ORIGINAL RESEARCH

Charlson Comorbidity Index: *ICD-9* Update and *ICD-10* Translation

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BACKGROUND: The original Charlson Comorbidity Index (CCI) encompassed 19 categories of medical conditions that were identifiable in medical records. Subsequent publications provided scoring algorithms based on *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*) codes. The recent adoption of *International Classification of Diseases, Tenth Revision, Clinical Modification* (*ICD-10-CM*) codes in the United States created a need for a new scoring scheme. In addition, a review of existing claims-based scoring systems suggested 3 areas for improvement: the lack of explicit identification of secondary diabetes, the lack of differentiation between HIV infection and AIDS, and insufficient guidance on scoring hierarchy. In addition, addressing the third need raised the issue of disease severity in renal disease.

OBJECTIVES: This initiative aimed to create an expanded and refined *ICD-9* scoring system for CCI, addressing the classification of issues noted above, create a corresponding *ICD-10* system, assess the comparability of *ICD-9*– and *ICD-10*–based scores, and validate the new scoring scheme.

METHODS: We created *ICD-9* and *ICD-10* code tables for 19 CCI medical conditions. The new scoring scheme was labeled CDMF CCI and was tested using claims-based data for individuals aged ≥65 years who participated in a Humana Medicare Advantage plan during at least 1 of 3 consecutive 12-month periods. Two 12-month periods were during the *ICD-9* era and the third 12-month period was during the *ICD-10* era. Because many individuals were counted in more than one 12-month period, we described the study population as comprising 3 panels. We used regression models to analyze the association between the CCI score and same-year inpatient admissions and near-term (90-day) mortality. Additional testing was done by comparing the mean CCI score or disease prevalence in the 3 subpopulations of people with HIV/AIDS, renal disease, or diabetes. Finally, we calculated area under the receiver operating characteristics (AUC-ROC) curve values by applying the Deyo system and our *ICD-9* and *ICD-10* scoring systems.

RESULTS: The CDMF *ICD-9* and *ICD-10* scoring scheme yielded comparable scores across the 3 panels, and inpatient admissions and mortality rates consistently increased in each panel as the CCI score increased. Comparisons of the performance of the Deyo system and our proposed CDMF *ICD-9* system in the 3 key subpopulations showed that the CDMF *ICD-9* system produced a lower CCI score in the presence of HIV infection without AIDS, achieved similar detection ability of diabetes, and allowed good differentiation between mild-to-moderate and severe renal disease. AUC-ROC values were similar between the CDMF *ICD-9* coding system and the Deyo system.

CONCLUSION: Our results support the implementation of the CDMF CCI scoring instrument to triage individual patients for disease- and care-management programs. In addition, the CDMF scheme allows for a more precise understanding of chronic disease at a population level, thus allowing health systems and plans to design services and benefits to meet multifactorial clinical needs. Preliminary validation sets the stage for further testing using long-term follow-up data and for the adaptation of this coding scheme to a chart review instrument.

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KEY POINTS

- Use of the Charlson Comorbidity Index (CCI) allows for the adjustment of mortality risk in claims-based studies and helps providers choose care-management resources based on risk.
- This study created a new CCI coding and scoring scheme consisting of an updated *ICD-9* system and a new *ICD-10* system, using data from 3 populations in a Medicare Advantage health plan.
- The new CCI scheme is labeled CDMF CCI to reflect these characteristics: **c**laims-based, **d**isease-specific refinements, **m**atching translation to *ICD-10*, **f**lexibility to allow use as a chart review instrument.
- The CDMF CCI scoring scheme yielded comparable scores across the 3 populations, and admissions and mortality rates increased as the CCI score increased.
- Compared with the Deyo system, use of the CDMF *ICD-9* system resulted in a lower CCI score for those with HIV infection without AIDS.
- The CDMF *ICD-9* scheme also achieved a comparable rate of diabetes detection and appropriate distinction between mild-to-moderate and severe renal disease.
- The CDMF CCI scoring scheme allows triage of patients for disease- and care-management programs and can help plans to design benefits for individual patient needs.

The original Charlson Comorbidity Index (CCI) chart review instrument designed by Charlson and colleagues produced a morbidity score that reflects mortality risk.[1] The score is determined based on 19 medical conditions and adjusts for variable morbidity rates within a patient population. In clinical practice, risk assessment facilitates triage, prioritization, and proactive patient engagement. More recently, various administrative claims data versions of this public domain instrument have enabled healthcare organizations, payers, and researchers to adjust for mortality risk in claims-based studies of large patient populations. Although mortality risk assessment was the original intent of the CCI scoring instrument, the correlation of mortality risk with expected healthcare resource consumption expands the usefulness of the instrument. The use of the CCI facilitates the prioritization of care-management resources based on patient risk.

The CCI scoring system is useful for several situations, including clinical settings in large population healthcare organizations and for research purposes. This scoring tool is easily administered and should yield near-identical results, regardless of whether it is used in the context of patient examinations, chart review, administrative data, or autopsy. This flexibility is what distinguishes the CCI instrument from other risk-adjustment and risk-assessment tools.

The original CCI chart review instrument was based on 19 different medical conditions categories.[1] Each category was assigned a score (weight) of 1, 2, 3, or 6.[1] These condition-specific scores were summed for the overall CCI score. Implicit in the instrument design was a hierarchical structure in which a more severe condition trumped a less severe condition. For example, 1 point was assigned to mild liver disease and 3 points were assigned to moderate or severe liver disease[1]; only the more severe category's score was active when both diagnoses were included in a medical record. A score for age was incorporated to account for mortality risk in the absence of clinical diagnoses: 1 point was added per decade, starting with the 50s. The final score was a sum of the scores for active condition categories plus the age adjustment.

