BRIEF REPORT

Predicting Mortality up to 14 Years Among Community-Dwelling Adults Aged 65 and Older

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OBJECTIVES: Extended validation of an index predicting mortality among community-dwelling US older adults.

DESIGN/SETTING: Examination of the performance of a previously developed index in predicting 10- and 14-year mortality among respondents to the 1997–2000 National Health Interview Surveys (NHIS) using the original development and validation cohorts. Follow-up mortality data are now available through 2011.

PARTICIPANTS: 16,063 respondents from the original development cohort and 8,027 respondents from the original validation cohort. All participants were community dwelling and ≥65 years old.

MEASUREMENTS: We calculated risk scores for each respondent based on the presence or absence of 11 factors (function, illnesses, behaviors, demographics) that make up the index. Using the Kaplan Meier method, we computed 10- and 14-year mortality estimates for the development and validation cohorts to examine model calibration. We examined model discrimination using the c-index.

RESULTS: Participants in the development and validation cohorts were similar. Participants with risk scores 0–4 had 23% risk of 14-year mortality whereas respondents with risk scores (13+) had 89% risk of 14-year mortality. The c-index of the model in both cohorts was 0.73 for predicting 10-year mortality and 0.72 for predicting 14-year mortality. Overall, 18.4% of adults 65–74 years and 60.2% of adults ≥75 years have >50% risk of mortality in 10 years.

CONCLUSIONS: Our index demonstrated excellent calibration and discrimination in predicting 10- and 14-year mortality among community-dwelling US adults ≥65 years. Information on long-term prognosis is needed to help clinicians and older adults make more informed person-centered medical decisions and to help older adults plan for the future. **J Am Geriatr Soc 2017.**

Key words: mortality prediction; life expectancy; prevention; older adults

Consideration of older adults' long-term prognosis when deciding on medical interventions (e.g., cancer screening, diabetes treatment, joint replacement surgery) is increasingly recognized as a necessary component of high quality care.[1–3] To help clinicians and researchers estimate older adults' prognosis, we previously developed and validated an index to predict 5- and 9-year mortality among adults ≥65 years.[4,5] We developed our index using National Health Interview Survey (NHIS) data, the principal source of information on the health of the civilian non-institutionalized population of the United States (US).[4] Our development cohort included a random 2/3 of individuals who participated in NHIS from 1997–2000; we validated our index's performance among the remaining 1/3 of participants. Mortality data for NHIS participants were previously available through December 31, 2006 and we found that our index had excellent calibration and discrimination (c-index 0.75) in predicting up to 9-year mortality.[4,5]

Our index and the Lee prognostic index, which was developed and validated using Health and Retirement Study data, are the only two indices available that take into account older adults' functional status when predicting absolute risk of nine- or 10-year mortality.[6] The indices are similar in that they both consider individual's age, sex, body mass index, mobility (BMI), current cigarette use and history of chronic obstructive pulmonary disease (COPD), diabetes, and/or cancer.[6] However, our index also includes whether older adults need help with household chores, past cigarette use, perceived health, and hospitalizations in the past year. In a recent review of the top predictors of 5-year mortality in four countries, age, sex, limitations in instrumental activities of daily living,

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mobility, and perceived health were all found to be top predictors and all of these variables are in our index.[7] While there have been no direct comparisons of the performance of our index with other methods for estimating older adults prognosis; Pollack et al.[8] found that there was 84.9% agreement in categorization of Medicare beneficiaries as having <50% chance of survival in 9–10 years when our index, the Lee index, and a method for estimating life expectancy that uses US life table data while accounting for individuals' comorbidity were compared. To date, no studies have examined whether using our index or other methods for estimating older adults' 10-year life expectancy improves clinician prognostication; however, in 2012 our index and the Lee index were made publicly available at ePrognosis.org. An initial evaluation of the first 4,426 visits to ePrognosis found that 91% of users felt that the prognostic calculator they used was useful and 47% of healthcare professionals reported that the calculated prognosis affected clinical decision making.[11]

