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New ICD-10 version of the Charlson Comorbidity Index predicted in-hospital mortality

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Abstract

Background and objective: The ICD-9-CM adaptation of the Charlson comorbidity score has been a valuable resource for health services researchers. With the transition into ICD-10 coding worldwide, an ICD-10 version of the Deyo adaptation was developed and validated using population-based hospital data from Victoria, Australia.

Methods: The algorithm was translated from ICD-9-CM into ICD-10-AM (Australian modification) in a multistep process. After a mapping algorithm was used to develop an initial translation, these codes were manually examined by the coding experts and a general physician for face validity. Because the ICD-10 system is country specific, our goal was to keep many of the translated code at the three-digit level for generalizability of the new index.

Results: There appears to be little difference in the distribution of the Charlson Index score between the two versions. A strong association between increasing index scores and mortality exists: the area under the ROC curve is 0.865 for the last year using the ICD-9-CM version and remains high, at 0.855, for the ICD-10 version.

Conclusion: This work represents the first rigorous adaptation of the Charlson comorbidity index for use with ICD-10 data. In comparison with a well-established ICD-9-CM coding algorithm, it yields closely similar prevalence and prognosis information by comorbidity category.

Keywords: Comorbidity; Charlson; ICD-10; Administrative data

1. Introduction

The Charlson comorbidity index [1] has been a useful tool for health researchers in their effort to measure comorbid disease status or casemix in health care databases. Charlson et al. [1] defined numerous clinical conditions through reviewing hospital charts and assessed their relevance in the prediction of 1-year mortality. A weighted score was assigned to each of 17 comorbidities, based on the relative risk of 1-year mortality. As a consequence, the sum of the index score is an indicator of disease burden, and a strong estimator of mortality. Since then, the Charlson Index has been validated in various larger populations [2,3]. These studies consistently demonstrate that the Charlson Index is a valid prognostic indicator. Coding algorithms in ICD-9-CM were later developed for each of the variables in the Charlson Index by other researchers [4–6].

The first version of the International Classification of Disease was adopted in 1900 to monitor and compare mortality statistics and causes of death. Now under the auspices of the World Health Organization, the classification has been revised periodically to accommodate new knowledge of disease and health [7]. The United States modified the ninth version, ICD-9, by specifying many categories and extending coding rubrics to describe the clinical picture in more detail, known as ICD-9-CM [8].

ICD-10, the newest version of this nosology, has been used by many European countries for coding mortality and/or morbidities since 1994 [9–11]. Canada, Australia, and the United States enhanced the ICD-10 by adding new codes and have developed their own versions [12–14]. Advantages of ICD-10 include the fact that its coding structure leaves room for future expansion and allows the coding of richer clinical information [14].

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Despite these potential advantages of ICD-10, the use of such data in health services research initiatives has been limited to date, perhaps because of the lack of familiarity and agreement among researchers on coding algorithms for defining clinical conditions in ICD-10, such as the above-mentioned ICD-9-CM coding algorithms that define the 17 comorbidities that constitute the Charlson Index. Clearly, the development and validation of similar algorithms for ICD-10 would represent a contribution to the field of health services research, at a time when much of the world is shifting to ICD-10 coding for hospital discharges.

The State of Victoria, Australia, has maintained administrative data on all hospital admissions for a number of years. Prior to July 1, 1998, all discharges were coded in ICD-9-CM format, but from that date forward, all hospital discharges have been coded in ICD-10-AM, the Australian version of ICD-10. Given the current availability of several years of ICD-10 data, we initiated this methodological study, with specific objectives being (1) to develop an ICD-10 coding algorithm that permits definition—in ICD-10 data—of the 17 variables that constitute the Charlson Index, (2) to validate the algorithm by assessing the prevalence of the resulting comorbidity variables in ICD-10 data relative to prevalence of the same variables in the earlier ICD-9-CM data, and (3) to further validate the algorithm by assessing the association between the resulting comorbidity variables and in-hospital mortality.

2. Methods

2.1. Data source for validation

Victoria is Australia's second largest state, with a population of more than 4.5 million [15]. As part of a universal health system, each state maintains administrative data on all hospital admissions. The Victorian Admitted Episodes Dataset (VAED), maintained by the Victorian Department of Human Services, is based upon hospital data compiled by individual public and private hospitals in Victoria [16]. The dataset contains demographic and clinical information on each discharge. The diagnostic and procedure codes in Victoria's hospital dataset were coded in ICD-9-CM format until June 30, 1998. After this, all hospitals began using the first-edition version of ICD-10-AM.

