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Comorbidity-Adjusted Life Expectancy: A New Tool to Inform Recommendations for Optimal Screening Strategies

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Background: Many guidelines recommend considering health status and life expectancy when making cancer screening decisions for elderly persons.

Objective: To estimate life expectancy for elderly persons without a history of cancer, taking into account comorbid conditions.

Design: Population-based cohort study.

Setting: A 5% sample of Medicare beneficiaries in selected geographic areas, including their claims and vital status information.

Participants: Medicare beneficiaries aged 66 years or older between 1992 and 2005 without a history of cancer (n = 407 749).

Measurements: Medicare claims were used to identify comorbid conditions included in the Charlson index. Survival probabilities were estimated by comorbidity group (no, low/medium, and high) and for the 3 most prevalent conditions (diabetes, chronic obstructive pulmonary disease, and congestive heart failure) by using the Cox proportional hazards model. Comorbidity-adjusted life expectancy was calculated based on comparisons of survival models with U.S. life tables. Survival probabilities from the U.S. life tables providing the most similar survival experience to the cohort of interest were used.

Results: Persons with higher levels of comorbidity had shorter life expectancies, whereas those with no comorbid conditions, including very elderly persons, had favorable life expectancies relative to an average person of the same chronological age. The estimated life expectancy at age 75 years was approximately 3 years longer for persons with no comorbid conditions and approximately 3 years shorter for those with high comorbidity relative to the average U.S. population.

Limitations: The cohort was limited to Medicare fee-for-service beneficiaries aged 66 years or older living in selected geographic areas. Data from the Surveillance, Epidemiology, and End Results cancer registry and Medicare claims lack information on functional status and severity of comorbidity, which might influence life expectancy in elderly persons.

Conclusion: Life expectancy varies considerably by comorbidity status in elderly persons. Comorbidity-adjusted life expectancy may help physicians tailor recommendations for stopping or continuing cancer screening for individual patients.

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Uncertainty exists about the optimal use of cancer screening tests in elderly persons (1), particularly surrounding decisions to stop screening. The benefits associated with early detection and subsequent treatment of cancer decline sharply with age because elderly persons are more likely to die of comorbid conditions or other causes (2). Moreover, the long period typically required before benefits are realized from cancer screening can be an important consideration for elderly patients and their physicians. For many, a survival benefit from early detection of colorectal or breast cancer may only occur 5 or more years after screening (1). Those with a shorter life expectancy would probably not experience a survival benefit. The harms of screening are another consideration, including complications from screening or follow-up tests (for example, perforation and bleeding associated with colonoscopy), as well as the identification and treatment of a disease that may never otherwise become symptomatic during an elderly person's remaining years of life. In addition to the potential physical harms, screening and follow-up testing may contribute to physical discomfort and psychological distress (3). For all of these reasons, it is crucial to weigh potential benefits and harms of cancer screening in elderly persons in relation to life expectancy (4).

Some guidelines (5–7) and studies (8, 9) suggest that screening decisions in elderly persons be individualized and take into account health status, life expectancy, and patient preferences rather than merely chronological age. For breast cancer screening, the U.S. Preventive Services Task Force concluded that evidence to access the balance of the benefits and harms of screening women aged 75 years or older is insufficient (10), whereas the American Cancer Society recommends continuing mammography as long as women are in good health (7). The U.S. Preventive Services Task Force does not recommend routine colorectal cancer screening in adults aged 75 years or older (11), whereas the American College of Physicians recommends that clinicians stop screening adults with a life expectancy of less than 10 years or those aged 75 years or older who have substantial comorbidity (6). In fact, heterogeneity of health status (for example, the existence of acute or chronic conditions) contributes to substantial variability in life expectancy among elderly persons (1, 12); hence, a single estimated life table based on basic demographic characteristics may not clearly inform physician recommendations for cancer screening. Although an individual's exact life expectancy is impossible to predict, incorporating

See also:

Web-Only
Supplement

Context

Some experts recommend consideration of health status and life expectancy when deciding whether to screen for cancer.

Contribution

This population-based cohort study examined the life expectancy of Medicare beneficiaries with and without comorbid conditions. Persons with no comorbidity, including very elderly persons, had longer life expectancies than those with comorbidity. At age 75 years, life expectancies for persons with no comorbidity were about 3 years longer and those for persons with high comorbidity were about 3 years shorter than U.S. population-based estimates.

Caution

Functional status and severity of comorbid conditions were not examined.

Implication

Comorbidity-adjusted life expectancy could help physicians tailor cancer screening recommendations.

—The Editors

strong predictors of survival—namely age, sex, and comorbidity—may allow for better estimation of life expectancy in elderly persons (13).

The objective of this study is to develop life tables for elderly persons without a history of cancer, taking into account their comorbid conditions. We build on previous work in which life tables for the comorbidity of patients with cancer were adjusted for. Those tables were developed to aid treatment decision making at the time of diagnosis (14). However, health status related to noncancer life expectancy of patients with cancer vary by cancer type (15) and may not accurately reflect that of persons without cancer. Therefore, there is a need to calculate life expectancy for persons without a history of cancer, accounting for heterogeneities of their health status. Here, we estimate life expectancy adjusted by comorbid conditions to facilitate decisions about cancer screening among persons without cancer.

