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Original Contribution

Changes in Life Expectancy and Disability-Free Life Expectancy in Successive Birth Cohorts of Older Cancer Survivors: A Longitudinal Modeling Analysis of the US Health and Retirement Study

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The population of older cancer survivors in the United States is rapidly growing. However, little is currently known about how the health of older cancer survivors has changed over time and across successive birth cohorts. Using data from the US Health and Retirement Study, we parameterized a demographic microsimulation model to compare partial cohort life expectancy (LE) and disability-free LE for US men and women without cancer and with prevalent and incident cancer diagnoses for 4 successive 10-year birth cohorts, born 1918–1927 to 1948–1957. Disability was defined as being disabled in ≥1 activity of daily living. These cohorts had midpoint ages of 55–64, 65–74, and 75–84 years during the periods 1998–2008 (the "early" period) and 2008–2018 (the "later" period). Across all cohorts and periods, those with incident cancer had the lowest LE, followed by those with prevalent cancer and cancer-free individuals. We observed declines in partial LE and an expansion of life spent disabled among more recent birth cohorts of prevalent-cancer survivors. Our findings suggest that advances in treatments that prolong life for individual cancer patients may have led to population-level declines in conditional LE and disability-free LE across successive cohorts of older cancer survivors.

aging; cancer; disability; life expectancy; microsimulation modeling

Abbreviations: ADL, activities of daily living; CI, confidence interval; DFLE, disability-free life expectancy; HRS, Health and Retirement Study; LE, life expectancy; PC, partial cohort.

The intersection of population aging with continually improving cancer survival rates is projected to result in a doubling of the US cancer survivor population aged 65 and over, to approximately 19 million people by 2040 (1). The US National Cancer Institute defines cancer survivors as persons who are diagnosed with cancer, from the time of their diagnosis until the end of life (2). In recent decades, cancer survival rates have markedly improved due to advances in screening technology and implementation, as well as the effectiveness of treatments (3). However, as populations around the world age, cancer prevalence is growing, and cancer is now the second leading cause of death in the United States and a leading cause of death in several other high-income populations (3, 4). Compared with the cancer-free adult population, adult cancer survivors have higher prevalence of disability, chronic pain, comorbidities, anxiety, and depression (5–9). In the United States, cancer incidence has followed distinct age, period, and cohort trends, with incidence rising over the past decades among younger-old individuals (ages 65–85 years) and a trend of incidence occurring at earlier ages among more recently born cohorts (10).

However, very little is known about how the health of older cancer survivors has changed over time across successive birth cohorts, as the probability of long-term survival has increased. In the classical epidemiologic transition, expansion in life expectancy (LE) was thought to result in a compression of disability to a smaller proportion of a person's later life (11, 12). However, expansions in LE may instead result in individuals with worse health surviving longer than they would have in the past, leading to increased prevalence of chronic conditions and disability (13). A more balanced framework, the dynamic equilibrium model, posits that improvements in medical technology and early

diagnoses may lead to disease being discovered and controlled at early stages, resulting in an increase in prevalence but steady or declining rates of associated disability and mortality (14).

It is unknown whether recent increases in LE for older cancer survivors have resulted in a compression of disability, whereby older cancer survivors are increasingly living their additional years in good health, or an expansion of disability, whereby older cancer survivors who would not have previously survived are now living longer but potentially in poor health. This question has implications for the care of older cancer survivors who face late-life effects of cancer and its treatments alongside other aging-related health risks, as well as for understanding the impact of increasing cancer survival rates on overall population health.

We aimed to investigate changes in life and health expectancies over time for successive birth cohorts of cancer survivor and cancer-free older adults in the United States. Specifically, we compared disability-free life expectancy (DFLE) and activities of daily living (ADL)-disabled LE with and without cancer for men and women in 4 successive 10-year cohorts spanning the birth years 1918–1927 to 1948–1957.

METHODS

Sample

Data were from the US Health and Retirement Study (HRS), a nationally representative cohort study of adults aged 50 years or older in the United States, established in 1992 with a sample of people born in 1931–1941 (15). Enrollment was expanded in 1993 to include those born before 1924, in 1998 to include the 1924–1930 and 1942–1947 birth cohorts, in 2004 to include the 1948–1953 birth cohort, and in 2010 to include the 1954–1959 birth cohort. Study participants are interviewed every 2 years. Exit interviews are conducted with family members of participants who die between interview waves, and proxy interviews with a family member are conducted for participants who are too physically or cognitively impaired to directly participate. Our analyses use data from the 1998 through 2018 interview waves, as incident cancer diagnoses were collected beginning in 1998.

Measures

Cancer diagnoses. Incident cancer diagnoses were identified at each HRS interview wave with the question, "Has a doctor ever told you that you have cancer or a malignant tumor, excluding minor skin cancers?" (yes; no) along with self-reported month and year of diagnosis. We used diagnosis data from the HRS RAND Corporation files, which incorporated previous and current interview responses on cancer diagnoses to identify new (incident) cancer diagnoses at each wave. We distinguished between prevalent long-term cancer survivors (individuals reporting a cancer history prior to the baseline wave) and incident-cancer survivors (individuals reporting a new cancer diagnosis during the follow-up).

