HHS Public Access

Author manuscript

Cancer. Author manuscript; available in PMC 2019 May 01.

Published in final edited form as:

Cancer. 2018 May 01; 124(9): 2018–2025. doi:10.1002/cncr.31269.

Adapting the Elixhauser Comorbidity Index for Cancer Patients

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Abstract

Backgrounds—We aimed to adapt the Elixhauser comorbidity index for four cancer-specific populations (breast, prostate, lung, and colorectal) and compare three versions of the Elixhauser comorbidity score (individual comorbidities, summary comorbidity score, and cancer-specific summary comorbidity score) with three versions of the Charlson comorbidity score in predicting 2-year survival in four cancers.

Methods—This cohort study used Texas Cancer Registry linked Medicare data from 2005–2011 of older patients diagnosed with breast (n=19,082), prostate (N=23,044), lung (n=26,047), or colorectal (n=16,693) cancer. For each cancer cohort, the data were split into training and validation cohorts. In the training cohort, competing risk regression was used to model the association of Elixhauser comorbidities with 2-year non-cancer mortality, and cancer-specific weights were derived for each comorbidity. In the validation cohort, competing risk regression was used to compare three versions of the Elixhauser comorbidity score with three versions of the Charlson comorbidity score. Model performance was evaluated using c-statistics.

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Conflicts of Interest: All authors report no conflicts of interest.

Author Disclosures: None

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Results—The 2-year non-cancer mortality rate was 14.5% (lung), 11.5% (colorectal), 5.7% (breast), and 4.1% (prostate cancer). Cancer-specific Elixhauser comorbidity scores (c-statistics: breast=0.773, prostate=0.772, lung=0.579, colorectal=0.680) performed slightly better than cancer-specific Charlson comorbidity scores, i.e., the National Cancer Institute combined index (breast=0.762, prostate=0.767, lung=0.578, colorectal=0.674). Individual Elixhauser comorbidities performed best (c-statistics: breast=0.779, prostate=0.783, lung=0.587, colorectal=0.687).

Conclusions—The cancer-specific Elixhauser comorbidity score performed as well as or slightly better than the cancer-specific Charlson comorbidity score in predicting 2-year survival. If sample size permits, using individual Elixhauser comorbidities may best control for confounding in cancer outcomes research.

Keywords

Charlson comorbidity score; Elixhauser comorbidity score; National Cancer Institute combined index; confounding control; comorbidity

INTRODUCTION

Comorbidity is common among cancer patients and affects cancer diagnosis, treatment, and outcomes.[1] Given the increased risk of comorbidities in the aging cancer population, improved methods to assess comorbidities are needed. Accurate measurement and control of comorbidities in cancer outcomes research is crucial to reduce confounding. Different methods such as the Charlson comorbidity score, the National Cancer Institute (NCI) combined index, and the Elixhauser comorbidity score are available to control for comorbidities.[2–4]

A comorbidity measure developed or adapted for a specific disease population performs better than a generic score.[5] The Charlson score includes 17 comorbidities and was originally developed to predict 1-year mortality using all inpatient data from one hospital and validated in breast cancer patients from another hospital.[2] Klabunde et al. modified the Charlson comorbidity index for breast, prostate, colorectal, and lung cancer patients using the Surveillance, Epidemiology, and End Results (SEER)-Medicare data.[3] This cancer-specific Charlson comorbidity score, called the NCI combined index, outperformed the original Charlson comorbidity score in predicting 2-year survival in cancer patients.