METHODS

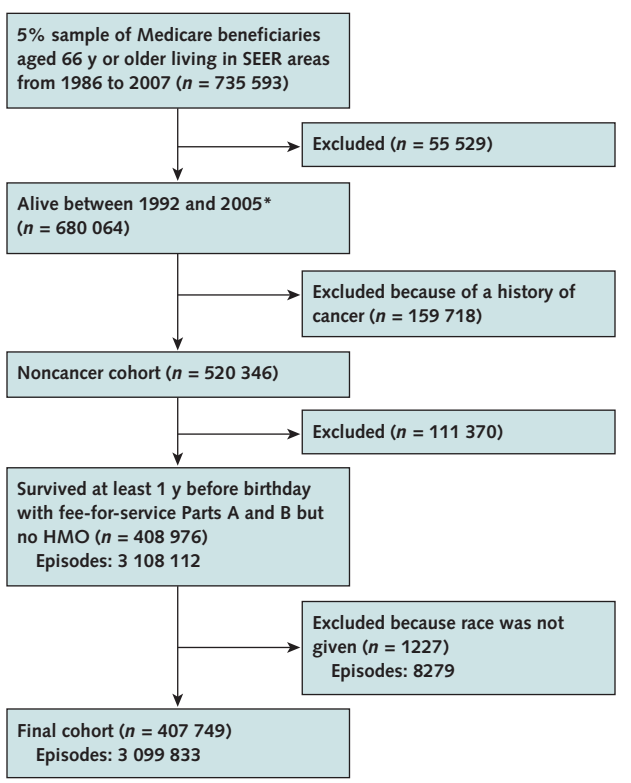
Data Sources and Study Population

We identified a noncancer cohort from a random 5% sample of Medicare beneficiaries residing in the Surveillance, Epidemiology, and End Results (SEER) cancer registry areas (Atlanta, Georgia; Connecticut; Detroit, Michigan; Hawaii; Iowa; New Mexico; Seattle–Puget Sound, Washington; Utah; and San Franciso-Oakland, Los Angeles, and San Jose–Monterey, California) (for more information, see http://appliedresearch.cancer.gov/seermedicare/). We selected beneficiaries who were alive and aged 66 years or older between 1992 and 2005 and excluded beneficiaries who had a previous cancer diagnosis between 1975 and 2005 (16). We used Medicare Part A inpatient and Part B physician supplier and outpatient facility claims between 1991 and 2005 to identify comorbid conditions. To assess comorbidity, we included only beneficiaries enrolled in Parts A and B with fee-for-service coverage, not enrolled in HMOs, and having at least 1 year of complete entitlement before birthdays occurring between 1992 and 2005. A full 12-month entitlement that satisfies the inclusion criteria before a birthday constitutes 1 episode. Each episode is associated with an age. The final study cohort comprised 407 749 beneficiaries with 3 099 833 episodes. Further details on cohort assembly are shown in **Figure 1**.

Comorbidity Measurement

Each Medicare claim contains diagnoses coded according to the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) (17), and procedures coded according to the 4th edition of Current Procedural Terminology (18) or the ICD-9-CM. Comorbid conditions were identified from claims in each episode occurring between 1992 and 2005 by using standard methods and algorithms (19–21). The algorithm searches

Figure 1. **Study flow diagram.**



SEER = Surveillance, Epidemiology, and End Results.
* Includes claims between 1991 and 2005. National claims history and outpatient claims were not available before 1991 and cancer diagnosis data used were up to 2005 in the 2008 SEER–Medicare linkage.

for procedure and diagnosis codes in all claims during an episode to capture comorbid conditions identified by Charlson and colleagues (19), which are widely used in administrative claims–based studies and health services research (22). The ICD-9-CM and Current Procedural Terminology codes used to identify each condition and the types of diseases included are listed in **Appendix Table 1** (available at www.annals.org). The conditions are AIDS, cerebrovascular disease, chronic renal failure, congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), dementia, diabetes, diabetes with sequelae, cirrhosis or chronic hepatitis, moderate or severe liver disease, acute myocardial infarction, history of myocardial infarction, paralysis, peripheral vascular disease, rheumatologic disease, and ulcer disease. In the analyses, diabetes and diabetes with sequelae were grouped together. We excluded the diagnostic codes corresponding to solid tumors and lymphoma or leukemia because the study population was cancer-free. Consistent with previous research (20, 21), a rule-out algorithm was applied in which only conditions appearing on more than 1 physician or outpatient claim were included to ensure that diagnoses recorded only in Part B claims were less likely to be rule-out procedures or transient episodes. The number of episodes and measured comorbid conditions varies by person (approximately 9% of beneficiaries had only 1 episode). For some persons, comorbidity measurements were missing for some years because of lack of eligibility. In the analysis, we imputed comorbidity for any missing entitlement years (n = 368 474) with observed comorbid conditions in the closest previous episode available. The cohort used for data analysis had 3 468 307 episodes, with 10.6% of data imputed. Data characteristics are shown in **Table 1** and **Figure 2**. For more details on data, see the **Supplement** (available at www.annals.org).

Overview: 3-Step Approach

We used a 3-step approach similar to that of Mariotto and colleagues (14) to estimate life expectancy by comorbidity. First, we estimated the effect of comorbid conditions on survival and constructed a comorbidity score. We then used these scores to classify comorbidity status into 1 of 3 groups: no, low/medium, or high comorbidity. Second, we estimated age-specific survival curves for each comorbidity group and for the 3 most common comorbid conditions (diabetes, COPD, and CHF). Third, we estimated comorbidity-adjusted life expectancy. We used Proc Phreg in SAS, version 9.2 (SAS Institute, Cary, North Carolina), for the statistical analysis. More details on methods and mathematical formulation of the models are provided in the **Supplement**.

Step 1: Summarizing Comorbidity Status

Estimating the Effect of Comorbid Conditions on Survival: Comorbidity Weights. We used the Cox proportional hazards model, in which indicators for comorbid conditions were treated as time-dependent covariates, to estimate comorbidity weights reflecting the effects of comorbid conditions on the risk for death. Sex and race were included as covariates in the model, and the event of interest was death from any cause. We used age as a time scale to directly account for its effect on mortality and adjust for confounding (23, 24). In particular, we used the counting process formulation of the Cox model to allow for time-dependent comorbid conditions and left-truncated survival time (25, 26). The coefficient estimates of the condition indicators comprise the weights for the comorbid conditions.

Calculating Comorbidity Score and Defining Comorbidity Groups. The comorbidity score was calculated as the sum of the weights multiplied by their condition indicator (1 = has the condition; 0 = does not have the condition) (14, 20). If there was more than 1 condition, the score was calculated as the sum of the weights for all conditions present. A higher score represented a greater burden of comorbidity (that is, more or more severe comorbid conditions). We calculated a comorbidity score for each age after an episode.