Since our index is being used by clinicians, researchers, and policy makers it is important to continue to understand its performance.[10,11] Therefore, we aimed to examine follow-up transportability of our model or how well our model predicts outcomes over different time periods. Mortality data on NHIS participants through 2011 were recently made available allowing us to examine performance of our model in predicting mortality at 10- and 14-year follow-up.[12,13] Evaluating our model's performance over this extended timeframe is important for several reasons. First, cancer screening guidelines use 10-year life expectancy as a cut-off for deciding whether or not to recommend screening to older adults. Second, it would be helpful to have our model's 10-year mortality estimates to be able to compare results directly with the Lee index which has been validated at four and 10 years. Third, estimates of 14-year mortality would be useful when deciding on medical interventions that have greater than 10-year lag-time to benefit (i.e., the amount of time between undergoing an intervention until benefits [e.g., mortality reduction] are seen in randomized controlled trials [RCTs]).[14] For example, in an overview of RCTs of radiotherapy after breast conserving surgery (BCS), radiotherapy was found to reduce breast cancer mortality 15 years after treatment.[15] Being able to estimate which women have <15 years survival would help inform use of radiotherapy after BCS among older women. More generally, clinicians and older adults want long-term prognostic information in order to make more person-centered medical decisions and to plan for the future.[16,17]

METHODS

Conducted annually by the National Center for Health Statistics (NCHS),[13] NHIS consists of several components, including a Family and Sample Adult Core that remain largely unchanged from year to year and that collect information on individuals' health and use of medical services. The Sample Adult Core collects more detailed health information from one randomly selected adult at home at the time of the survey. Data on participant mortality is ascertained from a probabilistic match between NHIS and National Death Index death certificate records. The methodology for record matching has been previously reported[18] and has been shown to correctly identify 99% of all living NHIS respondents and 97% of those who died.[19] The mean participation rate for NHIS years 1997–2000 was 74.0% (range 80.4% in 1997 to 69.6% in 1999).

Brief Review of Index Development

We previously used data from NHIS years 1997–2000 to develop our index.[6] Our sample included 24,115 community dwelling adults ≥65 years without dementia, representing 32 million US adults; of which 16,077 were in our development cohort and 8,038 were in our validation cohort. We considered 41 mortality risk factors in our model and found that 11 risk factors were independently and significantly associated with mortality: age, sex, cigarette use, BMI, functional limitations, difficulty with mobility, hospitalizations in the past year, perceived health, and history of COPD, diabetes, and cancer (excluding non-melanoma skin cancers).[4] We chose not to include race/ethnicity in our model since the association of these variables with mortality may be due to differences in quality of care and we did not want to develop an index that would contribute to care inequities. Based on the final model's beta coefficients, we assigned points for each factor. We previously reported the risk of 5- and 9-year mortality for adults in the development and validation cohorts.[4,5]

Current Sample

For the current study, we retained our original development and validation cohorts and linked these participants to their mortality data through 2011. Vital status information was unavailable for 25 participants so our current sample included 16,063 participants from the development cohort and 8,027 from the validation cohort.

Survival Outcomes

Respondents were assigned a vital status code (0 = presumed alive; 1 = presumed deceased) based on their status as of December 31, 2011. Sampling weights account for adults who were not matched successfully, which are used in mortality analyses to produce nationally representative estimates. We measured survival time from the date of the respondent's interview until death or end of follow-up (December 31, 2011), whichever came first.

Statistical Analysis

We compared the proportion of participants with each risk factor in the model and race/ethnicity between the development and validation cohorts using chi-square statistics. We then calculated a mortality risk score for each participant based on the presence or absence of model risk factors. We excluded respondents with missing data on risk factors (n = 940 or 3.7%). We then stratified risk scores into quintiles and calculated estimates for 10- and 14-year mortality by quintile using the Kaplan–Meier method. We used descriptive statistics to compare estimated 10- and 14-year mortality between the development and validation cohorts. We also calculated estimates for 10- and 14-year

Table 1. Probability of 10-year Mortality in the Development and Original Validation Cohorts Using the Index[a]