The Elixhauser comorbidity index includes 29 comorbidities.[4,6] A systematic review found that the Elixhauser comorbidity score performs better than Charlson comorbidity score in predicting mortality beyond 30 days.[7] In oral and colorectal cancer patients, two studies reported that the Elixhauser performed better than the Charlson comorbidity score in predicting three-year survival.[8,9] In contrast, one study showed better performance of the Charlson comorbidity score in bladder cancer patients.[10]

No consensus exists on the optimal method to define comorbidities in cancer.[1,11] While the Charlson comorbidity index has been adapted for cancer patients, the Elixhauser comorbidity index has not. Moreover, both Charlson and Elixhauser comorbidity measures

can be used as: (i) individual comorbidities, (ii) a summary score using generic weights, and (iii) a cancer-specific summary score using cancer-specific weights.

Modifying the Elixhauser comorbidity index for cancer-specific populations may improve its performance in this population. Therefore, the study objectives were to (i) adapt the Elixhauser comorbidity index for four cancer-specific populations and (ii) compare the performance of three versions of the Elixhauser comorbidity score with three versions of the Charlson comorbidity score in predicting 2-year survival in the four most common cancers diagnosed in the United States (breast, prostate, lung, and colorectal).

METHODS

Data Source and Study Sample

The study used the Texas Cancer Registry (TCR) linked Medicare data from 2005 to 2011. The TCR is linked with Medicare data under the guidance of NCI, TCR, and the Centers for Medicare and Medicaid Services. This linked data set provides detailed information on elderly adults with cancer in Texas, and approximately 98% of all people aged 65 and older in TCR are matched with Medicare enrollment and claims files. Similar to SEER files, TCR provides detailed information on patient demographics and the clinical characteristics of cancer such as stage of disease, tumor size, the first course of therapy, and cause of death, i.e., cancer or non-cancer.[12] Medicare data provide information on the patient's health care utilization. Medicare files used for this study included the denominator file, the Medicare provider analysis and review file (MedPAR) for inpatient claims, the carrier claims file, and the outpatient Standard Analytical File.

Four cancer-specific cohorts were developed by including older adults (age >65 years) diagnosed with breast, prostate, lung, or colorectal cancer. Patients were included in the final cohorts if they had continuous enrollment in Medicare Parts A and B, with no health maintenance organization enrollment, in the year before cancer diagnosis.

Outcome

The study outcome was 2-year non-cancer mortality; cancer mortality was treated as a competing risk. The underlying cause of death was determined from death certificate data as recorded by the TCR. The TCR is equivalent to SEER in timeliness, completeness and data quality.[21] The agreement between the cause of death reviewed from the medical charts compared to SEER reported cause of death is over 95%.[13,14] Non-cancer mortality was selected as an outcome because of our focus on deaths attributable to comorbid conditions; this method was consistent with the Charlson, Klabunde and NCI methodologies.[2,3,15]

Covariates

Age, sex (for lung and colorectal cancer) and stage of cancer (local, regional, and distant) were included as covariates.

Comorbidity Scores

Medicare inpatient and outpatient claims data were used to identify comorbidities. We used a baseline one year to define comorbidity scores. Comorbidity was identified as when the patient had at least one diagnosis from the inpatient file or at least two distinct diagnoses recorded >30 days apart from the outpatient file in the 365 days before cancer diagnosis.[3,16]

Charlson comorbidity score—The Charlson comorbidity index includes 17 comorbidities. The original Charlson comorbidity score was derived using inpatient data from 607 patients from New York Hospital-Cornell Medical Center and validated in 685 women with breast cancer from Yale New Haven Hospital. Weights for each comorbidity was derived and summed to obtain a summary comorbidity score. Klabunde et al. adapted the Charlson comorbidity index for four cancers and derived cancer-specific weights.[3] This cancer-specific Charlson comorbidity score was termed the NCI combined index. The documentation and SAS codes for the NCI combined index are available on the NCI website.[17]

In this study, we used three versions of the Charlson comorbidity score: (i) individual Charlson comorbidities, (ii) a summary Charlson comorbidity score derived using original weights,[2] and (iii) a cancer-specific summary Charlson comorbidity score, i.e., NCI combined index, derived using cancer-specific weights.[3]

Adapting the Elixhauser Comorbidity Score for Cancer Patients

The Elixhauser comorbidity index includes 29 disease conditions.[4] Walraven et al. developed weights for 29 Elixhauser comorbidities to operationalize the score as a summary score.[6] However, the weights were derived using inpatient data from a hospital, and they were not cancer-specific. Therefore, first we constructed cancer-specific weights for the Elixhauser comorbidity score. To do so, we performed a 50:50 split to derive training and validation cohorts for each cancer. The derivation cohort was used to obtain cancer-specific weights for Elixhauser comorbidities. We derived weights for each cancer cohort separately.

