardial infarction). They were instructed to find all codes relevant to each clinical term.

the 2 coders met to compare their codes to generate a consensus list of ICD-10 codes. If no consensus could be reached, a physician was involved in the discussion until consensus was achieved. For List 3, the 2 coders above recoded the 17 comorbidities. At this time, clinical terms taken from the ICD-9-CM manual for all ICD-9-CM codes that were developed by Deyo et al[3] for each Charlson comorbidity were provided to the coders. The 2 coders followed a methodology similar to that used in generating List 2 described above.

Step 2

The 3 lists were combined for a comprehensive list, with their specific ICD-10 codes and their clinical descriptions as listed in the ICD-10 manual. Four physicians reviewed the comprehensive coding list independently and then met to discuss whether each condition met the clinical definition and whether there were missing conditions based on Charlson's clinical definition of comorbidities. For the few codes without consensus, 1 additional physician was consulted to finalize this coding algorithm.

Development of the ICD-10 Coding Algorithm for Elixhauser Comorbidities

Because 6 comorbidities are common to the Charlson and Exliahsuer lists (ie, congestive heart failure, peripheral vascular disease, chronic pulmonary disease, hemiplegia/paraplegia, AIDS/HIV, and metastatic solid tumors), all codes allocated to these 6 comorbidities in the aforementioned process were retained as is. For the remaining 24 Elixhauser comorbidities, we proceeded as following.

Step 1

Three lists of ICD-10 codes were generated for the ICD-10 Elixhauser comorbidities. For List 1, Elixhauser's clinical terms were directly translated into ICD-10. This was performed initially by the 2 coders independent of each other using the ICD-10-CA computerized code finder.[15] Afterward, they met to create a consensus list. If any disagreement between coders occurred, a physician discussed the discrepancies with them. For List 2, the same 2 coders recoded the 30 comorbidities. At this time, they coded each clinical term taken from the ICD-9-CM manual for all ICD-9-CM codes in Elixhauser's original coding algorithm. The same method described in List 1 was followed to generate List 2. For List 3, Elixhauser's original ICD-9-CM codes were converted to ICD-10 using a cross-table mapping algorithm from the National Centre for Classification in Health at the University of Sydney in Australia.[16,17]

Step 2

The 3 lists were combined to yield a comprehensive list, with their specific ICD-10 codes and their clinical descriptions. Four physicians reviewed the comprehensive coding list independently. They were instructed to include conditions that they judged to fall under the general clinical label for each of the comorbidity variables. They were also asked to propose including any conditions that were relevant but missing from the list. They then met to discuss whether each condition should be included. For the few codes without

consensus, 1 additional physician was consulted to finalize this coding algorithm.

Development of Enhanced ICD-9-CM Coding Algorithms

The enhanced ICD-9-CM coding algorithms for Charlson and Elixhauser comorbidities were developed for the following reasons. (1) While reviewing ICD-10 code descriptions for our finalized coding algorithms and ICD-9-CM code descriptions for Deyo's and Elixhauser's original ICD-9-CM coding algorithms, we noticed discrepancies among coding algorithms for some conditions. The discrepancies may be related to different taxonomy in ICD-10 and ICD-9-CM, and to lack of explicit criteria of clinical definitions to guide coding development. Therefore, investigators are likely to assign different sets of codes to the same comorbidities based on their interpretation of clinical definitions. (2) Deyo's and Elixhauser's original ICD-9-CM coding algorithms for defining the 6 shared comorbidities are not identical. Inconsistent ICD-9-CM codes for these comorbidities are problematic for development of 1 set of ICD-10 codes for these comorbidities. The inconsistency in coding algorithms is also an issue while comparing studies that used different coding algorithms. (3) The ICD-9-CM coding system is still widely used. Comparable ICD-10 and ICD-9-CM coding algorithms could unify methodology for measuring comorbidities.

The steps taken to develop the enhanced ICD-9-CM algorithms were as follows.

Step 1

The ICD-10 codes for Charlson and Elixhauser comorbidities were described using clinical terms from the ICD-10 manual. The descriptions were recoded by 1 coder and 1 physician independently using the ICD-9-CM code finder.[18]

Step 2

The coder and physician examined the 2 lists of back-translated ICD-9-CM codes together and decided on whether to include specific codes. This process involved discussion and frequent reference to both the ICD-9-CM and ICD-10 manuals. In case of no consensus, the principal investigator (H.Q.) chose codes after consulting an additional coder and physician.

Application of Algorithms to ICD-9-CM and ICD-10 Data

The coding algorithms were applied to hospital discharge data for patients discharged between April l, 2001, and March 31, 2003, from Calgary Health Region hospitals, in the province of Alberta, Canada. The Calgary Health Region has coded the data using ICD-10-CA since April 1, 2002. The first 16 diagnostic coding fields (including major and secondary diagnostic codes) were extracted for each hospital separation for patients 18 years of age and older. For patients with more than 1 admission in each fiscal year, only the first admission for the patient was included.

For the ICD-9-CM data from fiscal year 2001 (April 1, 2001, through March 31, 2002), Deyo's algorithm, Elixhauser's original algorithm, and Elixhauser's AHRQ-Web ICD-9-CM coding algorithm were used to define comorbidities and then the enhanced ICD-9-CM coding algorithms were used to redefine these comorbidities. For the ICD-10 data from fiscal year 2002 (April 1, 2002, through March 31, 2003), the ICD-10 coding algorithms were used to define the comorbidities. We did not employ the Diagnosis Related Group (DRG) screen option described by Elixhauser et al[2] because the objective of this work was to develop algorithms to define comorbidities in undifferentiated hospital discharge data, and to then directly assess how well comorbidities derived from those algorithms predict mortality.