	Development Cohort–10-Year Follow-up		Validation Cohort–10-Year Follow-up	
	n = 15,436	Mortality 10-Year % (95% Confidence Interval)	n = 7,739	Mortality 10-Year % (95% Confidence Interval)
Quintile of risk				
1 (0–4 points)	3,140	14 (13–16)	1,524	12 (10–14)
2 (5–6 points)	2,645	24 (22–26)	1,304	24 (22–27)
3 (7–9 points)	3,659	36 (35–39)	1,857	39 (37–42)
4 (10–12 points)	2,862	59 (57–61)	1,484	58 (55–60)
5 (13+ points)	3,130	80 (78–81)	1,570	79 (77–81)
Point score				
0	219	7 (4–11)	99	5 (2–14)
1	371	11 (9–15)	203	11 (6–18)
2	554	12 (9–15)	278	9 (6–13)
3	888	15 (13–18)	428	12 (9–15)
4	1,094	18 (15–20)	505	15 (12–19)
5	1,317	21 (19–24)	600	21 (18–25)
6	1,295	26 (24–29)	696	26 (23–30)
7	1,265	31 (28–34)	679	37 (33–41)
8	1,233	36 (33–39)	622	37 (37–42)
9	1,169	45 (42–48)	558	44 (40–49)
10	1,063	55 (51–59)	516	53 (49–58)
11	947	61 (57–65)	504	60 (55–65)
12	859	64 (57–60)	466	60 (55–65)
13	760	71 (67–74)	342	68 (62–73)
14	626	74 (70–78)	317	74 (68–80)
15	507	80 (76–84)	271	76 (69–82)
16	432	84 (80–88)	207	87 (82–91)
17	268	85 (80–90)	148	86 (80–91)
18+	555	92 (89–94)	289	92 (88–95)

[a]In these analyses we only included individuals with complete data for all factors of interest.

mortality for each of the raw point scores (up to 18+ points) and plotted calibration curves. In addition, we examined the relationship between expected and observed mortality at 10 and 14 years using estimates from the development and validation cohorts for the most common covariate patterns (>5 individuals with the same pattern).[20] We fit a least-squares regression with the validation set estimate as the dependent variable and the development set estimates as the independent variable. We report the beta coefficient (slope of the line of the plot between the expected and observed mortality values) and Pearson correlation. If a model is well calibrated the slope of the line should approximate one and mortality probabilities should be highly correlated.

We used SAS-callable SUDAAN software (version 11, Research Triangle Institute, Research Triangle Park, NC, USA) for analyses since NHIS uses a complex sampling design involving stratification, clustering, and multistage sampling. Results from all analyses are weighted to reflect US population estimates and to adjust for non-response and mortality non-linkage; we present sample sizes (n) whenever possible. Currently, SUDAAN software does not have the capability to compute a c-index from a Cox model to assess model discrimination. Therefore, as we did previously, we used a SAS macro designed by Harrell et al.[21] to calculate a c-index for censored data to test the performance of the model in predicting 10- and 14-year mortality. The macro also provides a cross-validation c-index based on bootstrap resampling of the data.

In addition, we used descriptive statistics to present the proportion of US adults by age, sex, and race that had >50% mortality at 10 and 14 years. We chose this threshold since individuals with >50% mortality risk over a specified time frame are generally expected to have a life expectancy less than the given time frame.[22]

RESULTS

Sample

Validation cohort participants were similar to development cohort participants (Figure S1). Overall, 54.2% (n = 13,421) of participants died by the end of 2011; there were no significant differences by cohort.

Calibration and Discrimination

The index demonstrated excellent calibration and discrimination in predicting 10- and 14-year mortality (Tables 1 and 2, and Figures S2 and S3). Through 10 years' follow-up, individuals with scores of 0–4 had 14% risk of mortality in 10 years while those who scored ≥13 points had 79% risk of 10-year mortality. Through 14 years' follow-up, participants with scores of 0–4 had 23% risk of 14-

Table 2. Probability of 14-Year Mortality in the Development and Original Validation Cohorts Using the Index