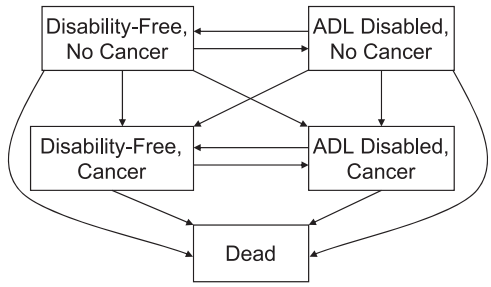

Figure 1. State-space for the analysis of total and disability-free life expectancy among cohorts of cancer survivors in the United States. ADL, activities of daily living.

Disability. We investigated patterns of self-reported disability in ADL (16). ADL represent the core activities required to live independently. Individuals were classified as ADL-disabled if they reported difficulty or inability to do any of the following 6 activities: bathing, eating, getting in/out of bed, toileting, dressing, and walking across a room. Where necessary, proxy responses on ADL disability are used. Individuals who reported no ADL disabilities were classified as disability-free.

Mortality. Information on mortality and date of death came from the HRS tracker file, which draws on the National Death Index and exit interviews with a spouse or knowledgeable family member.

State-space. Our analysis model used a state-space with 5 states to represent older adults' life-course experiences with cancer and disability, in order to estimate the implications of cancer for population-level life expectancy and disability-free life expectancy. Using the above categorizations of cancer diagnosis and disability status, we classified individuals as: 1) no cancer, disability-free; 2) no cancer, ADL-disabled; 3) cancer, disability-free; 4) cancer, ADL-disabled; 5) dead. We allowed transitions between all alive states, with the exception that individuals could not move from having a cancer diagnosis to never having a cancer diagnosis. Figure 1 provides a graphical representation of this state-space, including all potential transitions between states.

Covariates. Covariates included age (continuous) and sex (male vs. female). Analyses were stratified by birth cohort (4 birth cohorts spanning 10-year periods, of those born 1918–1927 to 1948–1957).

Statistical analyses

Multistate partial-cohort model. We compared partial cohort LE (PC-LE) and PC-DFLE in 2 successive 10-year periods (1998–2008, 2008–2018) across 4 successive 10-year birth cohorts (born 1918–1927, 1928–1937, 1938–1947, and 1948–1957). Thus, we compared life and health expectancies across 2 successive 10-year birth cohorts for each of age groups 55–64 (young old), 65–74 (middle old), and 75–84 (older old). This partial cohort method allows the

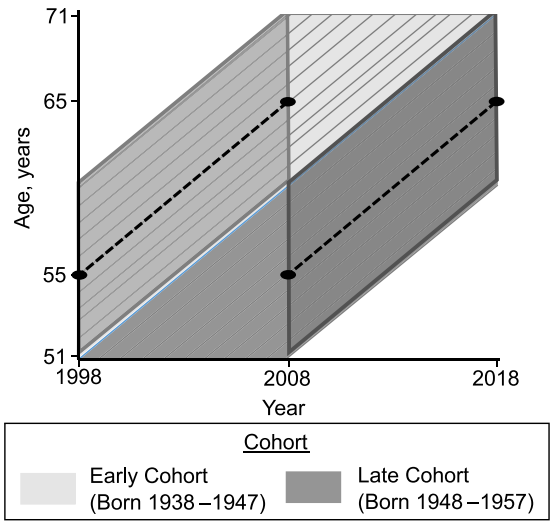

Figure 2. Lexis diagram showing cohort contrasts at ages 55–64 between two 10-year birth cohorts, Health and Retirement Study, United States, 1998–2018. This figure demonstrates the period-cohort approach, whereby the youngest cohort member is exactly age 51 at the start of each 10-year observation period, and the oldest cohort member is just under 71 by the end of each 10-year observation period. For a 10-year birth cohort, the period-cohort approach requires data spanning 10 years of calendar time, but members of the cohort are observed spanning 20 years. Given that 20 years of data are available, this period-cohort approach was chosen to maximize the number of cohort comparisons that could be made (as opposed to an age-cohort approach, which would require observing a cohort over 20 years of calendar time, but only 10 years of age).

identification of contractions or expansions in life and health expectancies within a given time period across successive birth cohorts and thus can ascertain how disability and mortality conditions are changing across cohorts during key age groups (17, 18). These cohort-specific partial LE estimates are also known as "temporary" life expectancy, and they represent a measure of LE bounded between 2 ages—for example, the LE of a given birth cohort of individuals between ages 55 and 64. The structure of these comparisons is best understood through a Lexis diagram, as shown in Figure 2, which compares 2 cohorts as an example: those born 1938–1947 (the "early" cohort, observed in years 1998–2008) and those born 1948–1957 (the "late" cohort, observed in years 2008–2018).