Canadian data contain a "diagnosis-type" indicator for each diagnosis that specifies the timing of specific diagnoses. The code flags diagnoses arising some time after hospital admission, and distinguishes such diagnoses from those present at time of admission.[19] This permitted us to assess the performance of each of the coding algorithms after exclusion of conditions that arose some time after admission.

Statistical Analysis

The frequency of individual comorbidities was calculated for the 3 lists of coding algorithms for Charlson comorbidities (ie, Deyo's original ICD-9-CM, enhanced ICD-9-CM and ICD-10 coding algorithms) and then for the 4 coding algorithms for Elixhauser comorbidities (ie, Elixhauser's original ICD-9-CM, Elixhauser's AHRQ-Web ICD-9-CM, enhanced ICD-9-CM, and ICD-10 coding algorithms) when conditions arising after hospitalization were excluded through use of the diagnosis type indicator, and also when such diagnoses were not excluded (as would occur in jurisdictions that do not have diagnosis type indicators).

The performance of the 7 coding algorithms for predicting in-hospital mortality was assessed using fourteen logistic regression models. The first 7 logistic models were fit using comorbidities that included conditions present at admission or after admission. The other 7 models were fit using comorbididites that were only present at baseline. Six of the logistic regression models used individual Charlson comorbidities as independent variables and the remaining 8 models used individual Elixhauser comorbidities as independent variables. In all models, the coded variable for AIDS/HIV was excluded due to its low frequency.

The C-statistic and the log likelihood statistic ($-2\ln L$) were used to compare the performance of each coding algorithm in predicting in-hospital mortality. The C-statistic is a measure of a model's ability to discriminate those who die of those who do not die in hospital.[20] The log likelihood statistic shows contribution of comorbidities to the decrease of deviance (between models with and without comorbidities).[21] A nonparametric method described by Delong et al[22] was employed to test statistical significance of differences in the C-statistic between the original and enhanced ICD-9-CM coding algorithms.

RESULTS

Coding Algorithms

ICD-9-CM and ICD-10 coding algorithms for Charlson comorbidities and Elixhauser comorbidities are presented in Tables 1 and 2, respectively. The second column in Table 1 shows Deyo's original ICD-9-CM coding algorithm and the same column in Table 2 shows Elixhauser's original ICD-9-CM coding algorithm. Elixhauser's AHRQ-Web ICD-9-CM coding algorithm is shown in the third column of Table 2. The ICD-10 coding algorithms for these comorbidities are shown in the third column of table 1 and in the fourth column of Table 2. The fourth column of Table 1 and the fifth column of Table 2 present the enhanced ICD-9-CM coding algorithms for

Charlson and Elixhauser comorbidities (SAS codes available: http://www.chaps.ucalgary.ca/sas.htm).

Frequency of Comorbidities

We studied 56,585 patients in fiscal year 2001 (ICD-9-CM data) and 58,805 patients in fiscal year 2002 (ICD-10 data) from the Calgary Health Region discharge database. Of these, 62.8% were women in 2001 and 62.5% in 2002. The mean age was 50.8 years in 2001 and 50.6 years in 2002 data. The in-hospital mortality rate was 2.2% in 2001 and 2.2% in 2002. The frequencies for most of the Charlson comorbidities were very similar across the 3 coding algorithms but varied for 4 comorbidities (Table 3). Differences between Deyo's original ICD-9-CM and the enhanced ICD-9-CM coding algorithm were 1.9% versus 2.9% for peripheral vascular