We used three versions of the Elixhauser comorbidity index: (i) individual Elixhauser comorbidities, (ii) a summary Elixhauser comorbidity score derived using Walraven weights, [6] and (iii) a cancer-specific Elixhauser comorbidity score derived using cancer-specific weights.

Statistical Analyses

Descriptive statistics were performed in the four cancer-specific cohorts to describe demographics, death rates, and comorbidity prevalence. A training sample was used to derive cancer-specific weights for the Elixhauser comorbidity score. Fine and Gray's competing risk model was used to model the association of Elixhauser comorbidities with 2-year survival, while controlling for age, gender, and stage of cancer. The beta coefficients obtained from the competing risk model were multiplied by 10 and rounded to the nearest integer to obtain weights for each comorbidity.[18] This was done separately for each cancer cohort.

We used the validation sample to compare the performance of three versions of the Elixhauser comorbidity score with three versions of the Charlson comorbidity score. Fine and Gray's competing risk model was used to predict 2-year non-cancer mortality. First, we constructed a baseline model that included age, gender, and stage of cancer. Six models were constructed: three for the Elixhauser comorbidity score and three for the Charlson comorbidity score. All models were compared using c-statistics and Akaike information criteria (AIC). Statistical comparison between c-statistics was performed using bootstrapped estimates with 1,000 replicates.

All statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC), STATA 13.2 (STATA Inc., College Station, TX) and R (R version 3.4.0). This study was considered non-human subjects research and was deemed exempt by the Institutional Review Board of the University of Texas Medical Branch.

RESULTS

Descriptive Statistics

The overall study sample included 19,082 breast, 23,044 prostate, 26,047 lung, and 16,963 colorectal cancer patients. Table 1 reports the descriptive statistics for the four cancers by stage of diagnosis. The mean age of patients ranged from 73.6 ± 5.8 years (prostate cancer) to 77.2 ± 7.3 years (colorectal cancer). Over 92% of breast and prostate cancer, 83% of colorectal cancer, and 50% of lung cancer patients were diagnosed with local or regional stage of cancer. The overall 2-year mortality rate was highest for lung (73.9%) followed by colorectal (33.8%), breast (12.1%), and prostate (8.1%) cancer. The 2-year non-cancer mortality rate followed a similar pattern: lung (14.5%), colorectal (11.5%), breast (5.7%), and prostate (4.1%) cancer. The cancer and non-cancer death rates were higher for patients with advanced stage of cancer.

Comorbidity Prevalence

Table 2 displays the prevalence of the Charlson and Elixhauser comorbidities among the four cancers. Among Charlson comorbidities, diabetes without chronic complications, chronic pulmonary disease, congestive heart failure, diabetes with complications, and moderate or severe renal disease were the most prevalent conditions. Among Elixhauser comorbidities, hypertension, uncomplicated diabetes, chronic pulmonary disease, hypothyroidism, and deficiency anemia were the most prevalent conditions.

Adapting the Elixhauser Comorbidity Score for Cancer Patients

The training dataset included 9,391 breast, 11,346 prostate, 12,804 lung, and 8,314 colorectal cancer patients. Using training datasets for the four cancers, we derived cancer-specific weights for Elixhauser comorbidities (Table 3). The weights for comorbidities differed slightly by cancer type. For instance, the weight for congestive heart failure were 7 for the breast cancer cohort, 9 for the prostate cancer cohort, 1 for the lung cancer cohort, and 3 for the colorectal cancer cohort. Four sets of cancer-specific weights were then used to calculate cancer-specific summary Elixhauser comorbidity scores.