For the purpose of this study, the analysis dataset included only an individual's first multiple-day hospitalization of any given year. This assures that individual hospitalizations are truly independent from each other and thus suitable for the conventional statistical analyses that we performed. All hospitalizations for patients under 18 years at the time of admission were excluded.

Until June 30, 2000, there were 12 diagnostic and procedure fields in the dataset; in the last two fiscal years, there have been 25. To maintain consistency across years, only 12 fields were used for analysis.

2.1.1. ICD-9-CM version of Charlson Index

In this study we have used Deyo's [4] coding algorithm for the Charlson Index (Table 1) as a starting point for our work in developing an ICD-10 algorithm. We chose the Deyo coding algorithm as a starting point because it appears to be the most widely used in the literature. Furthermore, studies have suggested that there is actually little difference between Deyo's coding algorithm and the Dartmouth–Manitoba coding algorithm in generating the Charlson Index score, and the two coding algorithms are similar in their ability to predict outcomes [17,18].

2.1.2. Translation of index into ICD-10-AM

The Deyo [4] coding algorithm was translated from ICD-9-CM into ICD-10-AM in a multistep process. Initially, coding experts at the Victorian Department of Human Service used a mapping algorithm from the National Centre for Classification in Health at the University of Sydney in Australia [19,20]. After this, the translated codes were manually examined by the coding experts and a general physician for face validity. As there have been three versions of ICD-10-AM, and given the higher discrimination of ICD-10 relative to ICD-9-CM, many of the translated codes are at the three-digit level in ICD-10. (One of the stated goals of the ICD-10-AM is to maintain "international compatibility" with ICD-10 [21].) This has allowed a relatively straightforward version of the ICD-10 translation to be developed. The resulting ICD-10-AM coding algorithm is presented in Table 1. The alphabetic part of the alphanumeric ICD-10-AM codes refers to the disease group into which the codes fall (e.g., 'I' is for diseases of the circulatory system).

2.1.3. Derivation of specific comorbid disease groups

The first 12 diagnostic fields were evaluated for the presence of the specific ICD codes. Each hospitalization was classified regarding the presence or absence of diagnostic codes within a disease category. Then, using the weights for the Charlson Index (Table 1) a final Charlson score was assigned.

2.2. Data analysis

The quality of the translation was assessed initially by calculating the prevalence of each comorbid disease by year, with 1998–99 being the first year during which the ICD-10 index was used. (For our analysis, each year began on July 1 and ended on June 30.) Prevalence of individual comorbidities prior to the 1998–99 year is thus based on the Deyo ICD-9-CM adaptation of the Charlson Index, whereas prevalence of the comorbidities from 1998–99 onward is based on our new ICD-10 coding algorithm. After this, the distribution of the Charlson Index values was compared across years. Next, the association between the Charlson Index and in-hospital mortality was evaluated in a bivariate analysis using the chi-square test. Finally, to assess the validity of the ICD-10 Charlson Index, the area under the receiver operating

Table 1
Diagnostic categories, original ICD-9-CM codes, and corresponding ICD-10-AM codes