TABLE 1. ICD-9-CM and ICD-10 Coding Algorithms for Charlson Comorbidities

Comorbidities	Deyo's ICD-9-CM	ICD-10	Enhanced ICD-9-CM
Myocardial infarction	410.x, 412.x	I21.x, I22.x, I25.2	410.x, 412.x
Congestive heart failure	428.x	I09.9, I11.0, I13.0, I13.2, I25.5, I42.0, I42.5–I42.9, I43.x, I50.x, P29.0	398.91, 402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, 425.4–425.9, 428.x
Peripheral vascular disease	443.9, 441.x, 785.4, V43.4 Procedure 38.48	I70.x, I71.x, I73.1, I73.8, I73.9, I77.1, I79.0, I79.2, K55.1, K55.8, K55.9, Z95.8, Z95.9	093.0, 437.3, 440.x, 441.x, 443.1–443.9, 47.1, 557.1, 557.9, V43.4
Cerebrovascular disease	430.x–438.x	G45.x, G46.x, H34.0, I60.x–I69.x	362.34, 430.x–438.x
Dementia	290.x	F00.x–F03.x, F05.1, G30.x, G31.1	290.x, 294.1, 331.2
Chronic pulmonary disease	490.x–505.x, 506.4	I27.8, I27.9, J40.x–J47.x, J60.x–J67.x, J68.4, J70.1, J70.3	416.8, 416.9, 490.x–505.x, 506.4, 508.1, 508.8
Rheumatic disease	710.0, 710.1, 710.4, 714.0–714.2, 714.81, 725.x	M05.x, M06.x, M31.5, M32.x–M34.x, M35.1, M35.3, M36.0	446.5, 710.0–710.4, 714.0–714.2, 714.8, 725.x
Peptic ulcer disease	531.x–534.x	K25.x–K28.x	531.x–534.x
Mild liver disease	571.2, 571.4–571.6	B18.x, K70.0–K70.3, K70.9, K71.3–K71.5, K71.7, K73.x, K74.x, K76.0, K76.2–K76.4, K76.8, K76.9, Z94.4	070.22, 070.23, 070.32, 070.33, 070.44, 070.54, 070.6, 070.9, 570.x, 571.x, 573.3, 573.4, 573.8, 573.9, V42.7
Diabetes without chronic complication	250.0–250.3, 250.7	E10.0, E10.1, E10.6, E10.8, E10.9, E11.0, E11.1, E11.6, E11.8, E11.9, E12.0, E12.1, E12.6, E12.8, E12.9, E13.0, E13.1, E13.6, E13.8, E13.9, E14.0, E14.1, E14.6, E14.8, E14.9	250.0–250.3, 250.8, 250.9
Diabetes with chronic complication	250.4–250.6	E10.2–E10.5, E10.7, E11.2–E11.5, E11.7, E12.2–E12.5, E12.7, E13.2–E13.5, E13.7, E14.2–E14.5, E14.7	250.4–250.7
Hemiplegia or paraplegia	344.1, 342.x	G04.1, G11.4, G80.1, G80.2, G81.x, G82.x, G83.0–G83.4, G83.9	334.1, 342.x, 343.x, 344.0–344.6, 344.9
Renal disease	582.x, 583–583.7, 585.x, 586.x, 588.x	I12.0, I13.1, N03.2–N03.7, N05.2–N05.7, N18.x, N19.x, N25.0, Z49.0–Z49.2, Z94.0, Z99.2	403.01, 403.11, 403.91, 404.02, 404.03, 404.12, 404.13, 404.92, 404.93, 582.x, 583.0–583.7, 585.x, 586.x, 588.0, V42.0, V45.1, V56.x
Any malignancy, including lymphoma and leukemia, except malignant neoplasm of skin	140.x–172.x, 174.x.–195.8, 200.x–208.x	C00.x–C26.x, C30.x–C34.x, C37.x–C41.x, C43.x, C45.x–C58.x, C60.x–C76.x, C81.x–C85.x, C88.x, C90.x–C97.x	140.x–172.x, 174.x–195.8, 200.x–208.x, 238.6
Moderate or severe liver disease	456.0–456.21, 572.2–572.8	I85.0, I85.9, I86.4, I98.2, K70.4, K71.1, K72.1, K72.9, K76.5, K76.6, K76.7	456.0–456.2, 572.2–572.8
Metastatic solid tumor	196.x–199.1	C77.x–C80.x	196.x–199.x
AIDS/HIV	042.x–044.x	B20.x–B22.x, B24.x	042.x–044.x