We used the comorbidity scores to classify comorbidity status at each age in which an episode exists: no comorbidity (none) or having a low/medium or high comorbidity score. The groupings were based on estimated weights that reflect the effect of comorbidity on survival and clinical judgments (15). In particular, the high comorbidity group includes conditions that usually lead to organ failure or system dysfunctions. Episodes with several comorbid conditions or a comorbidity score more than 0.56 were included in the high comorbidity group. The comorbidity score was 0 for the no-comorbidity group. The conditions included in each group are listed in **Table 2**. Because of the small sample size in the low comorbidity group, the low and medium groups were combined.

Step 2: Estimating Age-Specific Survival by Comorbidity Group

We estimated age-specific survival curves, 1 for each age between 66 and 90 years, stratified by sex and comorbidity group. We fit the Cox proportional hazards models to estimate survival at each age, conditional on being alive. An age-specific cohort was constructed for each age to estimate survival. Survival time was time to death or to the end of the study period (31 December 2005) at a given age. Race was included as a covariate. The estimated survival curve is the survival experience up to 10 years for the group of persons with similar levels of observed comorbidities at the given age.

Step 3: Estimating Comorbidity-Adjusted Life Expectancy

Calculation of life expectancy requires reliable age-conditional probabilities of death until at least age 109 years. Our estimated survival models (step 2) were based on 10 years of follow-up. To calculate life expectancy and

Table 1. **Demographic Characteristics and Prevalence of Comorbid Conditions in the Study Cohort of Medicare Beneficiaries in SEER Areas Without a History of Cancer Diagnosis, 1992–2005***

Variable	Beneficiaries, *n* (%)†	Episodes, *n* (%)‡	
		Study Cohort	Imputed Data§
Age			
66–69 y	232 049 (56.9)	673 786 (21.7)	703 350 (20.3)
70–74 y	76 423 (18.7)	821 570 (26.5)	922 829 (26.6)
75–79 y	47 533 (11.7)	689 356 (22.2)	798 017 (23.0)
80–84 y	29 031 (7.1)	486 045 (15.7)	558 834 (16.1)
85–89 y	14 770 (3.6)	273 705 (8.8)	310 827 (9)
≥90 y	7943 (2)	155 371 (5)	174 450 (5)
Sex			
Female	247 413 (60.7)	1 966 271 (63.4)	2 194 227 (63.3)
Male	160 336 (39.3)	1 133 562 (36.6)	1 274 080 (36.7)
Race			
White	350 090 (85.9)	2 713 051 (87.5)	3 025 566 (87.2)
Black	31 463 (7.7)	223 353 (7.2)	250 942 (7.2)
Other	26 196 (6.4)	163 429 (5.3)	191 799 (5.5)
Life status			
Alive	285 456 (70)	2 249 854 (72.6)	2 531 252 (73)
Dead	122 293 (30)	849 979 (27.4)	937 055 (27)
Total	407 749 (100)	3 099 833 (100)	3 468 307 (100)
Comorbid conditions			
Diabetes	–	421 279 (13.6)	451 861 (13.0)
COPD	–	277 638 (9.0)	296 444 (8.6)
CHF	–	207 307 (6.7)	216 412 (6.2)
Cerebrovascular disease	–	159 874 (5.2)	169 184 (4.9)
Peripheral vascular disease	–	101 248 (3.3)	106 286 (3.1)
Dementia	–	60 806 (2.0)	62 538 (1.8)
Rheumatologic disease	–	59 259 (1.9)	63 072 (1.8)
History of myocardial infarction	–	44 584 (1.4)	47 421 (1.4)
Chronic renal failure	–	43 948 (1.4)	45 119 (1.3)
Ulcer	–	37 923 (1.2)	40 828 (1.2)
Acute myocardial infarction	–	30 653 (1.0)	32 702 (0.9)
Paralysis	–	19 456 (0.6)	20 776 (0.6)
Cirrhosis and chronic hepatitis	–	7475 (0.2)	7949 (0.2)
Moderate/severe liver disease	–	2407 (0.1)	2532 (0.1)
AIDS	–	430 (0.01)	455 (0.01)
Number of conditions			
None	–	2 125 944 (68.6)	2 426 170 (70.0)
1	–	649 227 (20.9)	702 265 (20.3)
2	–	207 401 (6.7)	218 341 (6.3)
≥3	–	117 261 (3.8)	121 531 (3.5)
Total	–	3 099 833 (100)	3 468 307 (100)

CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; SEER = Surveillance, Epidemiology, and End Results.
* Demographic characteristics and prevalence of comorbid conditions (in percentages) were similar to the study cohort after imputing missing entitlement.
† Age of beneficiaries at the first episode in the study period is displayed.
‡ Age of beneficiaries at each episode is displayed.
§ Missing entitlements were imputed.

extrapolate survival beyond the data and to older ages, we compared each survival model to several age-specific U.S. life tables until we found the best matching age-specific U.S. life table. More specifically, for each age and comorbidity group, we compared our estimated survival probabilities with those calculated from several age-specific U.S. life tables and measured the distance between the 2 curves (absolute difference between cumulative survival probabilities) over 10 years. The table that minimizes the distance, called "the best matching U.S. life table," provides the closest survival experience for the cohort of persons of a given age, sex, race, and comorbidity status and is used to estimate life expectancy for the cohort of interest. The life expectancies estimated on the basis of the U.S. life table may provide more stable results, especially for the groups with a small sample size. In this study, we used decennial 2000 U.S. life tables (27) by sex and race because they correspond most closely to the study period. More

details on life expectancy calculations are provided in the **Supplement**.

The best matching U.S. life table identifies the age of an average U.S. population that provides similar survival experiences to those of persons with a given comorbidity of interest. We refer to the U.S. life table age as the "health-adjusted age" (14). **Figure 3** illustrates an example of identifying health-adjusted age.

Role of the Funding Source

This study received no external funding.

RESULTS

Demographic Characteristics and Prevalence of Comorbid Conditions

The study cohort comprised predominantly women (60.7%) and white persons (85.9%). At least 1 comorbid condition was identified in 31.4% of the episodes. More details about demographic characteristics and the prevalence of comorbid conditions are shown in **Table 1**.