Condition	Weights	Codes	
		ICD-9-CM	ICD-10-AM
Acute myocardial infarction	1	410, 412	I21, I22, I252
Congestive heart failure	1	428	I50
Peripheral vascular disease	1	441, 4439, 7854, V434	I71, I790, I739, R02, Z958, Z959
Cerebral vascular accident	1	430–438	I60, I61, I62, I63, I65, I66,G450, G451, G452, G458, G459, G46, I64, G454, I670, I671, I672, I674, I675, I676, I677 I678, I679, I681, I682, I688, I69
Dementia	1	290	F00, F01, F02, F051
Pulmonary disease	1	490, 491, 492, 493, 494, 495, 496, 500, 501, 502, 503, 504, 505	J40, J41, J42, J44, J43, J45, J46, J47, J67, J44, J60, J61, J62, J63, J66, J64, J65
Connective tissue disorder	1	7100, 7101, 7104, 7140, 7141, 7142, 71481(now 5171), 725	M32, M34, M332, M053, M058, M059, M060, M063, M069, M050, M052, M051, M353
Peptic ulcer	1	531, 532, 533, 534	K25, K26, K27, K28
Liver disease	1	5712, 5714, 5715, 5716	K702, K703, K73, K717, K740, K742, K746, K743, K744, K745
Diabetes	1	25002501, 2502, 2503, 2507	E109, E119, E139, E149, E101, E111, E131, E141, E105, E115, E135, E145
Diabetes complications	2	2504, 2505, 2506	E102, E112, E132, E142 E103, E113, E133, E143 E104, E114, E134, E144
Paraplegia	2	342, 3441	G81 G041, G820, G821, G822
Renal disease	2	582, 5830, 5831, 5832, 5833, 5835, 5836, 5837, 5834, 585586588	N03, N052, N053, N054, N055, N056, N072, N073, N074, N01, N18, N19, N25
Cancer	2	14, 15, 16, 18, 170, 171, 172, 174, 175, 176, 179, 190, 191, 192, 193, 194, 1950, 1951, 1952, 1953, 1954, 1955, 1958, 200, 201, 202, 203, 204, 205, 206, 207, 208	C0, C1, C2, C3, C40, C41, C43, C45, C46, C47, C48, C49, C5, C6, C70, C71, C72, C73, C74, C75, C76, C80, C81, C82, C83, C84, C85, C883, C887, C889, C900, C901, C91, C92, C93, C940, C941, C942, C943, C9451, C947, C95, C96
Metastatic cancer	3	196, 197, 198, 1990, 1991	C77, C78, C79, C80
Severe liver disease	3	5722, 5723, 5724, 5728	K729, K766, K767, K721
HIV	6	042, 043, 044	B20, B21, B22, B23, B24

characteristic (ROC) curve was determined using the *C*-statistic from a logistic regression model with in-hospital death as the outcome and the Charlson Index as the only independent variable. The area under the ROC curve is a measure of the model's ability to discriminate between those subjects who experience the outcome of interest versus those who do not, and its typical values range from 0.5 (no discrimination beyond chance) to 1.0 (perfect discrimination) [22]. For a sensitivity analysis we reassessed the area under the ROC curve for a Charlson Index which did not include the first diagnostic code. All data manipulation, derivation of indices and data analysis were conducted using SAS version 8.2 [23].

3. Results

There were more than 400,000 multiple-day hospitalizations (overnight stay or longer) for each year of data used in our analysis (Table 2).

On average, the prevalence of the specific disease categories during multiple-day hospitalizations did not shift dramatically between the fiscal years 1997–98 and 1998–99, when the change from ICD-9-CM to ICD-10-AM occurred in Victoria.

The prevalence of congestive heart failure, peripheral vascular disease, chronic pulmonary disease, connective tissue disease, and peptic ulcer disease did decline across years, though the timing of the decline did not coincide with the switch from ICD-9 to ICD-10; rather, the decline occurred later. Dementia is the only exception, showing a drop in prevalence between 1997–98 and 1998–99. There was little change in mild liver disease, hemiplegia or paraplegia, malignancy, and metastatic solid tumor.

3.1.1. Impact of changing prevalence on the Charlson Index

Using the specific disease categories, a Charlson Index score was calculated for each hospitalization. The frequency distribution of the Charlson Index score by year is given in Table 3. Between the crucial years 1997–98 and 1998–99, when the impact of the new Charlson mapping would first be notable, there appears to be little difference in the distribution of the Charlson Index score. After this, there is a gradual increase in the no-comorbidity stratum (Charlson 0) and a decline in levels 1–4. These changes in distributions of Charlson scores occurred after the ICD-10 system had already been implemented, however, suggesting that they do not primarily reflect any artifact related to our new coding algorithm.

3.1.2. Association between Charlson Index level and in-hospital mortality

To validate the new ICD-10-AM version of the Charlson Index, the association between its levels and in-hospital

Table 2
Prevalence of specific disease categories in multiple-day hospitalizations