TABLE 2. ICD-9-CM and ICD-10 Coding Algorithms for Elixhauser Comorbidities

Comorbidities	Elixhauser's Original ICD-9-CM	Elixhauser AHRQ-Web ICD-9-CM	ICD-10	Enhanced ICD-9-CM
Congestive heart failure	398.91, 402.11, 402.91, 404.11, 404.13, 404.91, 404.93, 428.x	398.91, 402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, 428.x	I09.9, I11.0, I13.0, I13.2, I25.5, I42.0, I42.5–I42.9, I43.x, I50.x, P29.0	398.91, 402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, 425.4–425.9, 428.x
Cardiac arrhythmias	426.10, 426.11, 426.13, 426.2–426.53, 426.6–426.8, 427.0, 427.2, 427.31, 427.60, 427.9, 785.0, V45.0, V53.3	—	I44.1–I44.3, I45.6, I45.9, I47.x–I49.x, R00.0, R00.1, R00.8, T82.1, Z45.0, Z95.0	426.0, 426.13, 426.7, 426.9, 426.10, 426.12, 427.0–427.4, 427.6–427.9, 785.0, 996.01, 996.04, V45.0, V53.3
Valvular disease	093.2, 394.0–397.1, 424.0–424.91, 746.3–746.6, V42.2, V43.3	093.2, 394.x–397.1, 397.9, 424.x, 746.3–746.6, V42.2, V43.3	A52.0, I05.x–I08.x, I09.1, I09.8, I34.x–I39.x, Q23.0–Q23.3, Z95.2–Z95.4	093.2, 394.x–397.x, 424.x, 746.3–746.6, V42.2, V43.3
Pulmonary circulation disorders	416.x, 417.9	416.x, 417.9	I26.x, I27.x, I28.0, I28.8, I28.9	415.0, 415.1, 416.x, 417.0, 417.8, 417.9
Peripheral vascular disorders	440.x, 441.2, 441.4, 441.7, 441.9, 443.1–443.9, 447.1, 557.1, 557.9, V43.4	440. x, 441.x, 442.x, 443.1–443.9, 447.1, 557.1, 557.9, V43.4	I70.x, I71.x, I73.1, I73.8, I73.9, I77.1, I79.0, I79.2, K55.1, K55.8, K55.9, Z95.8, Z95.9	093.0, 437.3, 440.x, 441.x, 443.1– 443.9, 447.1, 557.1, 557.9, V43.4
Hypertension, uncomplicated	401.1, 401.9	401.1, 401.9, 642.0	I10.x	401.x
Hypertension, complicated	402.10, 402.90, 404.10, 404.90, 405.1, 405.9	401.0, 402.x–405.x, 642.1, 642.2, 642.7, 642.9	I11.x–I13.x, I15.x	402.x–405.x
Paralysis	342.0, 342.1, 342.9–344.x	342.x–344.x, 438.2–438.5	G04.1, G11.4, G80.1, G80.2, G81.x, G82.x, G83.0–G83.4, G83.9	334.1, 342.x, 343.x, 344.0–344.6, 344.9
Other neurological disorders	331.9, 332.0, 333.4, 333.5, 334.x, 335.x, 340.x, 341.1–341.9, 345.0, 345.1, 345.4, 345.5, 345.8, 345.9, 348.1, 348.3, 780.3, 784.3	330.x–331.x, 332.0, 333.4, 333.5, 334.x–335.x, 340, 341.1–341.9, 345.x, 347.x, 780.3, 784.3	G10.x–G13.x, G20.x–G22.x, G25.4, G25.5, G31.2, G31.8, G31.9, G32.x, G35.x–G37.x, G40.x, G41.x, G93.1, G93.4, R47.0, R56.x	331.9, 332.0, 332.1, 333.4, 333.5, 333.92, 334.x–335.x, 336.2, 340.x, 341.x, 345.x, 348.1, 348.3, 780.3, 784.3
Chronic pulmonary disease	490–492.8, 493.00–493.91, 494.x–505.x, 506.4	490x–492.x, 493.x, 494x–505.x, 506.4	I27.8, I27.9, J40.x–J47.x, J60.x–J67.x, J68.4, J70.1, J70.3	416.8, 416.9, 490.x –505.x, 506.4, 508.1, 508.8
Diabetes, uncomplicated	250.0–250.3	250.0–250.3, 648.0	E10.0, E10.1, E10.9, E11.0, E11.1, E11.9, E12.0, E12.1, E12.9, E13.0, E13.1, E13.9, E14.0, E14.1, E14.9	250.0–250.3
Diabetes, complicated	250.4–250.7, 250.9	250.4–250.9, 775.1	E10.2–E10.8, E11.2–E11.8, E12.2–E12.8, E13.2–E13.8, E14.2–E14.8	250.4–250.9
Hypothyroidism	243–244.2, 244.8, 244.9	243–244.2, 244.8, 244.9	E00.x–E03.x, E89.0	240.9, 243.x, 244.x, 246.1, 246.8
Renal failure	403.11, 403.91, 404.12, 404.92, 585.x, 586.x, V42.0, V45.1, V56.0, V56.8	403.01, 403.11, 403.91, 404.02, 404.03, 404.12, 404.13, 404.92, 404.93, 585.x, 586.x, V42.0, V45.1, V56.x	I12.0, I13.1, N18.x, N19.x, N25.0, Z49.0–Z49.2, Z94.0, Z99.2	403.01, 403.11, 403.91, 404.02, 404.03, 404.12, 404.13, 404.92, 404.93, 585.x, 586.x, 588.0, V42.0, V45.1, V56.x
Liver disease	070.32, 070.33, 070.54, 456.0, 456.1, 456.2, 571.0, 571.2–571.9, 572.3, 572.8, V42.7	070.22, 070.23, 070.32, 070.33, 070.44, 070.54, 456.0, 456.1, 456.20, 571.0, 571.2–571.9, 572.3, 572.8, V42.7	B18.x, I85.x, I86.4, I98.2, K70.x, K71.1, K71.3–K71.5, K71.7, K72.x–K74.x, K76.0, K76.2–K76.9, Z94.4	070.22, 070.23, 070.32, 070.33, 070.44, 070.54, 070.6, 070.9, 456.0–456.2, 570.x, 571.x, 572.2–572.8, 573.3, 573.4, 573.8, 573.9, V42.7

(Continued)