Comorbidity became more common as age increased. The proportion with no comorbidity decreased, and the proportion with high comorbidity increased (**Figure 2**, *top*). Diabetes, COPD, and CHF were prevalent across all ages, although CHF became more prevalent with increasing age (**Figure 2**, *bottom*).

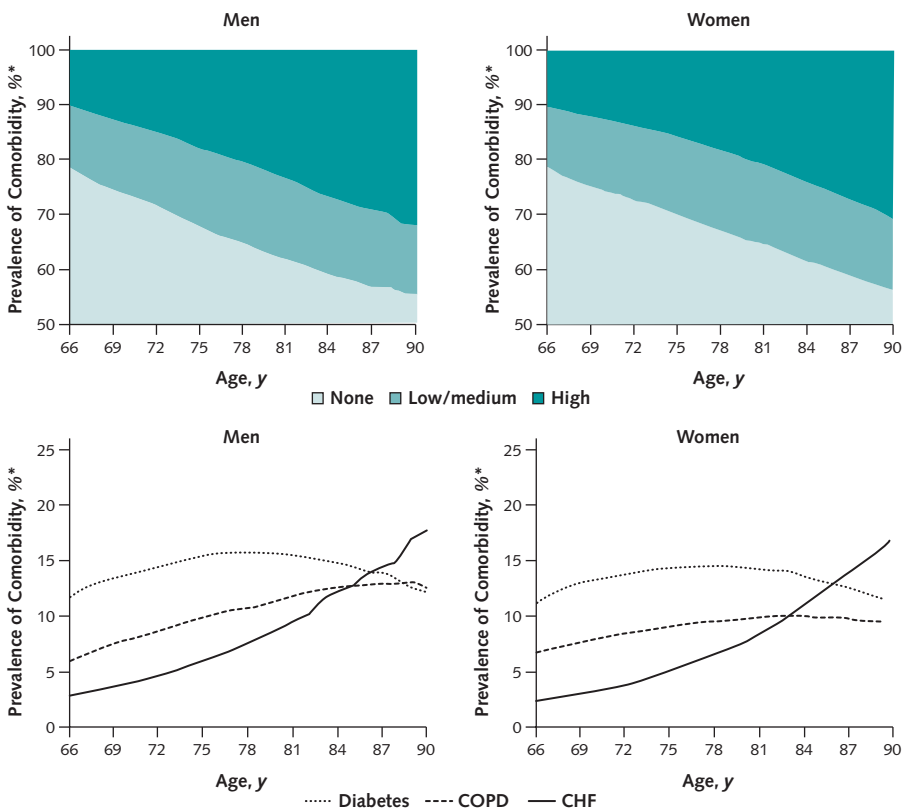
The Effect of Comorbid Conditions on the Risk for Death

Of all comorbid conditions examined, AIDS was associated with the highest risk for death (hazard ratio, 3.66 [95% CI, 2.72 to 4.92]). Persons with diabetes, COPD, and CHF had, respectively, at least a 1.45, 1.76, and 2.27 times greater hazard of dying compared with those with no comorbidity. The hazard of death for persons in the high comorbidity group was at least 1.76 times greater than that of persons in the no-comorbidity group (**Table 2**).

Life Expectancy by Comorbidity

Estimated life expectancies were longer for persons in the no-comorbidity group, shorter for the high group, and similar for the low/medium group when compared with life expectancies in the U.S. life table matched by age, race, and sex (**Table 3**). Relative to the life expectancy of the average U.S. population, the estimated life expectancy for persons aged 75 years with no comorbidity was approximately 3 years longer, but for persons with high comorbidity, it was approximately 3 years shorter. As age increases,

Figure 2. **Prevalence of comorbidity in the study cohort, by age.**



CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease. **Top.** By comorbidity groups (no, low/medium, or high comorbidity). **Bottom.** Diabetes, COPD, and CHF.

* The prevalence of comorbid conditions (in percentages) in the imputed data were similar.

Table 2. **Hazard Ratios and Comorbidity Weights Estimated From the Cox Proportional Hazards Model of Medicare Beneficiaries in SEER Areas Without a History of Cancer Diagnosis, 1992–2005***

Variable†	Hazard Ratio (95% CI)	Coefficient‡	SE	*P* Value
Sex and race				
Male	1.45 (1.43–1.46)	0.369	0.006	<0.001
Black	1.04 (1.02–1.06)	0.038	0.010	<0.001
Other	0.90 (0.88–0.93)	−0.101	0.014	<0.001
Comorbid conditions				
Low/medium comorbidity				
History of myocardial infarction	1.11 (1.08–1.15)	0.105	0.016	<0.001
Ulcer	1.13 (1.09–1.17)	0.123	0.018	<0.001
Acute myocardial infarction	1.28 (1.24–1.32)	0.247	0.017	<0.001
Rheumatologic disease	1.31 (1.26–1.35)	0.269	0.018	<0.001
Peripheral vascular disease	1.44 (1.42–1.47)	0.367	0.010	<0.001
Diabetes	1.45 (1.43–1.47)	0.372	0.007	<0.001
Paralysis	1.48 (1.43–1.54)	0.394	0.020	<0.001
Cerebrovascular disease	1.52 (1.50–1.55)	0.420	0.009	<0.001
High comorbidity				
COPD	1.76 (1.74–1.79)	0.567	0.008	<0.001
CHF	2.27 (2.23–2.30)	0.818	0.007	<0.001
Moderate/severe liver disease	2.30 (2.09–2.53)	0.832	0.049	<0.001
Chronic renal failure	2.30 (2.25–2.36)	0.834	0.012	<0.001
Dementia	2.35 (2.31–2.40)	0.855	0.010	<0.001
Cirrhosis and chronic hepatitis	2.82 (2.63–3.01)	1.035	0.035	<0.001
AIDS	3.66 (2.72–4.92)	1.298	0.151	<0.001

CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; SEER = Surveillance, Epidemiology, and End Results.
* The Cox proportional hazards model was used with time-dependent comorbid conditions using age as a time scale and accounted for left-truncated and right-censored survival time. Comorbid conditions in the missing entitlement were imputed.
† The reference category comprised white females with no comorbid conditions.
‡ Coefficient estimates of the comorbid conditions are comorbidity weights. Comorbid conditions are listed by increasing comorbidity weights.

the effect of comorbidity on life expectancy decreases. For example, compared with the life expectancies of the average U.S. white male population, the life expectancy of a white man in the high comorbidity group was about 6 years shorter at age 66 and 1 year shorter at age 90.