Our modeling strategy aggregated the transition probabilities observed in each cohort during the observation period to estimate the average PC-LE and PC-DFLE in each cohort-period combination. To increase interpretability and account for potential variation in the age composition within our 10-year cohorts, our model predicted transition probabilities and estimated PC-LE and PC-DFLE for the central age-trajectory in each cohort (55–64 in the first comparison, shown in the black dashed line). In all analyses, the cohorts in each comparison are distinct. Although some individuals will show up as part of the early and late cohorts in different age groups (e.g., the 1938–1947 cohort is the early cohort in the analysis of 55–64-year-olds (observed in 1998–2008), and the late cohort in the analysis of 65–74-year-olds (observed in 2008–2018)), there are no individuals contributing person-years of observation to both of the early or late cohorts within an age group.

Estimation approach. To estimate PC-LE and PC-DFLE for each period-cohort combination, we initially converted the HRS data to a person-year time scale, assuming that transitions between states (described in Figure 1) occur at random times between observations. We modeled these annual transition probabilities using a cumulative logistic regression model, stratified by initial state. The base model included age, age^2, sex, dummy variables for birth cohort, and interactions between birth cohort, age, and sex. From these models, we generated matrices of age-specific transition probabilities for each combination of cohort and sex, separately by initial state. Transition probability estimates were obtained using PROC LOGISTIC in SAS, version 9.4 (SAS Institute, Cary, North Carolina). These estimated transition probabilities are available in Web Tables 1–6 (available at https://doi.org/10.1093/aje/kwab241).

We used these observed transition probabilities as the input for the microsimulation-based multistate life table model, using an adapted version of the SPACE suite of SAS (SAS Institute) programs (17–19). First, we generated synthetic cohorts of 100,000 individuals with the same sex and initial disability and cancer state distribution as the observed cohorts. We then "aged" these individuals forward year by year using age- and sex-specific mortality rates and probabilities of transitioning in and out of disability, and probabilities of cancer diagnoses, estimated from the data. This process was repeated until the end of the age ranges under study. For example, when investigating PC-LE and PC-DFLE for a given cohort at ages 55–64 years, the model microsimulates the life courses of 100,000 individuals starting at age 55 and ending at exactly age 65, applying the transition probabilities estimated from the data. The resulting synthetic cohort is analyzed to estimate DFLE without cancer, ADL-disabled LE without cancer, DFLE with cancer, ADL-disabled LE with cancer, and total LE, all bounded between ages 55 and 64. Confidence intervals (CIs) were estimated via bootstrapping the above analysis sequence 499 times.

Given the complexity of the state-space described above, the population-averaged results are difficult to interpret. Differences in disability and LE between populations who start each period with and without cancer diagnoses may be substantial, and our research interests center more on comparing these groups over time, rather than with each other. As such, we present estimates of PC-LE and PC-DFLE separately for 3 groups:

- Individuals who did not have cancer at the initial (baseline) age and did not receive a diagnosis during the observation period (the cancer-free group)
- Individuals who did not have cancer at the initial age but did receive an incident cancer diagnosis during the observation period (the incident-cancer survivor group)

Table 1. Characteristics of the Birth Cohorts Under Study (Percentage of Total), Health and Retirement Study, United States, 1998–2018

Characteristic	% of Birth Cohort According to Age Group					
	55–64 Years		65–74 Years		75–84 Years	
	1938–1947 (*n* = 6,331)	1948–1957 (*n* = 3,826)	1928–1937 (*n* = 6,498)	1938–1947 (*n* = 4,407)	1918–1927 (*n* = 4,720)	1928–1937 (*n* = 4,907)
Women	56	56	54	54	54	56
ADL-disabled at baseline	11	12	13	14	18	19
Cancer status (over 10-year follow-up)						
Cancer-free	87	87	81	77	75	74
Incident-cancer survivors	7	7	9	9	9	7
Prevalent-cancer survivors	6	7	10	14	16	19

Abbreviation: ADL, activities of daily living.

- Individuals who had cancer prior to the initial age (the prevalent-cancer survivor group)

RESULTS

Summary statistics

Table 1 presents summary statistics of the analytical sample, by birth cohort and age comparison. Individuals were included in the analytical sample if they contributed any amount of person-time in a cohort-age grouping, and individuals missing data on outcomes were excluded from the analytical sample (<1% missing ADL disability status, <0.1% missing cancer status). The percent of each cohort reporting an ADL disability rose somewhat over age, and disability rates were slightly higher in the more recent birth cohorts than in cohorts born further in the past for all comparisons. At ages 55–64 years, 87% of the "early" and "later" birth cohorts spent the entire period cancer-free, while 7% had an incident cancer diagnosis and 6–7% had a prevalent cancer diagnosis. At ages 65–74 and 75–84, smaller proportions of each successive birth cohort spent the entire analysis period cancer-free, which was largely due to substantial increases in the proportion of each cohort with a prior cancer at the study baseline.