An early CCI instrument based on diagnosis codes translated chart review condition categories into *International Classification of Diseases, Ninth Revision* (*ICD-9*) diagnosis codes with 3-digit specificity.[2] The use of diagnostic coding for reimbursement purposes creates an incentive for providers to use more accurate and precise coding. Accordingly, newer claims-based versions of the CCI, such as the frequently used instrument designed by Deyo and colleagues, incorporated 4- and 5-digit codes.[3]

Why Propose a New Coding Scheme?

The Need for an ICD-10 Coding System

In October 2015, the US healthcare system transitioned from *ICD-9* to *International Classification of Diseases, Tenth Revision* (*ICD-10*). This created an immediate need for a CCI coding algorithm that included *ICD-10* codes. An increase in the number of codes from 14,025 to 69,823 also facilitated more nuanced and clinically updated categorization and severity assessment.[4] Many countries use or have adapted the *ICD-10* for their own healthcare systems.[5,6] The *ICD-10* CCI instrument created by Quan and colleagues for use in Canada includes the diabetes code families of E10, E11, E12, E13, and E14, whereas the current US version of *ICD-10* uses E08, E09, E10, E11, and E13.[7] An *ICD-10* coding algorithm for a version of the CCI that is specific to the United States has not yet been published.

Reasons for Creating a New ICD-9 Scoring System

We identified 3 reasons to create a new *ICD-9* scoring

system for the CCI before designing a corresponding *ICD-10* system. The first reason concerned the categorization of diabetes. Diabetes is largely represented by 2 *ICD-9* parent codes: 249 (secondary diabetes) and 250 (types 1 and 2 diabetes). *ICD-9* also allows diabetes to be coded as type 2 or unspecified (250.x0, 250.x2), which can result in misclassification. Older CCI coding schemes based on *ICD-9* have not incorporated *ICD-9* code 249, which prevents appropriate risk categorization for patients with secondary diabetes.

A second reason to update the *ICD-9*–based instrument was to reflect developments in the treatment of HIV infection, which in isolation is no longer associated with near-term (90-day) mortality. The category for AIDS created by Charlson and colleagues explicitly excluded HIV-positive status, whereas instruments based on administrative data either did not differentiate between the 2 conditions[3,7,8] or did not include AIDS and HIV infection as clinical categories.[9] Quan and colleagues assigned to HIV infection the same weight (6 points) that was assigned to metastatic cancer.[7] Adding to the problem, the World Health Organization has discontinued using the code for AIDS in *ICD-9* and *ICD-10*, leaving only HIV-positive category as a valid diagnosis.[10]

A final opportunity we found to improve the *ICD-9* instrument involved the hierarchies implied by any risk-assessment instrument. Condition classification systems, such as diagnosis-related groups and commercial risk-adjustment tools, rely on the fundamental principle that the most severe diagnosis made within a time period for a particular body system is the only system activated when setting risk weights.

To encourage the proper observance of these hierarchies, more explicit guidance on how to apply the instrument was warranted, which created an opportunity to address the severity spectrum of renal disease. The differences in morbidity and risk for mortality between patients with stage 5 or end-stage kidney disease and less severe disease are considerable. Other condition categories, such as cancer, may also have been updated, but we chose to remain consistent with the original emphasis on chronic disease.

Our study was intended to meet 4 main objectives: to create an expanded and refined *ICD-9* scoring system for the CCI, taking into account the 3 clinical conditions mentioned earlier (ie, diabetes, HIV/AIDS, renal disease); to create an *ICD-10* CCI scoring system with features that correspond to the refined *ICD-9* system; to assess the comparability of the *ICD-9*–based and *ICD-10*–based scores; and to validate the new scoring systems by testing their association with same-year hospital admissions and near-term mortality.

The essentials of this new set of scoring system are:

- **C**laims-based
- **D**isease-specific refinements
- **M**atching translation to *ICD-10*
- **F**lexibility to allow use as a chart review instrument, as originally conceived by Mary Charlson.

We refer to this new set of scoring scheme as CDMF CCI to reflect these characteristics.

Methods

Our new instrument was designed to yield a similar score whether the diagnoses were identified during face-to-face interaction with a patient or based on administrative data. Thus, the structure of the new instrument was kept consistent with the original chart review instrument published by Charlson and colleagues.[1] We also kept our scheme congruous with the administrative data versions created by Deyo and others.[3,7-9] The tool proposed here followed Deyo's decision to collapse 3 nonmetastatic cancer categories into 1 category,[3] but did create 2 additional categories by splitting renal disease into mild-moderate and severe categories, and by splitting the HIV/AIDs category into HIV-positive without AIDs and HIV-positive with AIDS. (Although liver disease was categorized as mild and moderate to severe in the original instrument, in this instrument renal disease has been categorized as mild to moderate and severe to reflect the dramatic increase in risk when a patient transitions to stage 5 kidney disease.)

The AIDS category was created by combining codes for HIV infection with those for opportunistic infections or AIDS-related cancers. In addition, the *ICD-9* code family for secondary diabetes (249.x) was incorporated into the CDMF coding scheme, corresponding to E08, E09, and E13 in *ICD-10*. The primary tools we used to identify diagnosis codes were www.ICD9Data.com and www.ICD10Data.com, which are matched resources with suggested crosswalks between *ICD-9* and *ICD-10*.

The point values we assigned to the new instrument were the same as those suggested by the original CCI instrument, with a few exceptions. For renal disease, we changed the 2 points for a single category to 1 for mild-to-moderate disease and to 3 for severe renal disease. We assigned 3 points to HIV without AIDS, based on our authors' consensus, and ascribed 6 points to AIDS as is the case in previous scoring versions.