Comparative Performance of Elixhauser with Charlson Comorbidity Score: Six Models

The validation dataset included 9,691 breast, 11,698 prostate, 13,243 lung, and 8,649 colorectal cancer patients. Table 4 reports the c-statistics of the different models. The c-statistics of the baseline model that included age, gender, and cancer stage was 0.722 for the breast, 0.725 for the prostate, 0.548 for the lung, and 0.629 for the colorectal cancer cohort. The addition of any comorbidity score to the baseline model improved the c-statistics for all four cancers (Table 4).

For both Elixhauser and Charlson comorbidity indices, a model with individual comorbidities performed better than models with summary comorbidity scores (Table 4). Individual Elixhauser comorbidities included in the model performed better than Charlson comorbidities used as individual variables (breast: 0.779 vs. 770, p=0.028; prostate: 0.783 vs. 0.772, p=0.011; lung: 0.587 vs. 579, p=0.046; colorectal: 0.687 vs. 679, p=0.042). Among summary comorbidity scores, a cancer-specific summary Elixhauser comorbidity score (breast: 0.773, prostate: 0.772, lung: 0.579, colorectal: 0.680) performed as well as or slightly better than a summary Elixhauser comorbidity score (breast: 0.764, prostate: 0.771, lung: 0.580, colorectal: 0.677), a summary Charlson comorbidity score (breast: 0.763, prostate: 0.762, lung: 0.576, colorectal: 0.672) or a cancer-specific summary Charlson comorbidity score (breast: 0.762, prostate: 0.767, lung: 0.578, colorectal: 0.674) (Table 4). AIC results are presented in Table 5. AIC results were similar to those using c-statistics. A cancer-specific summary Elixhauser comorbidity score had slightly lower AIC compared to other summary comorbidity scores, indicating better performance.

DISCUSSION

We adapted the Elixhauser comorbidity index for cancer patients and compared the performance of three versions of the Elixhauser comorbidity index with three versions of the Charlson comorbidity index in their ability to predict 2-year survival. For both Charlson and Elixhauser comorbidity indices, the use of individual comorbidities performed better than summary comorbidity scores; Elixhauser comorbidities as individual variables performed the best. Among summary scores, we found that the cancer-specific summary Elixhauser comorbidity score performed as well as or slightly better than generic and cancer-specific summary Charlson comorbidity scores.

Klabunde et al. derived cancer-specific weights for the Charlson comorbidity score. However, to our knowledge, this is the first study to adapt the Elixhauser comorbidity score for cancer patients by deriving four cancer-specific weights, and comparing them with three commonly-used versions of the Charlson comorbidity score. Several studies have shown that comorbidity scores predict survival and health-related quality of life in colorectal cancer patients.[19, 20, 21] Lieffers et al. reported that individual Elixhauser comorbidities (c=0.864) performed better than individual Charlson comorbidities (c=0.831) in predicting 2-year survival in colorectal cancer patients.[8] Chang et al. showed that Elixhauser performed better than Charlson when using a summary comorbidity score (c=0.654 vs 0.646) or separate indicator variables for comorbidities (c=0.677 vs 0.651) in oral cancer patients.[9] However, one study of bladder cancer patients showed that Charlson (c=0.798) performed better than Elixhauser (c=0.770) in predicting 5-year survival; the authors used the number of

comorbidities (0, 1, 2, 3, 4, ≥5) rather than a summary score or individual comorbidities.[10] Our findings extend the evidence on the performance of comorbidity indices in cancer outcomes research via our comprehensive comparison for four common types of cancer.