PC-LE and DFLE: ages 55–64 (young old)

Table 2 provides estimates of PC-LE and PC-DFLE for cohorts with and without cancer for men and women at ages 55–64 between cohorts born 1938–1947 (the "early" cohort) and 1948–1957 (the "later" cohort). In the cancer-free population, PC-LE and PC-DFLE were largely comparable across cohorts, with a small decrease in DFLE and a small increase in ADL-disabled LE at these ages across the 2 cohorts (Table 2). Among incident-cancer survivors, total LE was unchanged at these ages across the 2 cohorts. PC-LE was the lowest in the incident-cancer survivor group, compared with the cancer-free and prevalent-cancer survivor groups. Among prevalent-cancer survivors, PC-LE at ages 55–64 declined across cohorts, with a reduction of about 0.16 years (95% CI: −0.28, −0.11) of LE between the 1938–1947 and 1948–1957 birth cohorts for both men and women (Table 2). We also observed a reduction in PC-DFLE, with men born in 1948–1957 expected to live 0.73 fewer disability-free years (95% CI: −1.45, −0.02) than those born in 1938–1947 (Table 2). For women, this figure was 0.5 fewer disability-free years (95% CI: −1.22, 0.21). These declines in PC-DFLE across cohorts are partially offset by increases in ADL-disabled LE at ages 55–64, with individuals with a prior cancer diagnosis experiencing 0.43 more years of disabled life in the more recent birth cohort (95% CI: 0.06, 0.80; Table 2).

PC-LE and DFLE: ages 65–74 (middle old)

Table 3 provides estimates of PC-LE and PC-DFLE at ages 65–74 between cohorts born in 1928–1937 (the "early" cohort) and in 1938–1947 (the "later" cohort). We observed only minor differences across birth cohorts in the cancer-free and incident-cancer survivor groups in this middle-old age period. In the cancer-free population, women in the later cohort lived 0.18 (95% CI: 0.12, 0.25) more years with an ADL disability at these ages than those in the early cohort (Table 3). PC-LE was substantially lower in the incident-cancer group than the cancer-free and prevalent-cancer groups at these ages. In prevalent-cancer survivors, we observed significant declines in PC-LE across cohorts, with individuals born in 1938–1947 living, on average, 0.25 fewer years in ages 65–74 than those born 1928–1937 (95% CI: −0.31, −0.20; Table 3). In prevalent-cancer survivors, DFLE declined across the 2 birth cohorts, with estimated reductions of 0.32 years in men and 0.15 years in women. However, the confidence intervals around these estimates are somewhat large due to the small sample sizes in this group.

Table 2. Partial Cohort Years of Life Expectancy and Disability-Free Life Expectancy During Ages 55–64 in the 1938–1947 and 1948–1957 Birth Cohorts, According to Initial State (Cancer-Free, Incident Cancer Survivors, Prevalent Cancer Survivors), Health and Retirement Study, United States

Initial State	Birth Cohort				Difference	
	Born 1938–1947 (Observed 1998–2008)		Born 1948–1957 (Observed 2008–2018)			
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Cancer-Free						
Total	9.67	9.63, 9.70	9.70	9.66, 9.73	0.03	−0.01, 0.06
Disability-free	8.70	8.57, 8.86	8.64	8.49, 8.74	−0.09	−0.23, 0.05
ADL-disabled	0.96	0.83, 1.07	1.06	0.97, 1.18	0.12	−0.01, 0.24
Men						
Total	9.68	9.63, 9.71	9.70	9.65, 9.73	0.02	−0.02, 0.06
Disability-free	8.77	8.62, 8.91	8.66	8.50, 8.78	−0.13	−0.27, 0.02
ADL-disabled	0.91	0.79, 1.02	1.04	0.93, 1.17	0.14	0.02, 0.26
Women						
Total	9.66	9.62, 9.70	9.71	9.66, 9.74	0.04	0.01, 0.08
Disability-free	8.64	8.48, 8.83	8.61	8.42, 8.76	−0.06	−0.23, 0.11
ADL-disabled	1.02	0.86, 1.15	1.09	0.96, 1.25	0.09	−0.05, 0.24
Incident-Cancer Survivors						
Total	8.71	8.64, 8.75	8.67	8.60, 8.74	−0.03	−0.08, 0.03
Disability-free (cancer-free)	4.51	4.44, 4.72	4.58	4.43, 4.72	0.00	−0.14, 0.14
ADL-disabled (cancer-free)	0.49	0.37, 0.59	0.59	0.48, 0.72	0.11	0.00, 0.22
Disability-free (with cancer)	3.12	2.95, 3.23	2.92	2.77, 3.06	−0.18	−0.31, −0.04
ADL-disabled (with cancer)	0.58	0.46, 0.64	0.58	0.50, 0.69	0.04	−0.06, 0.13
Men						
Total	8.68	8.59, 8.75	8.66	8.55, 8.74	−0.02	−0.10, 0.06
Disability-free (cancer-free)	4.55	4.47, 4.77	4.63	4.44, 4.75	−0.01	−0.16, 0.14
ADL-disabled (cancer-free)	0.44	0.34, 0.56	0.55	0.44, 0.72	0.12	0.01, 0.23
Disability-free (with cancer)	3.11	2.85, 3.21	2.89	2.70, 3.06	−0.16	−0.34, 0.02
ADL-disabled (with cancer)	0.58	0.45, 0.68	0.59	0.49, 0.71	0.03	−0.08, 0.14
Women						
Total	8.73	8.67, 8.79	8.69	8.63, 8.78	−0.03	−0.09, 0.04
Disability-free (cancer-free)	4.48	4.38, 4.70	4.53	4.34, 4.71	0.00	−0.16, 0.17
ADL-disabled (cancer-free)	0.55	0.38, 0.65	0.65	0.49, 0.78	0.11	−0.02, 0.24
Disability-free (with cancer)	3.14	2.99, 3.28	2.96	2.78, 3.11	−0.18	−0.33, −0.04
ADL-disabled (with cancer)	0.57	0.44, 0.63	0.56	0.47, 0.69	0.04	−0.06, 0.14
Prevalent-Cancer Survivors						
Total	9.09	8.85, 9.26	8.89	8.65, 9.11	−0.16	−0.28, −0.11
Disability-free (with cancer)	7.88	7.12, 8.50	7.19	6.50, 7.98	−0.59	−1.12, −0.05
ADL-disabled (with cancer)	1.21	0.69, 1.86	1.70	1.06, 2.23	0.43	0.06, 0.80
Men						
Total	8.97	8.65, 9.25	8.66	8.34, 9.10	−0.21	−0.32, −0.09
Disability-free (with cancer)	7.80	7.11, 8.44	6.87	5.99, 7.92	−0.73	−1.45, −0.02
ADL-disabled (with cancer)	1.17	0.71, 1.71	1.79	1.00, 2.50	0.53	0.11, 0.95