TABLE 2. *(Continued)*

Comorbidities	Elixhauser's original ICD-9-CM	Elixhauser AHRQ-Web ICD-9-CM	ICD-10	Enhanced IC-9-CM
Peptic ulcer disease excluding bleeding	531.70, 531.90, 532.70, 532.90, 533.70, 533.90, 534.70, 534.90, V12.71	531.41, 531.51, 531.61, 531.7, 531.91, 532.41, 532.51, 532.61, 532.7, 532.91, 533.41, 533.51, 533.61, 533.7, 533.91, 534.41, 534.51, 534.61, 534.7, 534.91	K25.7, K25.9, K26.7, K26.9, K27.7, K27.9, K28.7, K28.9	531.7, 531.9, 532.7, 532.9, 533.7, 533.9, 534.7, 534.9
AIDS/HIV	042.x–044.x	042.x–044.x	B20.x–B22.x, B24.x	042.x–044.x
Lymphoma	200.x–202.3x, 202.5–203.0, 203.8, 238.6, 273.3, V10.71, V10.72, V10.79	200.x–202.3, 202.5–203.0, 203.8, 238.6, 273.3	C81.x–C85.x, C88.x, C96.x, C90.0, C90.2	200.x–202.x, 203.0, 238.6
Metastatic cancer	196.x–199.x	196.x–199.x	C77.x–C80.x	196.x–199.x
Solid tumor without metastasis	140.x–172.x, 174.x, 175.x, 179.x–195.x, V10.x	140.x–172.x, 174.x, 175.x, 179.x–195.x	C00.x–C26.x, C30.x–C34.x, C37.x–C41.x, C43.x, C45.x–C58.x, C60.x–C76.x, C97.x	140.x–172.x, 174.x–195.x
Rheumatoid arthritis/ collagen vascular diseases	701.0, 710.x, 714.x, 720.x, 725.x	701.0, 710.x, 714.x, 720.x, 725.x	L94.0, L94.1, L94.3, M05.x, M06.x, M08.x, M12.0, M12.3, M30.x, M31.0–M31.3, M32.x–M35.x, M45.x, M46.1, M46.8, M46.9	446.x, 701.0, 710.0–710.4, 710.8, 710.9, 711.2, 714.x, 719.3, 720.x, 725.x, 728.5, 728.89, 729.30
Coagulopathy	286.x, 287.1, 287.3–287.5	286.x, 287.1, 287.3–287.5	D65–D68.x, D69.1, D69.3–D69.6	286.x, 287.1, 287.3–287.5
Obesity	278.0	278.0	E66.x	278.0
Weight loss	260.x–263.x	260.x–263.x, 783.2	E40.x–E46.x, R63.4, R64	260.x–263.x, 783.2, 799.4
Fluid and electrolyte disorders	276.x	276.x	E22.2, E86.x, E87.x	253.6, 276.x
Blood loss anemia	280.0	280.0, 648.2	D50.0	280.0
Deficiency anemia	280.1–281.9, 285.9	280.1–281.9, 285.2, 285.9	D50.8, D50.9, D51.x–D53.x	280.1–280.9, 281.x
Alcohol abuse	291.1, 291.2, 291.5–291.9, 303.9, 305.0, V113	291.0–291.3, 291.5, 291.8, 291.9, 303.x, 305.0	F10, E52, G62.1, I42.6, K29.2, K70.0, K70.3, K70.9, T51.x, Z50.2, Z71.4, Z72.1	265.2, 291.1–291.3, 291.5–291.9, 303.0, 303.9, 305.0, 357.5, 425.5, 535.3, 571.0–571.3, 980.x, V11.3
Drug abuse	292.0, 292.82–292.89, 292.9, 304.0, 305.2–305.9	292.0, 292.82–292.89, 292.9, 304.x, 305.2–305.9, 648.3	F11.x–F16.x, F18.x, F19.x, Z71.5, Z72.2	292.x, 304.x, 305.2–305.9, V65.42
Psychoses	295.x–298.x, 299.1	295.x–298.x, 299.1	F20.x, F22.x–F25.x, F28.x, F29.x, F30.2, F31.2, F31.5	293.8, 295.x, 296.04, 296.14, 296.44, 296.54, 297.x, 298.x
Depression	300.4, 301.12, 309.0, 309.1, 311	300.4, 301.12, 309.0, 309.1, 311	F20.4, F31.3–F31.5, F32.x, F33.x, F34.1, F41.2, F43.2	296.2, 296.3, 296.5, 300.4, 309.x, 311

disease, 0.5% versus 1.3% for mild liver disease, and 1.0% versus 2.3% for renal disease. Meanwhile, dementia was present in 0.5% of cases for Deyo's, 2.8% for the ICD-10 and 1.1% for the enhanced ICD-9-CM coding algorithm. The difference for these 4 comorbidities persisted when conditions that arose after admission were excluded.

Most of the Elixhauser comorbidities had similar frequencies across the 4 coding algorithms (Table 4). Differences between Elixhauser's original ICD-9-CM and the enhanced ICD-9-CM coding algorithms were seen for the following variables: solid tumor without metastasis (10.4% vs. 7.0%), deficiency anemia (4.6% vs. 1.2%), psychoses (3.6% vs. 1.9%), and depression (3.4% vs. 5.4%). Elixhauser's AHRQ-Web algorithm and the enhanced ICD-9-CM revealed differences in the

prevalence of peptic ulcer disease excluding bleeding (0.1% vs. 0.7%), blood loss anemia (2.0% vs. 0.8%), deficiency anemia (5.7% vs. 1.2%), psychoses (3.6% vs. 1.9%), and depression (4.4% vs. 5.4%). When conditions arising after admission were excluded, differences in the prevalence of variables across algorithms were persistent.

Model Performance

The model performance for Charlson comorbidities that were defined using ICD-10 and enhanced ICD-9-CM coding algorithms was slightly better than for those defined using Deyo's ICD-9-CM coding algorithm (Table 5). For models containing conditions present at or after admission, the C-statistic for Deyo's ICD-9-CM algorithm (0.842) was

TABLE 3. Frequency of Charlson Comorbidities (%)

Comorbidities	Present At or After Admission			Present At Admission		
	Deyo's ICD-9-CM (% of 56,585 in 2001)	ICD-10 (% of 58,805 in 2002)	Enhanced ICD-9-CM (% of 56,585 in 2001)	Deyo's ICD-9-CM (% of 56,585 in 2001)	ICD-10 (% of 58,805 in 2002)	Enhanced ICD-9-CM (% of 56,585 in 2001)
Myocardial infarction	7.7	7.3	7.7	7.5	7.0	7.5
Congestive heart failure	5.2	5.0	5.7	4.8	4.7	5.4
Peripheral vascular disease	1.9	2.5	2.9	1.9	2.5	2.9
Cerebrovascular disease	4.1	4.2	4.1	4.0	4.0	4.0
Dementia	0.5	2.8	1.1	0.5	2.8	1.1
Chronic pulmonary disease	9.1	8.5	9.5	9.1	8.5	9.4
Rheumatologic disease	1.5	1.3	1.6	1.5	1.3	1.6
Peptic ulcer disease	1.3	1.2	1.3	1.3	1.1	1.3
Mild liver disease	0.5	1.1	1.3	0.5	1.1	1.3
Diabetes without chronic complication	7.0	7.2	7.1	7.0	7.2	7.1
Diabetes with chronic complication	1.4	1.5	1.5	1.4	1.5	1.5
Hemiplegia or paraplegia	0.9	1.4	1.2	0.9	1.3	1.1
Renal disease	1.0	2.6	2.3	0.9	2.6	2.3
Any malignancy, including leukemia and lymphoma	7.9	8.2	7.9	7.9	8.2	7.9
Moderate or severe liver disease	0.5	0.5	0.5	0.4	0.4	0.4
Metastatic solid tumor	3.3	3.2	3.3	3.3	3.2	3.3
AIDS/HIV	0.1	0.1	0.1	0.1	0.1	0.1