	Development Cohort–14-Year Follow-up		Validation Cohort–14-Year Follow-up	
	n = 15,381	Mortality 14-Year % (95% Confidence Interval)	n = 7,719	Mortality 14-Year % (95% Confidence Interval)
Quintile of risk				
1 (0–4 points)	3,140	26 (24–18)	1,524	23 (20–26)
2 (5–6 points)	2,645	42 (40–45)	1,304	40 (36–43)
3 (7–9 points)	3,659	57 (55–60)	1,857	60 (57–63)
4 (10–12 points)	2,862	79 (77–81)	1,484	78 (74–81)
5 (13+ points)	3,130	91 (90–92)	1,570	89 (87–91)
Point score				
0	219	11 (7–18)	99	21 (11–37)
1	371	21 (16–26)	203	19 (12–28)
2	554	21 (17–26)	278	19 (14–26)
3	888	29 (25–33)	428	24 (19–30)
4	1,094	31 (28–35)	505	27 (22–32)
5	1,317	40 (37–43)	600	36 (32–41)
6	1,295	44 (40–47)	696	42 (37–48)
7	1,265	50 (46–54)	679	52 (47–57)
8	1,233	56 (53–60)	622	61 (56–66)
9	1,169	67 (63–70)	558	67 (62–73)
10	1,063	76 (72–79)	516	74 (68–80)
11	947	79 (75–82)	504	78 (73–83)
12	859	83 (80–87)	466	81 (75–87)
13	760	87 (83–90)	342	83 (78–87)
14	626	89 (85–92)	317	87 (81–92)
15	507	91 (88–94)	271	88 (80–94)
16	432	95 (90–98)	207	100
17	268	100	148	100
18+	555	100	289	100

[a]In these analyses we only included individuals with complete data for all factors of interest.

year mortality while those who scored ≥13 had 89% risk of 14-year mortality. All participants who scored ≥17 points died within 14 years. The beta coefficient from the linear regression of estimated mortality probabilities was 0.97 and 0.89 at 10- and 14-year follow-up, respectively. The correlation between development and validation cohort mortality values was 0.99 at 10- and 14-year follow-up, indicating excellent calibration. The c-index of the model in both cohorts was 0.73 for predicting 10-year mortality and 0.72 for predicting 14-year mortality (bootstrapping of the data resulted in the same values).

Mortality Risk By Age, Sex, and Race (Table 3)

Overall, 18.4% of adults 65–74 years and 60.2% of adults ≥75 years have >50% risk of 10-year mortality and 41.5% of adults 65–74 years and 83.3% of adults ≥75 years have >50% risk of 14-year mortality.

DISCUSSION

Our 11-item index demonstrated excellent calibration and discrimination in predicting 10- and 14-year mortality

Table 3. Proportion of US Adults with >50% Mortality in 5, 10, and 14 years by Age, Sex, and Race

	>50% Mortality in 10 years, % (risk scores of 10+)					>50% Mortality in 14 years, % (risk scores of 10+)				
Age group	65–69	70–74	75–79	80–84	85+	65–69	70–74	75–79	80–84	85+
Overall (n = 24,000, representing 32 million US adults)	14.9	22.1	43.4	69.3	88.4	35.0	48.4	73.7	91.2	94.9
Men (n = 9,137, representing 13.6 million)	22.3	32.0	60.6	88.4	96.5	48.9	65.8	93.3	97.6	96.5
Non-Hispanic White men (n = 7,151, representing 11.4 million)	20.8	31.8	61.0	88.4	96.4	46.8	65.5	93.6	97.7	96.4
Non-Hispanic Black men (n = 954 representing 1.0 million)	32.1	41.0	64.1	86.9	97.9	62.0	69.2	88.8	96.9	97.9
Women (n = 14,953, representing 18.4 million)	8.8	14.2	30.3	57.6	84.4	23.3	34.5	59.1	87.3	94.1
Non-Hispanic White women (n = 11,758, representing 15.4 million)	8.6	13.9	29.3	56.8	84.9	21.9	33.9	58.3	87.5	94.3
Non-Hispanic Black men (n = 1,689 representing 1.6 million)	13.3	18.8	37.1	64.6	81.1	31.3	44.6	65.0	84.7	92.3

among community-dwelling US adults ≥65 years. When we previously examined our index's performance at 5-year follow-up, we found that there was high correlation (0.98) between the mortality risk estimates in the development and validation cohorts and that the model's c-index was 0.75.[4] With follow-up through 14 years, the correlation between mortality risk estimates in the development and validation cohorts remained high (0.99).[4] There was a small decline of the model's c-index over time (c-index was 0.73 at 10 years and 0.72 at 14 years); however, discrimination also remained high with increasing risk scores associated with higher mortality risk. With these analyses, our index is the only validated prognostic model available for predicting older adults' absolute risk of mortality in 14 years. This is helpful when older adults need to decide on medical interventions that have >10-year lag time to benefit and for providing older adults with the opportunity to plan and think about how they want to live as they age.