Table continues

Table 2. Continued

Initial State	Birth Cohort				Difference	
	Born 1938–1947 (Observed 1998–2008)		Born 1948–1957 (Observed 2008–2018)			
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Women						
Total	9.18	8.85, 9.36	9.02	8.77, 9.22	−0.13	−0.19, −0.07
Disability-free (with cancer)	7.93	6.88, 8.64	7.37	6.57, 8.12	−0.50	−1.22, 0.21
ADL-disabled (with cancer)	1.24	0.63, 2.08	1.64	1.01, 2.29	0.37	−0.10, 0.84

Abbreviations: ADL, activities of daily living; CI, confidence interval.

PC-LE and DFLE: ages 75–84 (older old)

Table 4 provides estimates of PC-LE and PC-DFLE at ages 75–84 between cohorts born in 1918–1927 (the "early" cohort) and 1928–1937 (the "later" cohort). Similar to the younger age groups, we observed mostly minor differences across the birth cohorts for the cancer-free and incident-cancer survivor groups at this older-old age period. In contrast to the younger age periods, prevalent-cancer survivors had the lowest PC-LE compared with the cancer-free and incident-cancer groups at these ages. Also, in contrast to the younger age periods, we found no substantial evidence for a compression or expansion of disability among prevalent-cancer survivors at this age period. However, among women there was a 0.17-year decrease in PC-LE (95% CI: −0.24, −0.01) across cohorts, which appears to primarily result from a 0.15-year decline in DFLE (95% CI: −0.6, 0.29; Table 4).

DISCUSSION

At the individual level, improvements in cancer early diagnosis and treatments over recent decades have undeniably improved cancer outcomes and survival. At the population level, however, these improvements may be having somewhat paradoxical effects on the life expectancy of adults with prior cancer diagnoses. We found that that partial LE has declined across successive birth cohorts of long-term cancer survivors who reach ages 55–64, 65–74, and 75–84 (among women only in this oldest-old age group). Incident-cancer survivors had the lowest overall partial LE at ages 55–64 and 65–74, followed by the prevalent-cancer survivors. Finally, we found that more recently born cohorts of long-term (prevalent) cancer survivors have experienced a greater burden of disability than earlier birth cohorts.

Our findings may be explained by changing patterns of survival selection across subsequent cohorts of cancer survivors who reach the age groups that we studied. Improvements in cancer early diagnosis and treatments in the mid to late 20th and early 21st centuries have increased 5-year survival rates for individuals newly diagnosed with cancer (20). At the population level, this delayed mortality appears to have translated to a worsening pattern of conditional LEs (that is, LEs conditional on surviving to age 55, 65, or 75) among cancer survivors. This improved survival may have shifted the underlying frailty distribution of older adults with cancer, such that older long-term cancer survivors at a given age now experience greater functional disability than previous birth cohorts of older long-term cancer survivors at that same age (21–23). In the past, a greater number of birth cohort members with cancer would have died at earlier ages. This differential mortality "pruning" across successive birth cohorts has been well described and often leads to selective survival bias when it occurs in epidemiologic studies (24). As a result, successive birth cohorts of cancer survivors are living with lower conditional LEs and spending more of these years with ADL disability at older adult ages.