	ICD-9-CM		ICD-10-AM			
Demographic and clinical characteristics	1996–97	1997–98	1998–99	1999–2000	2000–2001	2001–2002
Total hospitalizations, no.	407,983	**408,321**	**405,794**	408,651	414,846	416,235
Age, mean, years	53	53	53	53	53	54
Age, SD	21	21	21	21	21	21
Condition, %						
Acute myocardial infarction	2.5	2.5	2.9	2.9	2.2	2.1
Congestive heart failure	5.5	5.6	5.5	5.2	3.4	3.3
Peripheral vascular disease	1.2	1.2	1.3	1.3	0.8	0.7
Cerebral vascular disease	3.7	3.6	3.6	3.3	3.0	3.0
Dementia	1.1	0.9	0.5	0.5	0.5	0.5
Pulmonary disease	8.3	9.0	9.4	8.4	3.9	3.5
Connective tissue disease	1.1	1.2	1.1	1.0	0.5	0.4
Peptic ulcer disease	1.1	1.0	0.9	0.7	0.5	0.5
Liver disease	0.2	0.2	0.2	0.2	0.2	0.2
Diabetes	6.3	6.7	7.1	7.4	5.9	6.8
Diabetes with complications	0.4	0.5	0.5	0.3	1.0	1.3
Hemiplegia or paraplegia	1.3	1.3	1.4	1.4	1.4	1.5
Renal disease	1.4	1.4	2.0	2.0	1.7	1.8
Cancer	5.6	5.7	6.0	6.4	6.1	6.0
Metastatic cancer	2.3	2.3	2.4	2.3	2.3	2.3
Severe liver disease	0.2	0.2	0.2	0.1	0.1	0.1
HIV disease	0.1	0.1	0.1	0.1	0.1	0.1

mortality was explored (Table 4). Across years, and most importantly across versions of the Charlson Index, a closely similar stepped association is present between index scores and mortality, with scores of 0 corresponding to deaths rates of less than 0.5% and scores equal to or greater than 6 predicting death rates of ~20–25%. All scores in between demonstrate a stepped increase in mortality as comorbidity scores increase. This association is statistically significant on a Mantel–Haenszel chi-square test for trend.

3.1.3. Area under the ROC curve

The area under the ROC curve for the Charlson Index and in-hospital death is 0.87 in 1996–97 (Table 5). This decreases only slightly, to 0.85, by 2001–2002. When the primary discharge diagnosis code is excluded from the calculation of the index, the area under the ROC curve declines from 0.87 to 0.80 for 1996–97, and similarly for the years afterwards.

4. Discussion

The ICD-9-CM coding algorithms developed by Deyo et al. [4] and by the Dartmouth–Manitoba groups in the early 1990s were important developments; they provided a methodological foundation for a large number of studies based on administrative data [24–32].

We have presented the first ICD-10 version of the Charlson comorbidity index to be developed and tested on a large population-based dataset. In comparison with a well-established ICD-9-CM coding algorithm, it yields closely similar prevalence and prognosis information by comorbidity category.

In our assessment of the new ICD-10 algorithm, we have found that it has a generally similar prognosis for individual variables across years, and most importantly across the fiscal years 1997–98 and 1998–99, during which the switch from ICD-9 to ICD-10 occurred. This is supported by a closely similar prevalence of Charlson comorbidity score

Table 3
Frequency table of Charlson Index scores by year

	ICD-9-CM frequency, %		Frequency, ICD-10-AM frequency, %			
Charlson score	1996–97	1997–98	1998–99	1999–2000	2000–2001	2001–2002
0	70.9	**70.1**	**69.4**	70.2	76.2	75.9
1	15.1	**15.6**	**15.7**	15.3	11.7	11.8
2	7.4	**7.5**	**7.7**	7.6	6.4	6.3
3	3.2	**3.3**	**3.3**	3.0	2.2	2.3
4	1.1	**1.2**	**1.3**	1.2	0.8	0.9
5	1.7	**1.6**	**1.8**	2.1	2.1	2.1
⩾6	0.7	**0.7**	**0.8**	0.8	0.6	0.7

Bold indicates the transition years, when ICD-9 changed to ICD-10.

Table 4
Frequency of in-hospital death in relation to Charlson Index level

	In-hospital death during admission being evaluated, %					
	ICD-9-CM		ICD-10-AM			
Charlson score	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02
0	0.3	**0.3**	**0.4**	0.3	0.4	0.4
1	3.1	**2.7**	**2.7**	2.5	3.4	3.2
2	6.3	**5.4**	**5.8**	5.0	6.6	5.6
3	11.5	**9.7**	**9.6**	9.0	11.6	10.7
4	16.1	**14.4**	**13.3**	12.8	14.9	13.6
5	17.3	**16.9**	**16.2**	14.9	16.3	14.7
⩾6	25.1	**24.7**	**24.9**	21.1	24.8	23.6
Test for trend, *P*-value	<.0001	**.0001**	**.0001**	.0001	.0001	.0001

Bold text indicates the transition years, when ICD-9 changed to ICD-10.

categories across these crucial switch years, as well as similar prognostic associations with mortality across score levels. Finally, the area under the ROC curve for the ICD-10 algorithm ranges between 0.85 to 0.86, compared to ICD-9 algorithm values of 0.86 to 0.87. Even after excluding the first diagnostic code from the measurement of the index, the area under the ROC curve remains above 0.79. Hosmer and Lemeshow [22] suggest that areas between 0.8 and 0.9 demonstrate excellent discrimination and, realistically, represent the highest discrimination that may be expected from a predictive model or variable. A limitation of our study is that it validates the index based only on in-hospital mortality, whereas the original Charlson Index was validated with data on survival to 1 year. Notably, most of the studies exploring the validity of the Charlson Index for administrative datasets have also been limited to in-hospital mortality as their outcome.