Sample Selection

We tested the *ICD-9* and *ICD-10* scoring systems in the Medicare Advantage population of Humana (a national health and wellness organization), including only individuals who were continuously enrolled in Humana Medicare Advantage in at least 1 of 3 consecutive 12-

month periods. Individuals were excluded if they died during the 12-month continuous enrollment period or if they were aged <65 years or >110 years. Those with dual eligibility for Medicaid and Medicare were also excluded.

The initial two 12-month time windows were the last 1-year periods in which *ICD-9* codes were used exclusively in the United States (ie, October 2013-September 2014 and October 2014-September 2015). The third time window was the earliest 1-year window where *ICD-10* codes were used exclusively (ie, October 2015-September 2016). The CCI scoring was based on diagnosis codes in claims for services received during these time periods.

New Diagnosis Codes and Scoring Systems

The primary products of our initiative were scoring schemes and *ICD-9* and *ICD-10* code tables for the 19 CCI medical conditions. **Appendix I Table SI-1** (see **Supplemental Appendix I** at **www.AHDBonline.com**) shows the points (1, 2, 3, or 6) we assigned to each medical condition. Of these 19 conditions, 11 received 1 point. Especially serious conditions or severe levels of a condition received more points (eg, 1 point for diabetes without chronic complications and 2 points for diabetes with chronic complications).

Appendix I Table SI-2 (online) displays the 6 hierarchy categories. In each category, only the more severe condition should contribute to the CCI score when codes for both conditions are listed on an individual's claims record; for example, if an individual has cerebrovascular disease (1 point) and hemiplegia or paraplegia (2 points), only the 2 points for hemiplegia or paraplegia are counted. **Table 1A** and **Table 1B** provide an illustration of how the Deyo instrument, the new *ICD-9* system, and the new *ICD-10* system compare for HIV/AIDS. The full set of condition-specific tabular comparisons is shown in **Appendix I Tables SI-3a** to **SI-3s** (online) and is designed to allow the replication of the new scheme.

We used 4 sets of analyses to assess the performance of the scoring systems. First, we computed the prevalence of each of the 19 CCI condition categories for all 3 periods and assessed for consistency. Second, as a preliminary validation of the updated CCI instrument, we assessed the association between the CCI score and the current-year hospital admissions (marked by discharge dates) and the association with near-term (90-day) mortality. The relationship between CCI score and admissions was evaluated by using a linear regression model to predict the mean admissions per 1000, which was adjusted for sex (reference, female) and race (reference, white), using 13 binary variables for CCI scoring (reference value, 2). This approach allowed for an assessment of whether the relationship between the CCI score and utilization was linear.

Table 1A Deyo and CDMF CCI Coding Schemes: HIV Infection

Score	*ICD-9* diagnosis code (Deyo et al, 1992)		*ICD-9* diagnosis code (CDMF CCI)		*ICD-10* diagnosis code (CDMF CCI)	
3	042.x	Human immunodeficiency virus [HIV] disease	042.x	Human immunodeficiency virus [HIV] disease	B20.x	Human immunodeficiency virus [HIV] disease

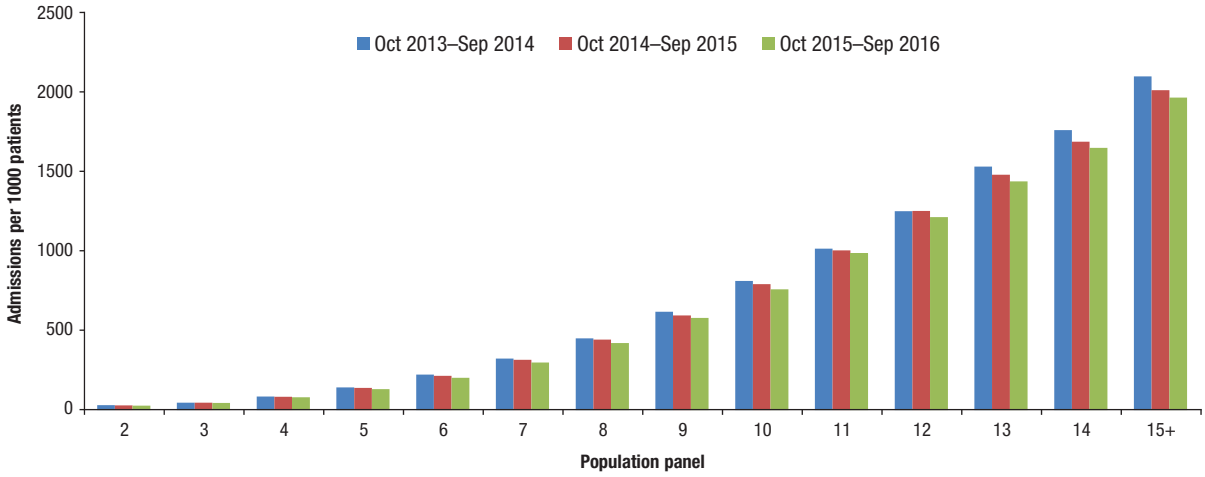
CCI indicates Charlson Comorbidity Index; *ICD-9*, *International Classification of Diseases, Ninth Revision*; *ICD-10*, *International Classification of Diseases, Tenth Revision*.