The use of Elixhauser comorbidities as individual variables had the best performance followed by the cancer-specific summary Elixhauser comorbidity score. This result is consistent with prior studies that showed that individual comorbidities have the best performance.[18,22] Moreover, the better performance of the Elixhauser comorbidity index may be attributed to the fact that it has more comorbidities than the Charlson comorbidity index. If sample size is not an issue, the use of individual comorbidities should be the first choice. However, summary comorbidity scores can be useful to describe the overall burden of comorbidities in a single measure and they offer advantages when the sample size is low and higher statistical power is desired.

Comorbidities are common in older adults with cancer and affect the disease progression, stage at diagnosis, treatment, and outcomes. No gold standard method exists to control for comorbidities in cancer outcomes research.[11] One study identified 21 separate approaches to measuring comorbidities in cancer patients. The authors concluded that, for administrative claims data, the Charlson comorbidity score, NCI combined index, and Elixhauser comorbidity scores were the best option, and the NCI combined index may be the best because of its cancer-specific weights.[11] The cancer-specific weights we derived for Elixhauser showed the same or slightly better performance than a cancer-specific Charlson comorbidity score, i.e., the NCI combined index.

Some of the comorbidities (hypertension, obesity) were negatively associated with survival. This has been found in other studies.[6] The explanation may vary with the comorbidity. For example, a hypertension diagnosis might be linked to access to medical care and to an increased likelihood that elevated blood pressure is recognized and treated. An obesity diagnosis indicates absence of cachexia, which is common in cancer patients and poor sign.

Our study had following strengths. We operationalized comorbidity indices in different ways and used Fine and Gray’s competing risk model to determine the asosciation of comorbidities with non-cancer mortality. However, our findings should be interpreted in the context of the study design. We used cancer registry data from Texas and our findings may not be generalizable to other populations. Moreover, we used TCR-Medicare linked data, and these findings may not be applicable to patients 65 years of age or less. Consistent with Charlson and Klabunde’s methods, we used non-cancer mortality as an outcome. The lower c-index among lung cancer patients suggests potential limitations in applying the ‘one size fits all’ approach using comorbidity scores even when considering cancer-specific scores. The inability to control for unknown confounders using large retrospective registry data is an inherent limitation. Due to high correlation between summary Charlson and Elixhauser comorbidity scores, we did not use them together in the same model. Future research can compare cancer-specific Elixhauser comorbidity scores with a pharmacy-based comorbidity index for cancer patients to determine if it improves the prediction of mortality.[23] Use of the most appropriate comorbidity score will not be a panacea to control all confounding; several sources of cofounding such as disease severity, functional status, social support and health

behavior need to be controlled to make unbiased treatment estimates in observational studies.

CONCLUSIONS

In conclusions, we adapted the summary Elixhauser comorbidity score for four cancer-specific populations. Elixhauser comorbidities used as individual variables in the model performed the best and, among summary scores, the cancer-specific summary Elixhauser comorbidity score performed equally to or slightly better than either the generic or cancer-specific Charlson comorbidity score. If sample size allows, one should use individual Elixhauser comorbidities to control for confounding due to comorbidities in cancer outcomes research. For small samples that require using a summary comorbidity score, cancer-specific summary Elixhauser comorbidity or Charlson comorbidity scores work equally well. The use of comorbidity scores is growing in cancer outcomes research. With changes in coding practices (ICD-9-CM to ICD-10-CM), future work should adapt algorithms to the new coding system and re-evaluate the applicability and comparative performance of comorbidity scores in cancer patients.

Acknowledgments

The authors thank Sarah Toombs Smith, PhD, Science Editor and Assistant Professor in the Sealy Center on Aging, University of Texas Medical Branch at Galveston, for her editorial assistance. Dr. Toombs Smith received no compensation for her assistance beyond her university salary.