It is important to note that there are other methods, besides prognostic indices, to estimate older adults' life expectancy. Some investigators propose using life table data adjusted for individual comorbidity to estimate older adults' life expectancy;[23,24] however, these data do not consider an older adult's functional status, tobacco use, or perceived heath which are important predictors of mortality. Studenski et al.[25] recommend clinicians assess older adults' gait speed since gait speeds <1.0 and <0.6 m/s are associated with >50% 10-year mortality in men and women 75–84 years, respectively. However, gait speed is not routinely measured in primary care. Future studies need to compare the predictive accuracy and feasibility of use of different methods for estimating older adults' life expectancy.

When attempting to predict the future, it is important to acknowledge the uncertainty that comes with prognostication. Our index provides information on the probability an individual with specific health characteristics will live a specified time. For example, individuals who score 10 on our index have a 53% chance of death within 10 years. However, this probability could be as high as 58% or as low as 49% based on the confidence intervals surrounding the point estimate from our validation cohort. We then approximate that these individuals have around 10-year life expectancy since life expectancy is the average survival of a population. Lee et al.[26] using the Gompertz Law of Human Mortality converted prognostic estimates from their index to median life expectancies. They found that point scores from their index that were associated with >50% probability of mortality in 10 years had median life expectancies of ≤10 years. Although inevitably some patients will outlive their estimated life expectancy, prognostic information may still be useful for clinical decision making. Furthermore, individuals may customize how they use prognostic information based on their comfort with uncertainty. For example, some clinicians may choose to use risk scores associated with higher than 50% risk of death in 10 years to estimate that an individual has <10-year life expectancy. While it is important that clinicians consider and discuss the uncertainty that comes with prognostication; reassuringly, older adults report that they would like prognostic information despite the inherent uncertainty.[27]

The most common medical decision for which primary care physicians (PCPs) are encouraged to consider older adults' life expectancy is when deciding whether or not to recommend cancer screening. While PCPs report being unfamiliar with prognostic tools,[16] high quality prediction tools tend to improve clinician prognostication.[28] Therefore, our index may be useful to older adults and their clinicians when weighing the probability that a patient will live long enough to experience the potential benefits of cancer screening with the probability that the patient may experience harm at the time of the test. Since PCPs feel ill-prepared to discuss prognosis with older adults, future work should develop communication strategies for PCPs to use during these conversations.

In the current healthcare system there are key misaligned incentives that serve as barriers to clinicians considering and discussing older adults' prognosis in medical decisions. For example, in an era of pay for performance, health care systems and physicians may be penalized for not screening adults 50–75 years for colon cancer. However, based on our findings 18.4% of US adults 65–74 years have >50% mortality in 10 years and are unlikely to benefit. Ideally, cancer screening decisions would be more person-centered rather than simply based on patient age alone. For example, when older women are provided information about their life expectancy and risk of breast cancer, and their values and preferences are elicited, they make more informed value-based decisions around mammography screening.[29]

Our index was not developed for nursing home residents or those with dementia and has not been validated in a clinical setting or outside the US.[4,5] However, it is the first prognostic index validated to estimate up to 14-year mortality among older adults and it includes all predictors found to be top predictors of mortality multinationally.[9] Ideally more guidelines and quality metrics would consider a more person-centered approach to care of older adults that takes into account older adults' prognosis, rather than their age-alone, when deciding on medical interventions.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Figure S1. Demographic and health status characteristics for survey years 1997–2000 of the National Health Interview Survey.*

Figure S2. Calibration curves for 10-year mortality.

Figure S3. Calibration curves for 14-year mortality.

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