Note: the proportion of patient without any of Charlson comorbidities at or after admission was 65.5% for Deyo's ICD-9-CM coding algorithm, 64.2% for ICD-10, and 63.8% for enhanced ICD-9-CM.

lower than that for the ICD-10 algorithm (0.860) and for the enhanced ICD-9-CM algorithm (0.859). These results were supported by a log likelihood statistic that was highest for the ICD-10 algorithm (2507.7), second highest for the enhanced ICD-9-CM algorithm (2393.8) and lowest for Deyo's ICD-9-CM algorithm (2220.8).

For models based on Elixhauser comorbidities that were present at or after admission, the C-statistic for the enhanced ICD-9-CM algorithm (0.878) was slightly better than for Elixhauser's original ICD-9-CM algorithm (0.868) and also better than for Elixhauser's AHRQ-Web ICD-9-CM algorithm (0.860).

For models based on conditions that were present at admission only, the C-statistic was 0.822 for Deyo's ICD-9-CM algorithm, 0.845 for our ICD-10 algorithm and 0.837 for our enhanced ICD-9-CM algorithm for Charlson comorbidities. The corresponding C statistic values were 0.849 for Elixhauser's original ICD-9-CM algorithm, 0.838 for Elixhauser's AHRQ-Web ICD-9-CM algorithm, 0.854 for our ICD-10 algorithm, and 0.857 for our enhanced ICD-9-CM algorithm for Elixhauser comorbidities.

Nonparametric tests suggest that the difference in C-statistics between the enhanced ICD-9-CM algorithms and the original Deyo/Elixhauser algorithms are statistically significant at $P < 0.001$ for both the Charlson and Elixhauser comparisons (Table 5).

DISCUSSION

We initially developed ICD-10 coding algorithms for defining Charlson and Elixhauser comorbidities and then revised the original Deyo and Elixhauser ICD-9-CM coding

algorithms to generate enhanced ICD-9-CM coding algorithms. We applied these coding algorithms in ICD-9-CM and ICD-10 data to observe their performance. Frequencies for most comorbidities were similar across algorithms but a few comorbidities had higher frequencies according to the ICD-10 algorithms relative to the original Deyo and Elixhauser ICD-9-CM coding algorithms. The enhanced ICD-9-CM coding algorithms corrected the discrepancies and resulted in similar frequencies with the ICD-10 coding algorithms. The ICD-10 and enhanced ICD-9-CM coding algorithms performed slightly better in predicting in-hospital mortality than the original Deyo/Elixhauser algorithms and also were better than the recently updated Elixhauser AHRQ-Web ICD-9-CM coding algorithm.

Physicians reviewed all of the descriptions of codes included in Deyo's and Elixhauser's coding algorithms. Through this careful review process, some codes were deleted or added. Frequencies for 13 Charlson comorbidities remained similar using either Deyo's ICD-9-CM, ICD-10 or the enhanced ICD-9-CM coding algorithm. Peripheral vascular disease, mild liver disease and renal disease were more frequent for the ICD-10 and enhanced ICD-9-CM coding algorithms than for the original Deyo ICD-9-CM coding algorithm. It should be noted that some, but not all, of the ICD-9-CM algorithm 'enhancement' arises from our addition of codes that were added to the ICD-9-CM coding system close to the time, or after, development of the original Deyo coding algorithm (and other related coding algorithms). For example, we included hypertensive renal disease with renal failure (403.x1), a code introduced in 1989, to the coding definition for renal disease; we also added chronic hepatitis B

TABLE 4. Frequency of Elixhauser Comorbidities (%)