Table 1B Deyo and CDMF CCI Coding Schemes: AIDS (HIV Infection + Opportunistic Infection)

Score	*ICD-9* diagnosis code (Deyo et al, 1992)	*ICD-9* diagnosis code (CDMF CCI)		*ICD-10* diagnosis code (CDMF CCI)	
6	—	112.x	Candidiasis of bronchi, trachea, esophagus, or lungs	B37.x	Candidiasis of bronchi, trachea, esophagus, or lungs
		180.x	Invasive cervical cancer	C53.x	Invasive cervical cancer
		114.x	Coccidioidomycosis	B38.x	Coccidioidomycosis
		117.5	Cryptococcosis	B45.x	Cryptococcosis
		007.4	Cryptosporidiosis, chronic intestinal (greater than 1 month's duration)	A07.2	Cryptosporidiosis, chronic intestinal (greater than 1 month's duration)
		078.5	Cytomegalovirus disease (particularly CMV retinitis)	B25.x	Cytomegalovirus disease (particularly CMV retinitis)
		348.3x	Encephalopathy, HIV-related	G93.4x	Encephalopathy, HIV-related
		054.x	Herpes simplex: chronic ulcer(s) (greater than 1 month's duration); or bronchitis, pneumonitis, or esophagitis	B00	Herpes simplex: chronic ulcer(s) (greater than 1 month's duration); or bronchitis, pneumonitis, or esophagitis
		115.x	Histoplasmosis	B39.x	Histoplasmosis
		007.2	Isosporiasis, chronic intestinal (greater than 1 month's duration)	A07.3	Isosporiasis, chronic intestinal (greater than 1 month's duration)
		176.x	Kaposi's sarcoma	C46.x	Kaposi's sarcoma
		200-209	Lymphoma, multiple forms	C81-C96	Lymphoma, multiple forms
		031.x	Mycobacterium avium comp	A31.x	Mycobacterium avium comp
		010-018	Tuberculosis	A15-A19	Tuberculosis
		136.3	Pneumocystis carinii pneumonia	B59	Pneumocystis carinii pneumonia
		V12.61 (exact)	Pneumonia, recurrent	Z87.01	Pneumonia, recurrent
		046.3	Progressive multifocal leukoencephalopathy	A81.2	Progressive multifocal leukoencephalopathy
		003.1	Salmonella septicemia, recurrent	A02.1	Salmonella septicemia, recurrent
		130.x	Toxoplasmosis of brain	B58.x	Toxoplasmosis of brain
		799.4	Wasting syndrome due to HIV	R64	Wasting syndrome due to HIV

CCI indicates Charlson Comorbidity Index; CMV, cytomegalovirus; *ICD-9*, *International Classification of Diseases, Ninth Revision*; *ICD-10*, *International Classification of Diseases, Tenth Revision*.

Figure 1 Inpatient Admissions per 1000 in 3 Consecutive Population Panels[a]



[a]Each panel included individuals aged ≥65 years who were continuously enrolled in a Medicare Advantage plan for 12 months.

We constructed a robust Poisson regression model[11] to assess the relationship between a CCI score and mortality in the 3-month period after the end of the analytic time window (October-September) and before the first enrollment month of a new plan year (January). We chose to use a robust Poisson regression model to predict near-term mortality, which allows for the direct modeling of relative risks. As in the utilization model, we included sex and race as covariates in addition to the CCI score (represented as 13 binary variables for the CCI score; reference value, 2).

Third, we applied the Deyo system and the new *ICD-9* system to the later of the 2 *ICD-9* era study panels. The mean CCI score or disease prevalence within the subpopulations with diagnoses were related to key changes in the new instruments. Using the Deyo scoring system, these subpopulations were identified within the October 2014 to September 2015 panel: HIV/AIDS, diabetes, and renal disease. As noted earlier, the Deyo system ascribes the same score to all individuals with HIV infection regardless of whether the patient has AIDS; it does not include the codes for secondary diabetes; and it does not take the severity of renal disease into account. Each subpopulation was then further divided according to the more granular scoring allowed by the new *ICD-9* system, and the 2 sets of mean CCI scores (HIV/AIDS, renal disease) or 2 sets of prevalence values (diabetes) were computed for each resulting group.

Finally, we constructed 3 logistic regression models for the prediction of near-term mortality, using CCI score as the independent variable, and the area under the receiver operating characteristics (AUC-ROC) curve was calculated for each model. These models computed CCI score according to the Deyo system, the new *ICD-9* system (for the October 2014-September 2015 panel), and the new *ICD-10* system; the same hierarchical scheme shown in Appendix I Table SI-2 was applied in all 3 calculations.

Process

The research supporting our new instruments was performed by a biomedical engineer (WPG), who had previously developed an SAS algorithm using claims data that was based on the CCI scoring scheme of the Deyo version of the CCI. Our new code sets were reviewed by a senior physician (AR), who is familiar with administrative data and with Humana's enhancement of the Diabetes Complications Severity Index.[12] A second physician (JD) then performed a check on this work and created code-scoring tables for each of the CCI dimensions, showing separate codes for the original Deyo *ICD-9* CCI, the CDMF CCI with *ICD-9* codes, and the CDMF CCI applied to *ICD-10*.

These 3 researchers then resolved any remaining inconsistencies. An SAS program was created that reflected the *ICD-9* scoring modifications and the new *ICD-10* scoring system. In an iterative process, the prevalence of the 19 conditions was compared between *ICD-9* and *ICD-10* populations to confirm the performance of the code, and modifications were made in response to any discrepancies.

Results

In several of the analyses, the new *ICD-9* and *ICD-10* scoring systems yielded comparable findings across similar

populations. **Appendix II Table SII-1** (online) shows the composition of the three 1-year population panels. The populations grew from 1,791,171 to 2,163,082 from the first (October 2013-September 2014) to the third (October 2015-September 2016) panel. The demographics were very similar between the 3 panels, with a near-identical distribution of the age-sex subgroups. From the first to the third panel, the populations were on average 0.16 years younger, included 0.69% more men, and included 2.59% more individuals of nonwhite race. Although the differences were small, they were significant (nonoverlapping 95% confidence intervals [CIs]) as a result of the size of the populations.