Funding: Supported by the Cancer Prevention and Research Institute of Texas (RP1607674), National Cancer Institute (K05 CA134923), Agency for Healthcare Research and Quality (R24 HS022134), Clinical and Translational Science Award Mentored Career Development (KL2) Award (KL2TR001441) from the National Center for Advancing Translational Sciences, National Institutes of Health (NIH).

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Table 1

Descriptive Statistics of Study Cohorts

Cancer site and stage	Number (%)	Age in years, mean ± SD	Female Gender, %	2-year Death Rate	
				Cancer, Number (%)	Non-cancer, Number (%)
Breast	19,082 (100)	75.8 ± 7.0	100	1,219 (6.4)	1,085 (5.7)
Local	12,523 (65.6)	75.7 ± 6.9	100	286 (2.3)	566 (4.5)
Regional	5,098 (26.7)	75.9 ± 7.1	100	376 (7.4)	344 (6.8)
Distant	1461 (7.7)	76.5 ± 7.4	100	557 (38.1)	175 (12.0)
Prostate	23,044 (100)	73.6 ± 5.8	0	926 (4.0)	952 (4.1)
Local/regional	21,642 (93.9)	73.3 ± 5.6	0	394 (1.8)	738 (3.4)
Distant	1,402 (6.1)	77.6 ± 7.6	0	532 (38.0)	214 (15.3)
Lung	26,047 (100)	75.7 ± 6.5	48.4	15,474 (59.4)	3,775 (14.5)
Local	6,084 (23.4)	76.0 ± 6.3	52.2	1,833 (30.1)	855 (14.1)
Regional	6,705 (25.7)	75.4 ± 6.3	47.7	3,484 (52.0)	1,019 (15.2)
Distant	13,258 (50.9)	75.8 ± 6.6	47.1	10,157 (76.6)	1,901 (14.3)
Colorectal	16,963 (100)	77.2 ± 7.3	53.3	3,778 (22.3)	1,955 (11.5)
Local	7,730 (45.6)	77.2 ± 7.2	52.4	675 (8.7)	841 (10.9)
Regional	5,900 (34.8)	77.4 ± 7.4	54.5	1,097 (18.6)	661 (11.2)
Distant	3,333 (17.1)	76.9 ± 7.4	53.1	2,006 (60.2)	453 (13.6)

Abbreviation: SD, standard deviation.

Table 2

Prevalence of Charlson/NCI combined index and Elixhauser Comorbidities in Four Cancer Cohorts[a]

Comorbidities, %	Breast N = 19,082	Prostate N = 23,044	Lung N = 26,047	Colorectal N = 16,963
Charlson Comorbidities[b]				
Myocardial infarction	1.3	1.6	3.3	2.6
Congestive heart failure	6.4	4.7	11.7	10.8
Peripheral vascular disease	3.1	3.3	8.8	5.3
Cerebrovascular disease	4.4	3.9	7.1	6.0
Dementia	1.3	0.5	1.4	1.7
Chronic pulmonary disease	9.1	8.1	32.3	12.1
Connective tissue disease/Rheumatologic disease	2.3	1.0	2.7	1.8
Ulcer disease	0.6	0.5	1.0	1.3
Mild liver disease	0.23	0.13	0.4	0.3
Diabetes without chronic complications	16.4	15.4	17.0	18.8
Hemiplegia or paraplegia	0.3	0.3	0.6	0.5
Moderate or severe renal disease	3.8	3.7	5.4	5.5
Diabetes with complications/ESRD	4.3	2.8	3.9	4.9
Moderate or severe liver disease	0.09	0.02	0.13	0.16
AIDS	0.01	0.05	0.07	0.04
Elixhauser Comorbidities				
Congestive heart failure	6.5	4.8	11.5	10.5
Valvular disease	4.5	3.7	5.4	5.5
Pulmonary circulation disorders	1.0	0.6	1.5	1.2
Peripheral vascular disorders	6.0	5.3	13.1	8.8
Hypertension	58.1	49.8	58.0	57.4
Paralysis	0.7	0.6	1.0	1.1
Neurodegenerative disorders	4.7	2.5	4.7	5.5
Chronic pulmonary disease	10.4	9.1	34.0	13.0
Diabetes, uncomplicated	20.5	18.1	20.7	23.5
Diabetes, complicated	5.4	3.7	5.2	6.2
Hypothyroidism	16.4	4.9	10.5	11.3
Renal failure	3.7	3.7	5.5	5.3
Liver disease	0.5	0.4	0.7	0.6
Peptic ulcer disease, no bleeding	0.05	0.03	0.07	0.08
AIDS/HIV	0.01	0.05	0.07	0.04
Rheumatoid arthritis/collagen vascular diseases	3.1	1.3	3.3	2.3
Coagulopathy	1.4	1.3	1.8	1.7
Obesity	2.1	1.2	1.7	2.0
Weight loss	1.0	0.9	3.4	2.9
Fluid and electrolyte disorders	6.0	3.8	9.4	8.4