The life expectancy of persons with CHF was shorter and that of persons with COPD was shorter or similar (for example, black women) compared with that of the average U.S. population of the same chronological age (**Table 3**). For example, the life expectancy of a white woman at age 75 years with CHF was 5 years less than that of the average U.S. white woman. When compared with a white woman with no comorbid conditions at age 75 years, the life expectancy for women with diabetes, COPD, and CHF was about 4, 5, and 8 years shorter, respectively. In the analyses stratified by diabetes, COPD, and CHF, we assumed that serious conditions overrode others. For example, persons with CHF and COPD or diabetes were included in the CHF group. Results for those with only diabetes or COPD or CHF without other conditions showed similar trends, but the magnitudes were smaller (data not shown).

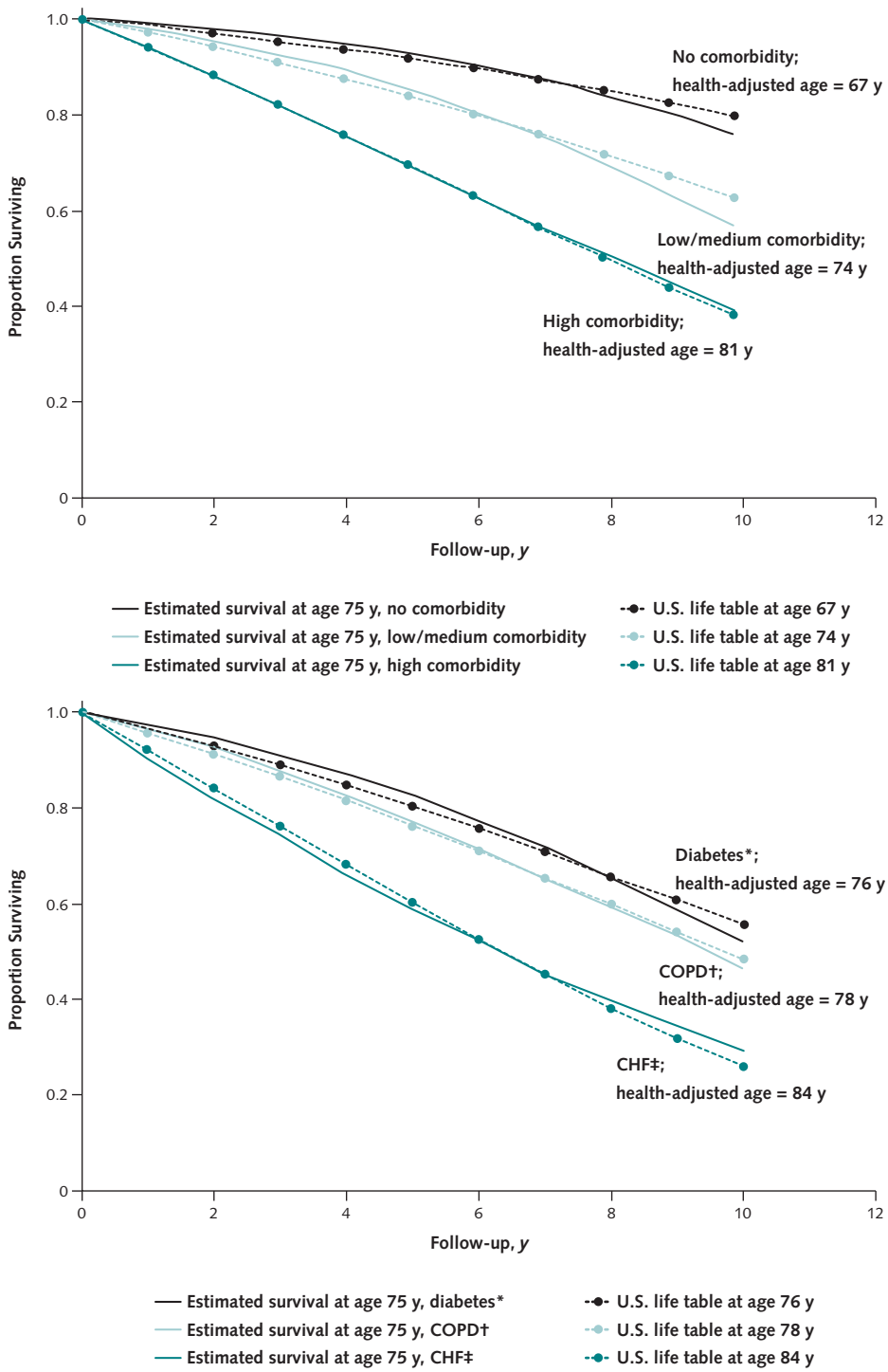
The results for "other" race were unstable because of the small sample size and the heterogeneity of populations in that category. Results from all races combined could be used instead. The estimated survival probabilities and health-adjusted ages are also shown in **Appendix Tables 2** and **3** (available at www.annals.org).

DISCUSSION

In this study, we estimated life expectancies for elderly persons without a history of cancer, taking into account their comorbid conditions. We found substantial variation between estimated life expectancies for healthy persons without comorbidity and those with high levels of comorbidity or specific conditions, such as diabetes, CHF, and COPD. Those with higher levels of comorbidity had shorter life expectancies relative to an average person of the same chronological age. Persons with no comorbid conditions, even in their 80s, had longer life expectancies relative to an average person of the same age.