Although early diagnosis rates and treatment effectiveness are continually improving, medical interventions often act to delay cancer death by months or a few years, leaving individuals well short of their potential LEs (25). As such, our results are consistent with the morbidity expansion and dynamic equilibrium frameworks, which may have particular salience for understanding cancer's average effects on population life and health expectancies (13, 14). The expanding rates of disability that we observed across successive birth cohorts may be explained by continual improvements in cancer treatments, survivorship care, and other medical technologies over time, if these changes are acting to keep cancer survivors with functional disabilities alive for longer (26). Similarly, if medical improvements result in only slight delays in mortality, we could see reductions in LE of cancer survivors at later ages, resulting from shifts in the underlying prevalence of disability of birth cohorts of cancer survivors who reach older ages.

Other contemporary phenomena may contribute to our results. Prescriptions of opioid medications to opioid-naive older cancer survivors increased over the early 2000s (27), timing that coincides with the reduced LE of more recent birth cohorts of long-term cancer survivors in this study.

Table 3. Partial Cohort Years of Life Expectancy and Disability-Free Life Expectancy in Ages 65–74 in the 1928–1937 and 1938–1947 Birth Cohorts, According to Initial State (Cancer-Free, Incident Cancer Survivors, Prevalent Cancer Survivors), Health and Retirement Study, United States

Initial State	Birth Cohort				Difference	
	Born 1928–1937 (Observed 1998–2008)		Born 1938–1947 (Observed 2008–2018)			
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
			Cancer-Free			
Total	9.28	9.29, 9.31	9.33	9.24, 9.38	0.03	0.01, 0.05
Disability-free	8.12	8.13, 8.21	8.10	7.78, 8.39	−0.08	−0.14, −0.03
ADL-disabled	1.16	1.10, 1.16	1.23	0.99, 1.46	0.11	0.07, 0.16
Men						
Total	9.19	9.19, 9.24	9.32	9.24, 9.34	0.10	0.06, 0.15
Disability-free	7.97	7.93, 8.07	8.13	7.84, 8.24	0.07	−0.05, 0.20
ADL-disabled	1.22	1.15, 1.26	1.19	1.10, 1.40	0.03	−0.06, 0.12
Women						
Total	9.35	9.35, 9.40	9.33	9.24, 9.43	−0.03	−0.06, 0.00
Disability-free	8.24	8.26, 8.38	8.05	7.69, 8.56	−0.21	−0.32, −0.11
ADL-disabled	1.11	1.02, 1.11	1.28	0.86, 1.55	0.18	0.12, 0.25
			Incident-Cancer Survivors			
Total	8.61	8.54, 8.63	8.51	8.48, 8.51	−0.09	−0.18, −0.01
Disability-free (cancer-free)	4.62	4.62, 4.72	4.57	4.24, 4.72	−0.15	−0.23, −0.08
ADL-disabled (cancer-free)	0.50	0.45, 0.52	0.58	0.40, 0.85	0.13	0.06, 0.19
Disability-free (with cancer)	2.89	2.70, 2.94	2.73	2.63, 2.82	−0.10	−0.28, 0.08
ADL-disabled (with cancer)	0.59	0.56, 0.67	0.63	0.53, 0.73	0.04	−0.06, 0.13
Men						
Total	8.61	8.52, 8.66	8.51	8.47, 8.49	−0.11	−0.23, 0.01
Disability-free (cancer-free)	4.61	4.56, 4.72	4.61	4.32, 4.69	−0.12	−0.24, 0.00
ADL-disabled (cancer-free)	0.48	0.44, 0.51	0.54	0.45, 0.79	0.11	0.04, 0.17
Disability-free (with cancer)	2.93	2.72, 2.97	2.74	2.63, 2.81	−0.13	−0.31, 0.04
ADL-disabled (with cancer)	0.60	0.54, 0.67	0.62	0.52, 0.71	0.03	−0.07, 0.14
Women						
Total	8.61	8.54, 8.65	8.52	8.48, 8.55	−0.07	−0.15, 0.01
Disability-free (cancer-free)	4.64	4.66, 4.73	4.51	4.12, 4.79	−0.20	−0.26, −0.15
ADL-disabled (cancer-free)	0.53	0.45, 0.54	0.65	0.33, 0.93	0.15	0.08, 0.22
Disability-free (with cancer)	2.86	2.68, 2.92	2.71	2.63, 2.84	−0.06	−0.25, 0.13
ADL-disabled (with cancer)	0.58	0.56, 0.66	0.65	0.54, 0.77	0.04	−0.05, 0.13
			Prevalent-Cancer Survivors			
Total	8.80	8.65, 8.96	8.62	8.24, 8.76	−0.25	−0.31, −0.20
Disability-free (with cancer)	7.76	7.35, 8.10	7.71	6.17, 7.92	−0.26	−0.77, 0.26
ADL-disabled (with cancer)	1.04	0.81, 1.36	0.91	0.78, 2.12	0.00	−0.29, 0.30
Men						
Total	8.87	8.62, 9.03	8.59	8.17, 8.77	−0.30	−0.38, −0.23
Disability-free (with cancer)	7.90	7.41, 8.21	7.73	6.32, 7.98	−0.32	−0.84, 0.20
ADL-disabled (with cancer)	0.97	0.75, 1.30	0.87	0.74, 1.97	0.02	−0.25, 0.28