Comorbidities	Present At or After Admission				Present at Admission			
	Original ICD-9-CM (% of 56,585 in 2001)	AHRQ-Web ICD-9-CM (% of 56,585 in 2001)	ICD-10 (% of 58,805 in 2002)	Enhanced ICD-9-CM (% of 56,585 in 2001)	Original ICD-9-CM (% of 56,585 in 2001)	AHRQ-Web ICD-9-CM (% of 56,585 in 2001)	ICD-10 (% of 58,805 in 2002)	Enhanced ICD-9-CM (% of 56,585 in 2001)
Congestive heart failure	5.4	5.4	5.0	5.7	5.1	5.1	4.7	5.4
Cardiac arrhythmias	8.1	—	9.1	9.5	7.7	—	8.4	8.8
Valvular disease	2.8	2.8	2.6	2.8	2.8	2.8	2.6	2.8
Pulmonary circulation disorders	0.7	0.7	1.3	1.3	0.7	0.7	1.2	1.2
Peripheral vascular disorders	2.7	2.9	2.5	2.9	2.7	2.9	2.5	2.9
Hypertension	19.3	20.9	21.2	20.8	19.2	20.9	21.1	20.8
Hypertension, uncomplicated	19.2	19.2	19.8	19.2	19.1	19.2	19.7	19.2
Hypertension, complicated	0.1	1.7	1.4	1.6	0.1	1.7	1.4	1.6
Paralysis	1.2	1.5	1.4	1.2	1.1	1.5	1.3	1.1
Other neurological disorders	3.4	4.0	3.7	3.5	3.2	3.9	3.5	3.3
Chronic pulmonary disease	9.1	9.1	8.5	9.5	9.1	9.1	8.5	9.4
Diabetes, uncomplicated	6.7	6.7	6.9	6.7	6.7	6.7	6.9	6.7
Diabetes, complicated	1.6	1.7	1.8	1.7	1.6	1.7	1.8	1.7
Hypothyroidism	5.6	5.5	5.0	5.6	5.6	5.5	5.0	5.6
Renal failure	2.2	2.2	2.6	2.2	2.2	2.2	2.6	2.2
Liver disease	1.0	1.1	1.3	1.4	1.0	1.0	1.2	1.4
Peptic ulcer disease excluding bleeding	1.3	0.1	0.6	0.7	1.2	0.04	0.6	0.7
AIDS/HIV	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Lymphoma	0.7	0.6	0.7	0.6	0.7	0.6	0.7	0.6
Metastatic cancer	3.3	3.3	3.2	3.3	3.3	3.3	3.2	3.3
Solid tumor without metastasis	10.4	7.0	7.1	7.0	10.4	7.0	7.1	7.0
Rheumatoid arthritis/collagen vascular diseases	1.7	1.7	1.6	1.9	1.7	1.7	1.6	1.9
Coagulopathy	1.4	1.4	1.4	1.4	1.1	1.1	1.1	1.1
Obesity	1.8	1.9	2.0	1.8	1.8	1.9	2.0	1.8
Weight loss	0.3	0.3	0.5	0.6	0.3	0.3	0.5	0.5
Fluid and electrolyte disorders	5.2	5.2	4.9	5.3	4.2	4.2	4.0	4.2
Blood loss anemia	0.8	2.0	0.7	0.8	0.7	1.4	0.7	0.7
Deficiency anemia	4.6	5.7	1.3	1.2	4.1	5.1	1.3	1.2
Alcohol abuse	4.2	4.4	3.7	4.5	4.2	4.4	3.6	4.5
Drug abuse	1.8	2.4	1.9	2.4	1.8	2.3	1.9	2.3
Psychoses	3.6	3.6	1.6	1.9	3.5	3.5	1.5	1.8
Depression	3.4	4.4	4.7	5.4	3.3	4.3	4.6	5.3

Note: the proportion of patient without any of Elixhauser comorbidities at or after admission was 47.1% for Elixhauser's original ICD-9-CM coding algorithm, 47.2% for Elixhauser's AHRQ-Web ICD-9-CM, 49.0% for ICD-10, and 47.3% for enhanced ICD-9-CM.

(070.22), a code introduced in 1994, to the coding definition for mild liver disease. Our enhanced ICD-9-CM coding algorithm for Charlson comorbidities also included a few more preexisting codes than Deyo's. For example, we added specified peripheral arterial diseases (444.3–444.8) and atherosclerosis (440.x) to peripheral vascular disease. The higher frequency of dementia in ICD-10 data relative to ICD-9-CM data reflects the different taxonomies between the ICD-10 and ICD-9-CM coding systems. The ICD-10 coding system classifies dementia according to syndromes (organic mental disease, F code) and etiology (brain disease, G code). Therefore, the ICD-10 coding system is more likely to code dementia than ICD-9-CM.

For Elixhauser's measures, 4 comorbidities (ie, solid tumor without metastasis, deficiency anemia, psychoses, and depression) had frequency differences between the original Elixhauser ICD-9-CM algorithm and the enhanced ICD-9-CM coding algorithm. In the enhanced ICD-9-CM coding algorithms, the 'V' codes for history of cancer were excluded. This decision was made due to the uncertainty of the length of history. For deficiency anemia, we excluded unspecified anemia (285.9) from the Elixhauser codes. The major change to the Elixhauser algorithm influenced the frequency of depression and psychosis. In the enhanced coding algorithms, major depressive disorder, single episode (ICD-9-CM: 296.2), major depressive disorder, recurrent episode (296.3)

TABLE 5. Performance of Comorbidities in Predicting In-Hospital Mortality by Coding Algorithms

Charlson Comorbidities	Present At or After Admission				Present at Admission			
	Deyo's ICD-9-CM (in 2001 Data)	ICD-10 (in 2002 Data)	Enhanced ICD-9-CM (in 2001 Data)	$P*$ (in 2001 Data)	Deyo's ICD-9-CM (in 2001 Data)	ICD-10 (in 2002 Data)	Enhanced ICD-9-CM (in 2001 Data)	$P*$ (in 2001 Data)
C-statistic	0.842	0.860	0.859	<0.001	0.822	0.845	0.837	<0.001
Log likelihood statistic	2220.8	2507.7	2393.8		1902.6	2251.5	2063.9	

Elixhauser comorbidities	Present At or After Admission					Present at Admission				
	Original ICD-9-CM (in 2001 data)	AHRQ-Web ICD-9-CM (in 2001 data)	ICD-10 (in 2002 data)	Enhanced ICD-9-CM (in 2001 data)	$P*$ (in 2001 data)	Original ICD-9-CM (in 2001 data)	AHRQ-Web ICD-9-CM (in 2001 data)	ICD-10 (in 2002 data)	Enhanced ICD-9-CM (in 2001 data)	$P*$ (in 2001 data)
C-statistic	0.868	0.860	0.870	0.878	<0.001	0.849	0.838	0.854	0.857	<0.001
Log likelihood statistic	2731.0	2586.2	2794.5	2859.1		2252.4	2163.2	2396.6	2313.4	

*P values are for comparison of the original ICD-9-CM algorithms versus the enhanced ICD-9-CM algorithms in 2001 data.

and bipolar affective disorder, depressed (296.5) were all reclassified into depression whereas these were classified under "psychoses" in the original Elixhauser algorithm.