Appendix II Table SII-1 also presents the mean CCI scores. Although the mean CCI scores were not significantly different between the first and second panels, there was a significant decrease, as shown by nonoverlapping 95% CIs, from the second panel (mean CCI score, 4.915) to the third panel (mean CCI score, 4.883) with the shift from *ICD-9* to *ICD-10*. The number and proportion of individuals with each of the 19 conditions, after application of the 6 condition hierarchies, is shown in **Appendix II Table SII-2** (online); these data reveal a similar morbidity profile across the 3 populations. There was some shifting of classification within hierarchies with the transition from *ICD-9* to *ICD-10*, notably with a greater proportion of diabetes complications and metastatic cancer present in the *ICD-10* era. Other changes occurred steadily from the earliest to the latest panels, indicating changes in enrollment composition from year to year and/or possible population morbidity drift, rather than an artifact of changes in the *ICD* diagnosis classification system.

Appendix II Tables SII-3a and **SII-3b** (online) show the distribution of CCI scores. In the absence of age adjustment, more than 66% of the population had at least 1 CCI condition category (score of ≥1), with the prevalence steadily decreasing from no condition to the maximum of 20 conditions for a few individuals in the first and third panels (Appendix II Table SII-3a). With the age adjustment, the minimum CCI score was 2 and the mode was 3. The distribution was right skewed and nearly identical for all panels (Appendix II Table SII-3b).

The 2 approaches to validation yielded expected results. **Figure 1** shows that mean inpatient admissions per 1000 per year increased monotonically as CCI score values increased from 2 to a capped value of ≥15. **Appendix II Table SII-4** (online) reveals nonoverlapping CIs for the means within all 3 panels. The same pattern persisted, again with nonoverlapping CIs, after adjustment for race and sex (**Table 2**). These data suggest a near-linear relationship with a slightly increasing slope from low to high CCI score level. The 3 utilization models explained 16.8%, 16.7%, and 16.6% of the variability within the 3 panels.

Table 2 Adjusted Same-Year Inpatient Admissions, per 1000

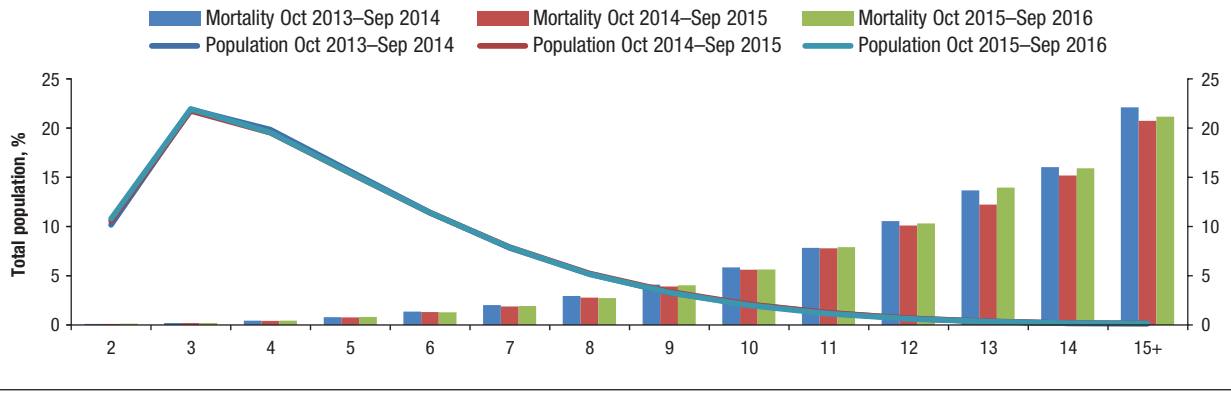
Model covariate	Oct 2013-Sept 2014 (*ICD-9*) Change in mean admissions/1000 (95% CI)	Oct 2014-Sept 2015 (*ICD-9*) Change in mean admissions/1000 (95% CI)	Oct 2015-Sept 2016 (*ICD-10*) Change in mean admissions/1000 (95% CI)
Male sex (referent, female)	−17.8 (−19.5 to −16.2)	−16.9 (−18.4 to −15.4)	−14.8 (−16.3 to −13.4)
Race (referent, white)			
Black	−46.4 (−49.1 to −43.8)	−46.5 (−48.9 to −44.1)	−38.9 (−41.0 to −36.8)
Hispanic	−98.6 (−105.8 to −91.9)	−86.7 (−93.3 to −80.1)	−76.4 (−82.5 to −70.4)
Other	−37.1 (−42.1 to −32.1)	−35.1 (−39.4 to −30.7)	−40.0 (−43.8 to −36.2)
CCI score (referent, 2)			
CCI 3	16.0 (12.9 to 19.1)	16.7 (13.9 to 19.5)	15.8 (13.2 to 18.4)
CCI 4	54.4 (51.2 to 57.6)	54.8 (51.9 to 57.6)	50.9 (48.2 to 53.5)
CCI 5	113.3 (110.0 to 116.6)	111.4 (108.4 to 114.4)	103.4 (100.6 to 106.2)
CCI 6	194.2 (190.7 to 197.8)	188.2 (185.0 to 191.4)	175.5 (172.5 to 178.5)
CCI 7	297.4 (293.5 to 301.3)	290.9 (286.4 to 293.5)	271.9 (268.6 to 275.2)
CCI 8	425.2 (420.8 to 429.6)	417.6 (413.6 to 421.7)	395.2 (391.4 to 399.0)
CCI 9	593.2 (588.0 to 598.3)	570.3 (565.6 to 575.0)	554.6 (550.2 to 559.1)
CCI 10	787.0 (780.8 to 793.2)	768.1 (762.4 to 773.8)	734.4 (729.0 to 739.8)
CCI 11	991.6 (983.8 to 999.4)	981.6 (974.4 to 988.7)	960.1 (953.3 to 967.0)
CCI 12	1228.7 (1218.5 to 1238.9)	1229.7 (1220.4 to 1239.0)	1191.0 (1182.0 to 1199.9)
CCI 13	1509.9 (1496.2 to 1523.6)	1457.9 (1445.4 to 1470.4)	1416.1 (1404.1 to 1428.2)
CCI 14	1739.7 (1720.6 to 1758.8)	1666.0 (1648.7 to 1683.4)	1626.8 (1610.4 to 1643.3)
CCI 15+	2079.4 (2059.6 to 2099.2)	1991.0 (1972.9 to 2009.2)	1944.9 (1928.2 to 1961.6)

CCI indicates Charlson Comorbidity Index; CI, confidence interval; *ICD-9, International Classification of Diseases, Ninth Revision*; *ICD-10, International Classification of Diseases, Tenth Revision*.