Comorbidities, %	Breast	Prostate	Lung	Colorectal
	N = 19,082	N = 23,044	N = 26,047	N = 16,963
Blood loss anemia	0.7	0.4	1.0	2.4
Deficiency anemia	10.9	7.5	14.7	22.3
Alcohol abuse	0.2	0.5	0.8	0.5
Drug abuse	0.05	0.05	0.14	0.04
Psychosis	2.6	1.2	2.4	2.3
Depression	4.3	1.6	4.4	3.9

[a]Charlson and Elixhauser used different algorithms to identify comorbidities. Therefore, the prevalnce of ceratin conditions may differ for both comorbidity indices.

[b]Both Charlson comorbidity and National Cancer Institute (NCI) combined index have the same comorbidities. They differ only in the weights assigned to each.

Table 3

Coefficients for Elixhauser Comorbidities for Four Cancers Derived from the Training Sample [a,b]

Elixhauser Comorbidities	Breast N = 9,391			Prostate N = 11,346			Lung N =12,804			Colorectal N = 8,314		
	β	HR	Weight	β	HR	Weight	β	HR	Weight	β	HR	Weight
Congestive heart failure	0.71	2.03	7	0.86	2.36	9	0.11	1.11	1	0.34	1.41	3
Valvular disease	0.08	1.08	1	0.12	1.13	1	0.13	1.14	1	0.13	1.14	1
Pulmonary circulation disorders	0.46	1.58	5	−0.21	0.81	−2	0.31	1.36	3	0.09	1.10	1
Peripheral vascular disorders	0.39	1.48	4	0.27	1.31	3	0.21	1.23	2	0.21	1.23	2
Hypertension	−0.11	0.90	−1	−0.08	0.93	−1	−0.04	0.96	0	−0.04	0.96	0
Paralysis	0.60	1.82	6	0.27	1.31	3	0.16	1.18	2	−0.25	0.78	−2
Neurodegenerative disorders	0.52	1.69	5	0.22	1.24	2	0.30	1.35	3	0.24	1.27	2
Chronic pulmonary disease	0.46	1.58	5	0.48	1.62	5	0.26	1.29	3	0.50	1.64	5
Diabetes, uncomplicated	0.33	1.40	3	0.22	1.25	2	−0.02	0.98	0	0.14	1.15	1
Diabetes, complicated	−0.07	0.93	−1	0.23	1.26	2	0.15	1.16	1	0.21	1.23	2
Hypothyroidism	0.07	1.07	1	−0.38	0.69	−4	0.10	1.11	1	0.14	1.15	1
Renal failure	0.28	1.33	3	0.15	1.16	1	0.19	1.21	2	0.15	1.16	1
Liver disease	0.65	1.91	6	−0.42	0.66	−4	−0.02	0.98	0	0.65	1.91	6
Rheumatoid arthritis/collagen vascular diseases	0.00	1.00	0	0.01	1.01	0	0.30	1.35	3	0.11	1.11	1
Coagulopathy	0.20	1.22	2	0.03	1.03	0	−0.15	0.86	−1	0.18	1.20	2
Obesity	−0.56	0.57	−6	−0.75	0.47	−7	−0.06	0.94	−1	−0.29	0.75	−3
Weight loss	0.28	1.32	3	0.09	1.09	1	0.26	1.30	3	0.28	1.32	3
Fluid and electrolyte disorders	0.17	1.18	2	0.40	1.49	4	0.03	1.03	0	0.26	1.30	3
Blood loss anemia	0.21	1.23	2	−0.63	0.53	−6	−0.03	0.97	0	0.13	1.14	1
Deficiency anemia	0.08	1.08	1	0.20	1.22	2	0.00	1.00	0	0.12	1.12	1
Alcohol abuse	0.19	1.21	2	0.94	2.56	9	−0.02	0.98	0	−0.09	0.91	−1
Psychosis	0.38	1.47	4	0.44	1.56	4	0.05	1.05	1	0.16	1.17	2
Depression	0.15	1.16	2	0.03	1.03	0	0.24	1.27	2	0.32	1.38	3