The enhanced ICD-9-CM coding algorithms derived by back-translation of the ICD-10 coding algorithms performed either similarly or slightly better than the ICD-10 coding algorithms for predicting in-hospital mortality. The first possible explanation for this finding is that the variation reflects temporal changes. In this study, the ICD-9-CM and ICD-10 coding algorithms were tested on data from different years. Therefore, we could not adjust for temporal changes across years. The second possible explanation is that the ICD-9-CM coding algorithms include more unspecified or unclassified codes than ICD-10 coding algorithms. This is likely to result in an over-estimation of comorbidities in ICD-9-CM. For example, to include gastric varices in defining liver disease, an unspecified code (ICD-9-CM: 456.8) was included in ICD-9-CM but, in contrast, a specific code (ICD-10: I86.4) for gastric varices was included in ICD-10. The third possible explanation is that the discrepancy may be the result of the quality of the databases. We used Calgary Health Region data 1 year before and after implementation of ICD-10. The general quality of coding in ICD-10 data may have been suboptimal in the first year of coding in the new system, and there may be potential for improvement in coming years as ICD-10 coding continues and coders familiarize themselves with the new coding systems. With ICD-10 data quality improvement, the performance of comorbidity coding algorithms applied to ICD-10 data could improve and may become similar to the performance of the enhanced ICD-9-CM coding algorithms (because the enhanced ICD-9-CM codes were derived directly from the ICD-10 coding algorithms). The fourth possible explanation is that the actual back-translation from ICD-10 to ICD-9-CM may not have been accurate. However, the independent coding by a coder and a physician, followed by a careful consensus process to determine the coding algorithms makes this less likely.

Distinguishing whether a code represents a complication or comorbidity is sometimes difficult. We made judgments regarding the inclusion or exclusion of specific codes based on a subjective clinical estimate of how often specific conditions tend to be present at time of admission, as opposed to complications arising after hospitalization. Tables 3 and 4 reassuringly reveal that for all conditions in each of the coding algorithms (ie, original versions, and our new versions), the diagnosis was present at the time of admission in a majority of cases. This was even the case for some seemingly acute conditions that sometimes arise as in-hospital complications. For example, of 59 cases with acute necrosis of the liver, 44 (74.6%) had the condition at admission versus only 15 (25.4%) who had it arise after admission. Similarly, of 362 cases with pulmonary embolism, 267 (73.8%) had the diagnosis present at admission, while only 95 (26.2%) had it arise after admission.

The decision of whether to include or exclude specific codes or conditions from a coding algorithm depends to a large extent on a given study's objectives. The original Charlson index used conditions present in hospitalized medical patients (regardless of whether the condition was present at baseline or arose

after admission) to predict *survival* over an ensuing year. For such a study, a decision to exclude conditions arising after admission would not be ideal, as it would result in a loss of prognostic information relevant to long-term survival, and an 'under-adjustment' in risk-adjusted survival analyses. In contrast, in the context of studying in-hospital outcomes of a surgical procedure, researchers would be best advised to confine their risk adjustment to variables that are predominantly present at baseline. In jurisdictions that have diagnosis type indicators, the methodological decision is simply one of deciding, based on study objectives, whether to use or not use the indicators. In regions or countries without diagnosis type indicators, meanwhile, the data that we present in Tables 3 and 4 can help researchers make decisions on a condition-by-condition basis of whether to include particular variables, depending on their study objectives.

It is difficult for us to make a quantitative statement as to *how much* better the new models (eg, the enhanced ICD-9-CM algorithms) are relative to the original models, and how 'important' those differences are. We can, however, point out that the 95% confidence intervals that we derived by bootstrapping for each C-statistic estimate do not overlap, a finding that indicates that the C-statistic differences favoring the new models are obvious and beyond what one would expect to see due to chance alone.

Our study had limitations. The ICD-9-CM and ICD-10 coding algorithms were not assessed in the same data (ie, ICD-9-CM in year 2001 and ICD-10 in year 2002). A second limitation is that the validity of the coding algorithms, and specifically their sensitivity and specificity relative to a criterion standard (eg, chart review data), remains to be determined. The third limitation is that we restricted the ICD-10 codes selected to the fourth digit (ie, the first letter and 3 numerical codes) to generalize our coding algorithms to other countries. This will likely ignore conditions that were further specified in Canadian and Australian (or other country-specific) versions of ICD-10. Weighing against these weaknesses are some strengths: We used a rigorous multistep process involving coding experts and clinicians in 3 countries to derive comprehensive coding algorithms. We then tested the coding algorithms on contemporary administrative data to demonstrate the strong performance of the resulting comorbidity measurement tools.

This study yields important new tools for analysis of ICD-10 and ICD-9-CM administrative data. The newly developed ICD-9-CM and ICD-10 coding algorithms are comparable in their performance for defining Charlson and Elixhauser comorbidities in administrative data, and the new algorithms developed here appear to slightly outperform existing algorithms. We now encourage researchers to test these coding algorithms in different administrative databases. If these coding algorithms are extensively applied and validated, they have the potential to become a new international standard.

ACKNOWLEDGMENTS

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