Figure 2 shows the CCI score prevalence (line graph) and the corresponding mortality risk (bar chart) by panel. The line plots demonstrate a Pareto-like (right-skewed) distribution of each population across the morbidity spectrum and a near-linear, monotonic increase in risk from the lowest to the highest CCI score level. There was a very slight increase in mortality versus CCI score slope from low to high CCI score level. **Table 3** also shows that the risk for mortality increased monotonically as the CCI score increased, and the 95% CIs were nonoverlapping. After adjustment for sex and race, the same pattern persisted for relative risk estimates, except for a slight overlap between CCI score levels 13 and 14 in the *ICD-10* panel (**Table 4**). All relative risk estimates were significant (P <.0001).

The comparison of scores and prevalence according to the Deyo system and CDMF *ICD-9* system showed the expected differences (**Table 5**). For individuals identified according to the CDMF *ICD-9* system as having HIV infection but not AIDS, the mean CCI score was lower

Figure 2 Prevalence of CCI Score (Line Graph) and Mortality (Bar Chart) as a Percentage of Total Individuals in Each of 3 Consecutive Panels[a]



[a]Each panel includes individuals aged ≥65 years who were enrolled in a Medicare Advantage plan continuously for 12 months.
CCI indicates Charlson Comorbidity Index.

Table 3 Three-Month Mortality Rates, by CCI Score Level

	Oct 2013-Sept 2014 (*ICD-9*)		Oct 2014-Sept 2015 (*ICD-9*)		Oct 2015-Sept 2016 (*ICD-10*)	
CCI score	Deaths, N	Mortality, % (95% CI)	Deaths, N	Mortality, % (95% CI)	Deaths, N	Mortality, % (95% CI)
2	182,155	0.10 (0.08-0.11)	216,931	0.10 (0.09-0.12)	233,257	0.12 (0.11-0.14)
3	391,886	0.18 (0.17-0.19)	446,029	0.18 (0.16-0.19)	473,993	0.18 (0.17-0.19)
4	355,262	0.36 (0.34-0.38)	400,801	0.35 (0.33-0.37)	422,856	0.36 (0.35-0.38)
5	279,579	0.66 (0.63-0.69)	316,130	0.63 (0.60-0.60)	333,952	0.66 (0.64-0.69)
6	204,762	1.11 (1.06-1.15)	234,164	1.06 (1.01-1.10)	246,482	1.05 (1.01-1.09)
7	140,435	1.60 (1.60-1.70)	162,471	1.50 (1.50-1.60)	170,387	1.60 (1.50-1.60)
8	92,981	2.40 (2.30-2.50)	107,559	2.20 (2.10-2.30)	111,999	2.20 (2.10-2.30)
9	59,228	3.30 (3.20-3.40)	70,022	3.10 (3.20-3.40)	71,370	3.20 (3.10-3.40)
10	37,438	4.70 (4.50-4.90)	43,476	4.50 (4.30-4.70)	43,640	4.50 (4.30-4.70)
11	22,045	6.30 (6.00-6.60)	25,672	6.20 (5.90-6.50)	25,336	6.30 (6.00-6.60)
12	12,295	8.40 (8.00-8.90)	14,226	8.10 (7.60-8.50)	14,166	8.30 (7.80-8.70)
13	6646	10.90 (10.20-11.70)	7691	9.80 (9.10-10.40)	7685	11.20 (10.50-11.70)
14	3345	12.80 (11.70-14.00)	3937	12.10 (11.10-13.20)	4047	12.70 (11.70-13.80)
15+	3114	17.70 (16.30-19.00)	3589	16.60 (15.40-17.80)	3912	16.90 (15.80-18.10)

CCI indicates Charlson Comorbidity Index; CI, confidence interval; *ICD-9, International Classification of Diseases, Ninth Revision*; *ICD-10, International Classification of Diseases, Tenth Revision*.

according to the CDMF *ICD-9* score than according to the Deyo score. Nonoverlapping CIs showed these differences to be significant. The Deyo and the CDMF *ICD-9* scores were similar in the group identified by the new *ICD-9* system as having AIDS.

In a similar comparison in the subpopulation with renal disease, the CDMF *ICD-9* system CCI score was lower than the Deyo score in the group of individuals identified by the CDMF system as having mild or moderate renal disease, and the CDMF *ICD-9* score was higher than the Deyo score in the group with severe renal disease; the CIs did not overlap.

In other words, compared with the Deyo system, the CDMF *ICD-9* system differentiated more sharply between individuals with mild-to-moderate renal disease and severe renal disease: a difference of 2.84 points (CDMF *ICD-9* system) versus a difference of 0.81 (Deyo system). Compared with the Deyo system, the CDMF *ICD-9* system identified slightly more individuals with diabetes and was slightly more likely to identify individuals as having severe diabetes, but the CIs overlapped considerably.