Abbreviations: β, regression coefficient; HR, hazards ratio.

[a]Weight is calculated as β*10 and rounded to the nearest integer.

[b] All models include age, gender, and stage of the cancer as covariates.

Table 4

Comparison of Comorbidity Scores in the Validation Sample, C-statistics[a]

	Breast N = 9,691	Prostate N = 11,698	Lung N = 13,243	Colorectal N = 8,649
Baseline model	0.722	0.725	0.548	0.629
Elixhauser comorbidity score				
Individual Elixhauser comorbidities	0.779	0.783	0.587	0.687
Summary Elixhauser comorbidity score	0.764	0.771	0.580	0.677
Cancer-specific summary Elixhauser comorbidity score	0.773	0.772	0.579	0.680
Charlson comorbidity score / NCI combined index				
Individual Charlson comorbidities	0.770	0.772	0.579	0.679
Summary Charlson comorbidity score	0.763	0.762	0.576	0.672
Cancer-specific summary Charlson comorbidity score or NCI combined index	0.762	0.767	0.578	0.674

[a]P-values for c-statistics comparison (significant p-values are bolded):

Model Comparison	Breast	Prostate	Lung	Colon
Elixhauser vs. Charlson – individual comorbidiites	**0.0284**	**0.0114**	**0.0462**	**0.0424**
Cancer-specific Elixhauser vs. generic Elixhauser comorbidity score	**0.0027**	0.8752	0.8878	0.5317
Cancer-specific Elixhauser vs. generic Charlson comorbidity score	**0.0100**	**0.0323**	0.4416	**0.0341**
Cancer-specific Elixhauser vs. NCI combined index	**0.0037**	0.2817	0.7018	0.1525
Generic Charlson comorbidity score vs. NCI combined index	0.7399	**0.0349**	0.5210	0.1606

Table 5

Comparison of Comorbidity Scores in the Validation Sample, Akaike Information Criterion (AIC)[a]

	Breast N = 9,691	Prostate N = 11,698	Lung N = 13,243	Colorectal N = 8,649
Baseline model	9702	8400	35827	17441
Elixhauser comorbidity score				
Individual Elixhauser comorbidities	9539	8241	35726	17211
Summary Elixhauser comorbidity score	9552	8266	35731	17237
Cancer-specific summary Elixhauser comorbidity score	9522	8253	35735	17208
Charlson comorbidity score / NCI combined index				
Individual Charlson comorbidities	9551	8261	35754	17241
Summary Charlson comorbidity score	9558	8283	35752	17253
Cancer-specific summary Charlson comorbidity score or NCI combined index	9566	8259	35743	17240

[a]The lower AIC indicates a better model fit.