Life expectancy rather than chronological age could be used to inform cancer screening guidelines (1) to ensure that patients live long enough to benefit from early detection. As shown in this study, there is considerable heterogeneity of life expectancy by comorbidity status. Therefore, maximizing the potential benefits of cancer screening while minimizing potential harms requires attention to comorbidity-adjusted life expectancy. Subjective estimation of life expectancy has been shown to be inaccurate (28–31). The comorbidity-adjusted life expectancy developed here may facilitate clinical decision making and recommendations tailored to individual patients. For example, some men and women at a younger chronological age with high levels of comorbidity might not benefit from cancer screening (for example, white men aged 70 years

Figure 3. **Estimated survival probabilities for white women aged 75 years, by comorbidity group, compared with the average U.S. white woman: an example of identifying health-adjusted age.**



Solid lines represent survival probabilities estimated from the model for white women at age 75 years, by comorbidity, and dashed lines represent survival probabilities from the best matching U.S. life table. CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease. **Top.** Comorbidity groups (no, low/medium, or high comorbidity). **Bottom.** Diabetes, COPD, and CHF.

* Includes diabetes only or diabetes with other conditions except COPD and CHF.

† Includes COPD only or COPD with other conditions except CHF.

‡ Includes CHF only or CHF with other conditions.

Table 3. **Estimated Life Expectancy, by Comorbidity Groups***

Age, y	Life Expectancy in Men, y							Life Expectancy in Women, y						
	Average U.S. Population†	Comorbidity						Average U.S. Population†	Comorbidity					
		None	Low/ Medium	High	Diabetes‡	COPD§	CHF‖		None	Low/ Medium	High	Diabetes‡	COPD§	CHF‖
All races														
66	15.4	18.5	15.7	9.9	14.7	12.2	7.4	18.4	22.5	18.4	12.0	16.1	15.4	8.0
70	12.8	16.3	13.5	8.9	13.1	11.0	7.0	15.4	19.3	15.7	10.8	14.7	13.3	8.0
75	9.9	12.7	11.0	7.4	10.3	8.9	5.8	12.0	15.3	12.4	8.5	11.4	10.8	7.1
80	7.4	9.8	8.2	5.8	7.4	7.0	4.8	9.0	11.6	9.4	6.6	8.5	8.0	5.8
85	5.5	7.2	5.8	4.2	5.5	5.1	3.7	6.6	8.7	7.0	5.1	6.2	6.2	4.7
90	3.9	5.1	3.9	3.0	3.7	3.7	3.0	4.7	5.7	4.7	3.5	4.4	4.4	3.5
White persons														
66	15.5	18.6	16.1	9.9	14.8	12.2	7.9	18.5	22.6	18.5	12.0	16.2	14.7	8.5
70	12.9	16.3	13.9	8.9	13.2	11.0	7.0	15.5	19.4	15.8	10.8	14.0	12.7	8.0
75	9.9	12.8	10.7	7.4	10.3	8.9	5.8	12.0	15.3	12.4	8.5	11.4	10.2	7.0
80	7.4	9.9	8.2	5.4	7.4	6.6	4.8	9.0	11.7	9.0	6.6	8.5	8.0	5.8
85	5.4	7.2	5.8	4.2	5.4	4.8	3.6	6.6	8.2	6.6	5.0	6.2	6.2	4.7
90	3.9	5.0	3.9	3.0	3.6	3.6	3.0	4.7	5.7	4.7	3.8	4.3	4.3	3.5
Black persons														
66	13.5	16.3	14.2	9.1	13.5	11.9	7.1	17.0	21.3	17.8	10.9	17.0	17.0	8.1
70	11.4	14.7	12.4	7.9	11.4	9.5	6.4	14.4	18.7	15.3	9.9	14.7	13.8	8.1
75	9.1	11.9	10.0	6.4	9.4	7.9	5.2	11.5	15.3	12.5	8.5	11.5	11.8	7.2
80	7.1	9.8	8.0	5.2	7.7	6.8	4.5	9.0	12.1	10.0	6.9	9.3	9.0	6.1
85	5.5	7.3	6.3	4.5	5.5	5.2	3.8	6.9	9.0	7.5	5.5	6.5	6.9	5.2
90	4.2	5.7	4.7	3.6	4.5	3.1	3.4	5.2	6.7	5.7	4.1	5.2	5.2	4.1

CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease.
* Rounded to the nearest tenth.
† From the 2000 U.S. decennial life table at the chronological age.
‡ Includes diabetes only or diabetes with other conditions except COPD and CHF.
§ Includes COPD only or COPD with other conditions except CHF.
‖ Includes CHF only or CHF with other conditions.

with high comorbidity may experience a remaining life expectancy of 9 years, which is similar to that of 77-year-old men in the average U.S. population), whereas others with older chronological age but no comorbid conditions might continue to benefit from cancer screening as their life expectancy exceeds that of the average, age-matched U.S. population. In addition, cervical cancer screening is recommended until the chronological age of 65 years (32). Our findings suggest that women without comorbid conditions might continue to benefit from screening until age 70 years because their life expectancy is similar to that of average women aged 65 years or younger.

Our life tables can be used in simulation modeling to evaluate the effectiveness and cost-effectiveness of different stopping ages for cancer screening based on health status. For example, they have been used by the Cancer Intervention and Surveillance Modeling Network investigators in comparative modeling to quantify the balance of benefits and harms of screening older persons for breast, colorectal, and prostate cancer by comorbidity level (33). Results indicate that ages of screening cessation based on comorbidity level differ from those recommended for the entire population. Moreover, our approach to developing estimates of comorbidity-adjusted life expectancy can be applied to screening for other conditions or to treatment decisions for patients in which benefits and risks vary by life expectancy. For example, the American Geriatrics Society has issued general guidance that older adults' life expectancy be considered in decisions about asymptomatic health screening (34), and the U.S. Preventive Services Task Force now recommends that life expectancy be taken into account when deciding whether to screen older women for osteoporosis (35). Ongoing evaluation of this tool for use in clinical practice will be important. In the context of cancer care, a related tool, the Cancer Survival Query System (36), has been developed for use by physicians to better understand patients' prognosis and is currently undergoing testing at a clinical center to assess health care providers' views of its content, usability, and implementation potential.