The AUC-ROC values for the logistic regression models for near-term mortality were similar for the CDMF *ICD-9* system (0.8) and the Deyo system (0.791).

A model of the CDMF *ICD-10* system had an AUC-ROC value of 0.804.

Discussion

This study tested the use of a new CCI coding and scoring scheme (CDMF CCI) in 3 population panels of demographically and clinically similar patients in a Medicare Advantage plan. The third panel represented the first 12 months after the adoption in the United States of the *ICD-10* codes system. Unadjusted and sex- and race-adjusted analyses of the association of CCI score with same-year inpatient admissions and with near-term mortality showed similar patterns and demonstrated the validity of the CDMF scheme. A comparison of mean scores based on the Deyo system and the CDMF *ICD-9* system revealed that by not differentiating between HIV infection and AIDS, the Deyo system may overestimate mortality risk for people with HIV infection only, which is inconsistent with the intent of the original CCI system to specifically identify the mortality risk associated with AIDS.

A similar performance comparison also suggested that the new system differentiates well between individuals with mild-to-moderate renal disease and those with severe renal disease. A significant difference in the ability of the CDMF *ICD-9* and the Deyo systems to identify individuals with diabetes was not detected, perhaps because of the relatively low prevalence of secondary diabetes. The overall accuracy of the CDMF and the Deyo CCI schemes was very similar.

The ultimate validation of any claims-based CCI instrument would entail a comparison with medical records data. The degree to which the new instrument proposed here, or any previously published claims-based instrument, is consistent with what might have been detected in the medical record is beyond the scope of this publication. Rather, it was the intent of this effort to lay the groundwork for such an investigation by anchoring the new instrument on the original Charlson instrument.

Choosing Medicare Advantage populations of individuals aged ≥65 years made it possible to investigate the prevalence of a condition in which morbidity was likely. A strength of the CDMF coding scheme is the size and heterogeneous morbidity of the test populations used to evaluate the scheme. The greatest advantage of testing in this population was revealed by the wide morbidity spectrum in each population panel and the consistent distribution across the panels. Although slight demographic trends were observed across time, the differences were small enough to eliminate concern when comparing the prevalence of a condition between years.

No attempt was made to compare this instrument's condition prevalence performance with that of other claims-based CCI instruments described in the literature. Rather, the primary goals were to make this new instrument reflect Charlson's original chart-review instrument as closely as possible and reflect the current understanding of mortality risk associated with specific conditions and severities of conditions. Given the lack of a distinction between AIDS and HIV infection and the limited use of condition hierarchies in previously published CCI instruments,[1,3,7-9] a fresh start with the original CCI version[1] as the benchmark constituted a simpler approach for our new scheme.

Although the prevalence of a condition was generally similar across the 3 time periods, a few differences were observed between the *ICD-9* and *ICD-10* eras. The most substantial discontinuity had to do with diabetes, where the condition was more likely to be classified as severe in the *ICD-10* era. The recently introduced *ICD-10* in the United States forces providers and coders to specify the

Table 4 Adjusted Mortality Risk (Robust Poisson Regression)

Model covariate	Oct 2013-Sept 2014 (*ICD-9*) Relative risk (95% CI)	Oct 2014-Sept 2015 (*ICD-9*) Relative risk (95% CI)	Oct 2015-Sept 2016 (*ICD-10*) Relative risk (95% CI)
Male sex (referent, female)	1.08 (1.05-1.11)	1.10 (1.07-1.13)	1.08 (1.05-1.11)
Race (referent, white)			
Asian	0.76 (0.63-0.91)	0.55 (0.45-0.67)	0.55 (0.46-0.66)
Black	0.69 (0.66-0.72)	0.69 (0.66-0.72)	0.73 (0.70-0.76)
Hispanic	0.51 (0.44-0.58)	0.56 (0.49-0.64)	0.55 (0.48-0.62)
North American	0.83 (0.59-1.17)	0.96 (0.71-1.29)	1.40 (1.10-1.80)
Other	0.57 (0.48-0.68)	0.47 (0.39-0.56)	0.63 (0.55-0.73)
Unknown	0.57 (0.38-0.83)	0.58 (0.43-0.79)	0.79 (0.63-1.00)
CCI score (referent, 2)			
CCI 3	1.82 (1.05-1.11)	1.70 (1.50-2.00)	1.50 (1.30-1.70)
CCI 4	3.70 (3.10-4.30)	3.40 (2.90-3.90)	3.00 (2.60-3.40)
CCI 5	6.70 (5.80-7.80)	6.10 (5.30-7.00)	5.50 (4.80-6.20)
CCI 6	11.40 (9.80-13.30)	10.20 (8.90-11.70)	8.70 (7.70-9.80)
CCI 7	16.80 (14.40-19.50)	14.80 (12.90-17.00)	12.80 (11.40-14.50)
CCI 8	24.40 (21.00-28.50)	21.80 (19.00-25.00)	18.30 (16.10-20.60)
CCI 9	34.10 (29.30-39.80)	30.70 (26.70-35.20)	26.70 (23.60-30.30)
CCI 10	48.50 (41.60-56.60)	44.00 (38.30-50.50)	37.60 (33.20-42.50)
CCI 11	65.00 (55.70-76.00)	60.90 (52.90-70.00)	52.40 (46.20-59.40)
CCI 12	87.60 (74.80-102.70)	79.10 (69.00-91.20)	68.50 (60.20-77.90)
CCI 13	113.20 (96.20-133.20)	95.60 (82.40-110.80)	92.40 (80.90-105.60)
CCI 14	133.10 (112.10-158.00)	118.60 (101.50-138.60)	105.90 (91.80-122.00)
CCI 15+	183.50 (155.50-216.60)	162.00 (139.30-188.30)	140.30 (122.40-160.70)