Our analysis does show a changing prevalence of specific clinical diagnoses in the coding algorithm, particularly in the last 2 fiscal years (decrease in frequencies of congestive heart failure, peripheral vascular disease, chronic pulmonary disease, connective tissue disease, and peptic ulcer disease). There may be more than one possible explanation for these changing rates: (1) a real change in prevalence of these conditions; (2) an apparent change in prevalence due to changes in admission practices, with more conditions managed on an outpatient basis; (3) a change in coding practices that is entirely independent of ICD version issues; and (4) a systematic change in coding practice with the second edition of ICD 10, such as the Additional Diagnosis Standard, which was instituted in Australia in July 2001. This new standard meant that additional diagnoses were required to meet more stringent criteria before being coded. As a result, conditions that are now coded less frequently include asthma, hypertension, heart disease, chronic obstructive lung disease, and other chronic conditions. Whatever the reason for the subsequent changes in prevalence for certain conditions, the strong predictive performance of our ICD-10 version of the Charlson Index is sustained and consistent across years, suggesting a generally robust index for use with administrative data.

One specific diagnosis, dementia, is unusual in that it shows a 50% drop in prevalence in the transition from the ICD-9 to ICD-10 algorithm. A real drop in the hospital prevalence of dementia is unlikely to explain this change. The Deyo adaptation of the Charlson Index includes the ICD-9-CM codes for dementia (ICD-9-CM 290, including dementia from Alzheimer disease) but not the code for Alzheimer disease itself (ICD-9-CM 3310). Our ICD-10 translation reflects this by not including the ICD-10 code for Alzheimer disease (G30). A change in coding practice with regard to Alzheimer disease (using ICD-10 G30 more often than ICD-9-CM 3310 had been used) may be one explanation of the downward change in prevalence.

Finally, the area under the ROC curve does drop approximately 1.2% with the ICD-10 algorithm. Our ICD-10 algorithm is faithful to the Deyo algorithm in terms of its disease categories, and the relevance of this slight drop in the area under the ROC curve is likely to be small. The essential

Table 5
Area under the ROC curve based on *C*-statistic for ICD-9-CM and ICD-10-AM versions of the Charlson Index

	Area under ROC curve					
	ICD-9-CM		ICD-10-AM			
Analysis	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02
With all diagnostic codes	0.87	**0.86**	**0.85**	0.86	0.86	0.85
Without first diagnostic code	0.80	**0.80**	**0.80**	0.80	0.79	0.79

Bold text indicates the transition years, when ICD-9 changed to ICD-10.

differences between ICD-9 and ICD-10, notably the greater discrimination of ICD-10 and the drop in ROC figures with the ICD-10 algorithm, suggest that this approach of adhering to the Deyo algorithm may need to be adjusted slightly. Future efforts may benefit from beginning with the Charlson Index itself as the base for the ICD-10 algorithm, rather than the ICD-9-CM codes of the Deyo algorithm. We expect that similar work by other groups will improve the coding algorithm, as was seen in the valuable back-and-forth debate that occurred with the ICD-9-CM versions. Such dialogue increased the general comfort with both the Deyo and the Dartmouth–Manitoba algorithms [17].

Our algorithm is predominantly at the third-digit level of ICD-10 coding. We translated the algorithm in this way in order to take into account the greater discrimination of ICD-10, as well as the fact that ICD-10 versions differ between countries. Our goal was to have a general, international version of the Charlson Index in ICD-10 form, with wide applicability. The majority of country-specific alterations in the basic ICD-10 coding are in the last digits (often the fifth digit), so we expect that the predominance of three- and four-digit codes in our algorithm will contribute to its usefulness internationally.

Our initial efforts at translating the Deyo version of the Charlson comorbidity index into ICD-10 are promising. The new algorithm maintains the strength of association to in-hospital mortality shown by the ICD-9-CM version, as evidenced by the area under the ROC curve. We eagerly await future work in assessing the applicability of this ICD-10 version of the Charlson Index.

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