Table continues

Table 3. Continued

Initial State	Birth Cohort				Difference	
	Born 1928–1937 (Observed 1998–2008)		Born 1938–1947 (Observed 2008–2018)			
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Women						
Total	8.73	8.60, 8.98	8.73	8.25, 8.90	−0.15	−0.23, −0.07
Disability-free (with cancer)	7.62	7.22, 8.10	7.66	5.90, 8.19	−0.24	−1.23, 0.75
ADL-disabled (with cancer)	1.11	0.85, 1.47	1.07	0.66, 2.40	0.09	−0.51, 0.68

Abbreviations: ADL, activities of daily living; CI, confidence interval.

Suicide rates are also higher among cancer survivors than in the general population (28). While the suicide rate in the general US population increased by 35% from 1999 through 2018 (29), the corresponding temporal trend in cancer-related suicides is unclear (30). The impacts of these and other recent population health trends on disability and mortality within cancer survivors deserve investigation in relation to our results.

Our study is not without limitations. Our multistate analyses follow a simple Markov logic and are not state-duration-dependent. A state-duration-dependent model may be more effective for modeling processes, like cancer survivorship, where the risk of mortality or disability onset is nonmonotonic and more tightly linked with time since diagnosis rather than chronological age (21, 31). However, given the limited time period of follow-up in the HRS, there is substantial left-censoring in our data in terms of time since cancer diagnosis. Although state-duration semi-Markov models using imputation for left-censoring do exist, these models are computationally difficult and require sample sizes substantially larger than those available from the HRS (31). The multistate life-table approach is also limited in its ability to handle a large number of covariates, which would require estimating a separate transition probability matrix for each combination of covariates. Future work is needed to explore within-population heterogeneity in our results, for instance by educational attainment or race/ethnicity.

Our use of a population-representative data source also results in some data limitations in our analysis. We were unable to distinguish between individual cancer types or stages at diagnosis, which are 2 key predictors of mortality risk. While it would be useful to determine which cancer types may be contributing the most to changes in life and health expectancies among cancer survivors, the aim of our analyses our was to focus on the total population average estimates for all cancers combined. Future research in larger sample sizes with more detailed data on cancer types and stages could elucidate trends regarding which cancers are having the largest population health impacts over time. We additionally relied on data on cancer and disability statuses provided by proxy respondents in cases where the primary respondent was unable to complete the interview. While these proxy respondents represented less than 5% of the sample, there is a possibility that they may not be fully aware of the primary respondents' cancer or physical disability status. Clinical data would allow a more detailed investigation of the cancer survivor groups, such as whether the cancer is clinically considered to be in remission, time since treatment ended, and history of recurrence and metastasis. These data are not readily available from the HRS. Additional clinical data on cancer cases would be valuable and should be the topic of future research that builds upon the present study.

Despite these limitations, our findings represent a substantial advance in knowledge on the impact of changes in cancer survivorship on population-level health across successive generations. These analyses directly identify how LE and DFLE have changed over successive cohorts of older cancer survivors. To the best of our knowledge, no other scholarship has explored the links between cancer survivorship and healthy longevity in cohort fashion, and only a few recent studies have explored cohort trends in other chronic health conditions (32–34). These partial cohort estimates measure how a given health condition affects health and disability across successive birth cohorts that are currently living, allowing researchers to monitor ongoing population health trends. In contrast, full cohort life and health expectancy estimates can only be generated once a birth cohort is extinct. Partial cohort measures can also identify trends in health during key periods of the life course—such as late middle age, where recent scholarship in the United States has shown rising trends in physical limitation, poor health, and mortality risk (35, 36).

In conclusion, we newly observed that successive birth cohorts of long-term cancer survivors have experienced reduced partial LE and an expansion of disability across the period from 1998 to 2018. Given steady improvements in cancer survival rates at the individual level, this finding is somewhat paradoxical at first glance. However, improvements in treatment and prolonged cancer survivorship may have, at the population level, led to a shift in frailty heterogeneity within the population of cancer survivors (21, 23), resulting in aggregate increases in disabled LE

Table 4. Partial Cohort Years of Life Expectancy and Disability-Free Life Expectancy in Ages 75–84 in the 1918–1927 and 1928–1937 Birth Cohorts, According to Initial State (Cancer-Free, Incident Cancer Survivors, Prevalent Cancer Survivors), Health and Retirement Study, United States