Our study has several limitations. The study population was a subset of a national random sample of Medicare beneficiaries with fee-for-service coverage who reside in SEER areas and who do not have cancer. This population is not necessarily representative of the entire U.S. elderly population. However, by including only Medicare beneficiaries in SEER areas, we definitively established the lack of a history of cancer from high-quality cancer registry data. Claims-based algorithms for identifying a history of cancer generally have poor performance (37). Because we used

data from Medicare claims in elderly persons, life tables by comorbidity were estimated only for the population aged 66 years or older. Developing estimates of comorbidity-adjusted life expectancy for younger populations will be an important extension of this method. Our measure of comorbidity was based on the Charlson index and includes 16 comorbid conditions that have been shown to predict survival, treatment choice, cost, and other outcomes, but may not capture all conditions that contribute to life expectancy in elderly patients. Further, administrative claims databases have been shown not to fully ascertain patients' comorbid conditions relative to medical records and patient reports (38). Our estimates do not incorporate differences in the severity within the comorbid conditions because this information is generally not available in Medicare data. The absence of information on functional status in the SEER and Medicare claims data is also a limitation because it might substantially contribute to an estimation of life expectancy, if available (39). Another limitation concerns the uncertainty of comorbidity measurement when information about the duration of comorbid illnesses is lacking. We conducted a sensitivity analysis that assumed that once identified, comorbid conditions are permanent and carry forward into subsequent years; it showed an increase in the prevalence of comorbid conditions (for example, 2-fold for COPD and CHF) but an attenuated influence on survival, resulting in slightly higher estimated life expectancies (for example, a maximum of 1.3 years in white persons). Additional work is needed to systematically investigate the effects of measurement error and varying approaches to longitudinal comorbidity assessment on life expectancy modeling. Finally, in the present study, we used comorbidity scores to group patients and estimated life tables stratified by comorbidity groups. One might consider using different groupings or the comorbidity score as a continuous measure (14) or categorical variable that assumes proportional hazards among groups. For more discussion, see the **Supplement**.

Despite these limitations, our study findings and method of calculating health-adjusted age and corresponding life expectancy may aid physicians and other health practitioners in individualizing recommendations for cancer screening in elderly persons (that is, to continue screening in persons with sufficient life expectancy who might benefit or to stop screening among those for whom benefits are unlikely). Even with additional information about life expectancy, discussions about continuing or stopping screening are complex and will need to be informed by patient preferences.

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Appendix Table 1. ICD-9-CM and CPT Codes That Correspond in Each Comorbid Condition

Condition	Diagnosis ICD-9-CM Code	Surgical ICD-9-CM Code	HCPCS CPT Code
Acute myocardial infarction	410.xx	–	–
History of myocardial infarction	412	–	–
CHF	428.xx	–	–
Peripheral vascular disease: includes intermittent claudication, aortic aneurysm, gangrene, prosthetic blood vessels, and resection and replacement of lower limb arteries	441.xx, 443.9, 785.4, and v43.4	38.13, 38.14, 38.16, 38.18, 38.43, 38.44, 38.46, 38.48, 38.33, 38.34, 38.36, 38.38, 39.22–39.26, 39.28, and 39.29	35011, 35013, 35045, 35081, 35082, 35091, 35092, 35102, 35103, 35111, 35112, 35616, 35621, 35623, 35626, 35631, 35636, 35641, 35121, 35122, 35131, 35132, 35141, 35142, 35151, 35152, 35153, 35311, 35321, 35331, 35341, 35351, 35506, 35507, 35511, 35516, 35518, 35521, 35526, 35531, 35533, 35536, 35541, 35546, 35548, 35549, 35551, 35556, 35558, 35560, 35563, 35565, 35566, 35571, 35582, 35583, 35585, 35587, 35601, 35606, 35612, 35616, 35621, 35623, 35626, 35631, 35636, 35641, 35646, 35650, 35651, 35654, 35656, 35661, 35663, 35665, 35666, 35671, 35694, 35695, and 35355–35381
Cerebrovascular disease	430–437.x and 438	38.12 and 38.42	35301, 35001, 35002, 35005, 35501, 35508, 35509, 35515, 35642, 35645, 35691, and 35693
COPD: includes COPD, pneumoconiosis, and chronic respiratory conditions due to fumes and vapors	490.xx–496, 500–505, and 506.4	–	–
Dementia: includes senile and presenile dementia	290.xx	–	–
Paralysis (hemiplegia or paraplegia)	342.xx and 344.1	–	–
Diabetes: includes diabetes with or without acute metabolic disturbances and diabetes with peripheral circulatory disorders	250, 250.0x–250.3x, and 250.7x	–	–
Diabetes with sequelae: includes diabetes with renal, opthalmic, or neurologic manifestations	250.4x–250.6x and 250.8x–250.9x	–	–
Chronic renal failure: includes chronic glomerulonephritis; nephritis and nephropathy; chronic renal failure; renal failure, unspecified; and disorders resulting from impaired renal function	582.xx, 583.xx, 585.x, 586, and 588.xx	–	–
Cirrhosis and chronic hepatitis: includes hepatic coma, portal hypertension, other sequelae of chronic liver disease, and esophageal varices	571.2 and 571.4x–571.6	–	–
Moderate/severe liver disease	456.0–456.21 and 572.2–572.8	39.1 and 42.91	37140, 37145, 37160, 37180, 37181, 75885, 75887, 43204, and 43205
Peptic ulcer disease: includes gastric, duodenal, and gastrojejunal ulcers and chronic forms of peptic ulcer disease	531.xx–534.xx	–	–
Rheumatologic disease: includes systemic lupus erythematosus, systemic sclerosis, polymyositis, adult rheumatoid arthritis, rheumatoid lung, and polymyalgic rheumatica	710.0, 710.1, 710.4, 714.0–714.2, 714.81, and 725	–	–
AIDS: includes AIDS, AIDS-like syndrome, AIDS-related complex, and symptomatic HIV infection	042.x–044.x	–	–

CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; CPT = Current Procedural Terminology; HCPCS = Healthcare Common Procedure Coding System; ICD-9-CM = International Classification of Diseases, Ninth Revision, Clinical Modification.