CCI indicates Charlson Comorbidity Index; CI, confidence interval; *ICD-9, International Classification of Diseases, Ninth Revision; ICD-10, International Classification of Diseases, Tenth Revision.*

Table 5 Comparison of the Deyo System and the CDMF *ICD-9* Performance: October 2014-September 2015 Panel

Comparing CCI scores within subpopulation identified with HIV/AIDS by Deyo system		
Presence of AIDS according to CDMF *ICD-9* system	**CCI instrument**	**Mean CCI (95% CI)**
HIV infection without AIDS (N = 1049)	Deyo CCI	11.10 (10.95-11.24)
	New CCI	8.22 (8.07-8.37)
HIV infection with AIDS (N = 241)	Deyo CCI	12.34 (11.97-12.70)
	New CCI	12.76 (12.37-13.15)
Prevalence of diabetes within overall panel (N = 2,038,848)		
Subpopulation	**CCI instrument**	**Patients with diabetes, % (95% CI)**
Diabetes	Deyo CCI	32.25 (32.18-32.31)
	New CCI	32.44 (32.38-32.50)
Mild-to-moderate	Deyo CCI	19.17 (19.12-19.22)
	New CCI	18.41 (18.35-18.46)
Severe	Deyo CCI	13.08 (13.03-13.12)
	New CCI	14.03 (13.99-14.08)
Comparison of CCI scores within subpopulation identified with renal disease by Deyo system		
Disease severity per CDMF *ICD-9* system	**CCI instrument**	**Mean CCI (95% CI)**
Mild/moderate renal disease (N = 337,119)	Deyo CCI	7.70 (7.69-7.70)
	New CCI	7.05 (7.05-7.06)
Severe renal disease (N = 44,703)	Deyo CCI	8.51 (8.49-8.54)
	New CCI	9.89 (9.87-9.91)

CCI indicates Charlson Comorbidity Index; CI, confidence interval; *ICD-9*, *International Classification of Diseases, Ninth Revision.*

diabetes type and increases the number of categories from 3 to 5, which could lead to greater scrutiny of the medical record by the coder and thus a greater likelihood of accurate documentation of diabetes severity. In another example of discontinuity, the *ICD-10* population showed a greater prevalence of metastatic cancer, which was likely a result of the dramatically greater specificity of site required by *ICD-10*.

A third discrepancy between the *ICD-9* and *ICD-10* populations of this study was a slight decrease in the prevalence of cerebrovascular disease. The breadth of conditions in this category, however, is large, which may have made it especially difficult to create comparable categories between the 2 code sets. Alternatively, the slight decrease in prevalence may represent diminished coding accuracy, which could affect the ability of the CCI score to predict mortality as a result of cerebral morbidity. However, to our knowledge, there is no evidence that the *ICD-10* codes for cerebrovascular disease do not perform as well as the *ICD-9* codes.

A final discrepancy between the *ICD-9* and *ICD-10* coding systems is related to our new instrument's ability to improve specificity by introducing the 6 explicitly specified condition hierarchies. The designation of AIDS as a condition category and HIV-positive status as a lesser condition within that disease spectrum was a particularly significant contribution. The mean AIDS scores for the 3 populations were relatively close, but there was a slight decrease in score with the introduction of *ICD-10*. This decrease could be the result of an actual change in morbidity, but it could also be a result of the newness of *ICD-10* to the healthcare system.

The phenomenon of "diagnosis-related group creep" is an example where the payment model created incentives for increasing coding intensity as providers became accustomed to the model. Given the financial incentives that payment models have implemented in more recent times (eg, episode-based payment for hospital stays and risk-adjusted payments to providers and health plans), a slight upward drift in CCI scores based on the new instrument may occur as familiarity with *ICD-10* increases.

Within each population, the right-skewed distribution of CCI scores supports the use of the CDMF CCI instrument in triaging patients for possible disease- and case-management programs. The smooth, curvilinear relationship between CCI level and the risk for resource consumption or mortality, as well as the generally nonoverlapping CIs for estimates of these associations, suggest that individual CCI levels are associated with unique levels of risk.

The performance of this new instrument as a predictor of mortality over a longer time frame, which is consistent with the validation methods used by Charlson and colleagues,[1] remains unknown and cannot be tested with *ICD-10* data for some time. This remains an area for future study, and an opportunity to adjust the new instrument's condition point values. Another useful next step would be to adapt this new instrument to one that could be administered either in a chart review setting or in patient triage, such as at a renal dialysis center.

Limitations

The limitations of this study include those inherent to analyses based on claims data, including incorrect coding and missing data. Validation of the new coding scheme was based on prediction of same-year inpatient admissions and near-term mortality, whereas the original instrument was validated against long-term mortality.

Our ability to test association with mortality was hampered by the lack of long-term follow-up data in the *ICD-10* era, as was previously noted.

Future studies should aim to validate this new scoring scheme with long-term mortality data and to compare its performance in long-term prediction with earlier algo-

rithms. External validation of this new instrument in other populations with Medicare Advantage coverage and in traditional Medicare populations is required to confirm its general usefulness.

Conclusions

Our new, more granular, and clinically updated claims-based coding scheme for the CCI, using *ICD-9* and *ICD-10* versions, yielded condition-specific point values and overall scores that were consistent across 3 panels of individuals in a Medicare Advantage plan and were positively associated with same-year inpatient admissions as well as near-term mortality. The distribution of resulting CCI scores supports the use of the CDMF CCI scoring instrument in segmenting and prioritizing patients for case-management support. In addition, this new instrument allows for a more precise understanding of chronic disease at a population level, thus allowing health systems and health plans to design services and benefits to meet multifactorial clinical needs. This research sets the stage for further testing with long-term follow-up data and for adaptation of the CDMF coding scheme to a chart review instrument. ■

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