Initial State	Birth Cohort				Difference	
	Born 1918–1927 (Observed 1998–2008)		Born 1928–1937 (Observed 2008–2018)			
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
			Cancer-Free			
Total	8.46	8.41, 8.53	8.38	8.42, 8.57	−0.01	−0.11, 0.10
Disability-free	6.64	6.59, 6.92	6.60	6.73, 7.18	0.22	−0.09, 0.53
ADL-disabled	1.82	1.61, 1.89	1.79	1.34, 1.70	−0.23	−0.46, 0.00
Men						
Total	8.32	8.3, 8.41	8.28	8.27, 8.45	−0.02	−0.09, 0.06
Disability-free	6.54	6.52, 6.72	6.67	6.66, 7.13	0.24	0.08, 0.40
ADL-disabled	1.79	1.67, 1.84	1.61	1.29, 1.66	−0.25	−0.40, −0.11
Women						
Total	8.56	8.48, 8.64	8.47	8.52, 8.67	0.02	−0.12, 0.17
Disability-free	6.71	6.58, 7.07	6.54	6.71, 7.23	0.22	−0.20, 0.65
ADL-disabled	1.85	1.57, 1.91	1.93	1.40, 1.83	−0.20	−0.50, 0.10
			Incident-Cancer Survivors			
Total	8.31	8.26, 8.33	8.24	8.20, 8.25	−0.05	−0.10, −0.01
Disability-free (cancer-free)	4.30	4.19, 4.45	4.38	4.44, 4.63	0.18	−0.04, 0.39
ADL-disabled (cancer-free)	0.78	0.65, 0.82	0.69	0.47, 0.67	−0.19	−0.34, −0.05
Disability-free (with cancer)	2.28	2.08, 2.26	2.31	2.26, 2.35	0.11	−0.03, 0.25
ADL-disabled (with cancer)	0.95	0.96, 1.10	0.87	0.79, 0.93	−0.15	−0.26, 0.04
Men						
Total	8.28	8.24, 8.33	8.25	8.18, 8.25	−0.06	−0.14, 0.02
Disability-free (cancer-free)	4.33	4.28, 4.44	4.45	4.44, 4.60	0.18	0.04, 0.31
ADL-disabled (cancer-free)	0.76	0.63, 0.78	0.55	0.37, 0.60	−0.22	−0.33, −0.11
Disability-free (with cancer)	2.23	2.02, 2.33	2.39	2.29, 2.44	0.16	−0.06, 0.38
ADL-disabled (with cancer)	0.96	0.98, 1.16	0.86	0.77, 0.92	−0.18	−0.33, −0.03
Women						
Total	8.33	8.23, 8.35	8.24	8.22, 8.27	−0.04	−0.13, 0.04
Disability-free (cancer-free)	4.28	4.10, 4.48	4.31	4.42, 4.66	0.17	−0.13, 0.48
ADL-disabled (cancer-free)	0.80	0.66, 0.87	0.81	0.52, 0.77	−0.15	−0.33, 0.03
Disability-free (with cancer)	2.32	2.12, 2.24	2.23	2.17, 2.29	0.06	−0.03, 0.14
ADL-disabled (with cancer)	0.94	0.94, 1.06	0.89	0.81, 0.94	−0.12	−0.23, −0.02
			Prevalent-Cancer Survivors			
Total	8.09	7.89, 8.27	8.03	7.72, 8.23	−0.09	−0.14, 0.04
Disability-free (with cancer)	6.58	6.06, 6.97	6.58	5.62, 7.07	−0.07	−0.48, 0.34
ADL-disabled (with cancer)	1.51	1.22, 1.91	1.45	1.10, 2.14	−0.02	−0.24, 0.20
Men						
Total	8.00	7.74, 8.26	8.07	7.63, 8.29	−0.05	−0.13, 0.04
Disability-free (with cancer)	6.52	5.87, 6.93	6.63	5.25, 7.18	−0.02	−0.66, 0.63
ADL-disabled (with cancer)	1.48	1.20, 1.96	1.44	1.05, 2.44	−0.03	−0.36, 0.30

Table continues

Table 4. Continued

Initial State	Birth Cohort				Difference	
	Born 1918–1927 (Observed 1998–2008)		Born 1928–1937 (Observed 2008–2018)			
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Women						
Total	8.18	7.88, 8.36	7.96	7.65, 8.21	−0.17	−0.24, −0.01
Disability-free (with cancer)	6.63	6.06, 7.09	6.50	5.51, 7.04	−0.15	−0.60, 0.29
ADL-disabled (with cancer)	1.55	1.18, 1.94	1.46	1.10, 2.21	−0.02	−0.25, 0.22

Abbreviations: ADL, activities of daily living; CI, confidence interval.

and reductions in total LE across successive birth cohorts. The roles of changing cancer diagnostic and treatment practices remains to be elucidated, as well as the roles of contemporary population health trends that may have differential effects on those with cancer, such as opioid use, suicide rates, and changing comorbidity patterns. Future research should also investigate whether changes in the incidence of specific cancer types over time could also contribute to these changes in LE across birth cohorts of cancer survivors. Ultimately, results from this line of inquiry will help with understanding both the trends in clinical care needs of older cancer survivors, and the changing effects of long-term cancer survival on overall population health in the United States.

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