Appendix Table 2. Estimated Cumulative Survival Probabilities, by Comorbidity Groups

Age	Men								Women							
	Average U.S. Population*		Comorbidity†						Average U.S. Population*		Comorbidity†					
			None		Low/ Medium		High				None		Low/ Medium		High	
	5 y	10 y	5 y	10 y	5 y	10 y	5 y	10 y	5 y	10 y	5 y	10 y	5 y	10 y	5 y	10 y
All races																
66 y	0.88	0.72	0.95	0.84	0.91	0.72	0.73	0.49	0.92	0.81	0.98	0.92	0.94	0.78	0.81	0.60
70 y	0.83	0.62	0.93	0.78	0.88	0.64	0.70	0.42	0.89	0.73	0.97	0.87	0.91	0.71	0.77	0.52
75 y	0.74	0.46	0.88	0.65	0.81	0.50	0.61	0.30	0.82	0.59	0.93	0.76	0.86	0.57	0.70	0.38
80 y	0.62	0.29	0.79	0.44	0.69	0.30	0.50	0.15	0.72	0.41	0.86	0.56	0.76	0.38	0.57	0.24
85 y	0.47	0.15	0.64	0.23	0.53	0.13	0.33	0.07	0.57	0.23	0.73	0.33	0.61	0.21	0.42	0.11
90 y	0.31	0.05	0.45	0.10	0.33	0.04	0.20	0.02	0.40	0.09	0.54	0.13	0.43	0.09	0.28	0.04
White persons																
66 y	0.88	0.72	0.95	0.85	0.91	0.73	0.74	0.50	0.92	0.81	0.98	0.92	0.94	0.79	0.82	0.61
70 y	0.83	0.62	0.93	0.79	0.88	0.65	0.71	0.42	0.89	0.73	0.97	0.88	0.91	0.71	0.78	0.53
75 y	0.74	0.46	0.88	0.65	0.82	0.51	0.62	0.31	0.82	0.59	0.93	0.76	0.85	0.56	0.70	0.38
80 y	0.62	0.29	0.79	0.44	0.69	0.30	0.49	0.15	0.72	0.41	0.86	0.56	0.75	0.38	0.57	0.24
85 y	0.47	0.14	0.64	0.23	0.53	0.13	0.32	0.06	0.57	0.23	0.73	0.33	0.60	0.20	0.42	0.11
90 y	0.30	0.05	0.44	0.10	0.33	0.04	0.19	0.01	0.40	0.09	0.54	0.13	0.42	0.08	0.27	0.04
Black persons																
66 y	0.82	0.62	0.91	0.74	0.87	0.62	0.66	0.39	0.89	0.74	0.96	0.87	0.92	0.74	0.76	0.52
70 y	0.77	0.53	0.89	0.68	0.83	0.53	0.64	0.33	0.85	0.67	0.95	0.82	0.91	0.69	0.72	0.44
75 y	0.68	0.40	0.84	0.55	0.76	0.40	0.54	0.22	0.78	0.54	0.92	0.71	0.84	0.54	0.68	0.36
80 y	0.58	0.27	0.77	0.41	0.66	0.26	0.48	0.14	0.69	0.39	0.86	0.56	0.77	0.42	0.58	0.25
85 y	0.46	0.16	0.64	0.23	0.56	0.15	0.38	0.10	0.57	0.25	0.74	0.34	0.63	0.22	0.46	0.14
90 y	0.34	0.07	0.50	0.14	0.33	0.04	0.25	0.03	0.44	0.13	0.61	0.19	0.53	0.16	0.32	0.06

* Estimated from 2000 U.S. life tables.
† Estimated by the Cox proportional hazards model for white and black persons (Kaplan–Meier estimates for all races combined).

Appendix Table 3. **Health-Adjusted Age (Years), by Comorbidity Groups**

Age*	Men									Women								
	All Races			White Persons			Black Persons			All Races			White Persons			Black Persons		
	None	Low/Medium	High	None	Low/Medium	High	None	Low/Medium	High	None	Low/Medium	High	None	Low/Medium	High	None	Low/Medium	High
66	57	65	75	57	64	75	58	64	75	53	66	75	53	66	75	53	63	76
67	58	65	75	58	65	75	59	65	76	55	67	75	55	67	75	54	64	77
68	59	66	76	59	66	76	59	66	77	56	67	76	56	68	76	55	65	77
69	60	67	76	60	67	76	60	67	78	57	68	77	58	69	77	57	66	78
70	61	68	77	61	67	77	61	67	78	59	69	77	59	69	77	58	67	78
71	62	68	78	62	68	77	62	68	79	61	70	78	61	70	78	59	68	79
72	64	69	78	64	69	78	63	69	80	62	71	79	63	71	79	61	69	79
73	65	70	79	65	70	79	65	70	81	64	72	79	64	72	79	62	70	80
74	66	71	80	66	71	79	66	71	82	65	73	80	66	73	80	63	71	81
75	68	72	80	68	73	80	67	72	82	67	74	81	67	74	81	65	72	81
76	69	74	81	69	74	81	68	73	83	68	75	82	69	75	82	66	73	82
77	70	75	82	70	75	82	69	74	84	70	76	82	70	76	82	68	74	83
78	71	76	83	71	76	83	70	75	85	71	77	83	72	77	83	69	75	83
79	72	77	84	73	77	84	71	76	85	73	78	84	73	79	84	70	76	84
80	74	78	84	74	78	85	72	77	86	74	79	85	74	80	85	72	77	85
81	75	79	85	75	79	86	73	78	86	75	80	86	76	81	86	73	79	86
82	76	81	86	77	81	87	75	79	87	77	81	87	77	82	87	75	80	87
83	78	82	87	78	82	87	76	80	88	78	82	87	78	83	87	76	81	88
84	79	83	88	79	83	88	77	81	89	79	83	88	79	84	88	78	82	88
85	80	84	89	80	84	89	79	82	89	80	84	89	81	85	89	79	83	89
86	81	85	90	82	85	90	80	83	90	82	85	90	82	86	90	80	84	90
87	83	86	91	83	86	91	81	85	91	83	86	91	83	87	91	82	85	91
88	84	87	92	84	87	92	82	86	92	84	88	92	84	88	92	83	86	92
89	85	88	93	85	88	93	83	87	93	85	89	93	85	89	93	84	87	93
90	86	90	94	86	90	94	84	88	93	87	90	94	87	90	93	85	88	94

* Chronological age.