The Gerontologist
cite as: *Gerontologist*, 2015, Vol. 55, No. 6, 901–911
doi:10.1093/geront/gnv130
Advance Access publication November 10, 2015

Feature Article

Lifespan and Healthspan: Past, Present, and Promise

Eileen M. Crimmins*

Davis School of Gerontology, University of Southern California, Los Angeles.

*Address correspondence to Eileen M. Crimmins, PhD, Davis School of Gerontology, University of Southern California, 3715 McClintock Avenue, Los Angeles, CA 90089-0191. E-mail: crimmin@usc.edu

Received April 21, 2015; Accepted July 15, 2015

Decision Editor: Rachel Pruchno, PhD

Abstract

The past century was a period of increasing life expectancy throughout the age range. This resulted in more people living to old age and to spending more years at the older ages. It is likely that increases in life expectancy at older ages will continue, but life expectancy at birth is unlikely to reach levels above 95 unless there is a fundamental change in our ability to delay the aging process. We have yet to experience much compression of morbidity as the age of onset of most health problems has not increased markedly. In recent decades, there have been some reductions in the prevalence of physical disability and dementia. At the same time, the prevalence of disease has increased markedly, in large part due to treatment which extends life for those with disease. Compressing morbidity or increasing the relative healthspan will require "delaying aging" or delaying the physiological change that results in disease and disability. While moving to life expectancies above age 95 and compressing morbidity substantially may require significant scientific breakthroughs; significant improvement in health and increases in life expectancy in the United States could be achieved with behavioral, life style, and policy changes that reduce socioeconomic disparities and allow us to reach the levels of health and life expectancy achieved in peer societies.

Key Words: Compression of morbidity—Delaying aging—Health expectancy—Life expectancy—Trends in morbidity

For most of the last century, social policy focused on increasing life expectancy in the population; but in recent decades, policy and research are increasingly focused on the potential of increasing healthy life or healthspan. In this article, I review the evidence on past and recent trends in lifespan and healthspan and use these as a basis for clarifying what I believe to be the near term future for likely increases in both lifespan and healthspan. My incentive in addressing these topics arises from the fact that I have heard many researchers in our multidisciplinary field of gerontology who are not fully aware of the empirical evidence. I am using the terms "lifespan" and "healthspan" as I believe they have come to be used among multidisciplinary researchers in the gerontological profession as meaning average lifespan or life expectancy and average healthspan or average length of healthy life. In addition, much of the data that I use refer to the United States, but the general patterns of change tend to be fairly similar in many developed countries.

An earlier version of this article "Lifespan and Healthspan: Past, Present and Promise" was presented as the 2012 Robert W. Kleemeier Award lecture on November 23, 2013 at the 66th Annual Scientific Meeting of The Gerontological Society of America, New Orleans, Louisiana.

Lifespan or Life Expectancy

Perhaps the greatest human accomplishment of the past century was the remarkable increase in life expectancy. In a century the world changed markedly from having almost no countries with life expectancy more than 50 years to having many countries with a life expectancy of 80 years as life expectancy almost doubled in the long-lived part of the world. As an example, in the United States life expectancy at birth over the 110 years from 1900 to 2010 went from 47.3 to 78.7 (Centers for Disease Control and Prevention/ National Center for Health Statistics [CDC/NCHS], 2012, 2013). At first, this increasing length of life resulted from declines in infectious disease and deaths concentrated among the young. After most deaths from infectious conditions were eliminated, cardiovascular conditions and cancer dominated the causes of death. These then became the targets of science and medicine in the second half of the last century.

Due in large part to declining mortality from heart disease, life expectancy continued to increase in the last decades of the 20th century. Because heart disease primarily causes death among older adults, recent increases in life expectancy have occurred at older ages. Life expectancy has increased all the way up the age range, certainly up to 100 years. For instance, life expectancy at ages 65 and 85 increased by about 50% over the century (Bell & Miller, 2005).

Living to and Dying at Older Ages

The most recent U.S. life table (2010) implies that half of males born today will survive to 78 years and half of females will survive to age 83 years (CDC/NCHS, 2013). These ages were 55 and 58 years in 1900 (Bell & Miller, 2005). The increases in life expectancy mean that now most people will live to old age; and once they reach old age, they will live longer than they used to. The changing distribution of age in lifetable deaths for the last half century provides an even clearer picture than life expectancy of the changes in mortality at older ages. In more recent years, the modal age at death is increasingly older and the shape of the curve showing the distribution of deaths by age is increasingly peaked; deaths are very concentrated at older ages. This is shown for U.S. males in Figure 1. This concentration of death about the modal age has increased in the United States and in a number of other countries (e.g., France, Sweden, and Japan), but not all countries as Denmark is an outlier (Robine, 2011). Over the period from 1950 to 2010, this modal age has risen by about 10 years from about 77 to 87 years (Robine, 2011). However, while even with these changes in the age at death, the increase in life expectancy at age 85 over more than a century was just over 1 year for men and 2 years for women; above age 95 it was only half of that (Figure 2). So while the percentage increase in the length of life was substantial, the absolute increase was not great.

There have been increases over time in the likelihood we will reach very old age—100 years of age—in the United States and in other countries (Vaupel & Jeune, 1995). In Japan, the country with longest life expectancy at present, the number of centenarians has doubled every decade since 1960 (Robine & Saito, 2003). Again, the percentage increases are great, but estimates from the Social Security Administration of the United States from the 2010 period lifetable indicate that only about 1% of persons survive to 100 years; this is expected to increase to about 8% for the cohort of 2100, still a very small percentage.

Very few people make it to 100 years because mortality rates are extremely high at very old ages, generally increasing in an exponential manner through the older years. Even though centenarian death rates have declined, they have declined from levels of about 50% a year to levels of 35% a year in Japan (Robine & Saito, 2003). Because so few survive to 100 years, and because they have a very short life expectancy at that age, there is currently very little increase in total life expectancy at birth resulting from changes in mortality over age 100. Whether the proportion of people surviving to 100 years and life expectancy will increase markedly at the oldest ages depends on whether we are facing a biologically maximum limit to life expectancy that we cannot exceed (Manton, Stallard, & Tolley, 1991).

Projections of Future Life Expectancy

Researchers argue about the rate of increase in mortality at the oldest ages and whether the shape of the curve will

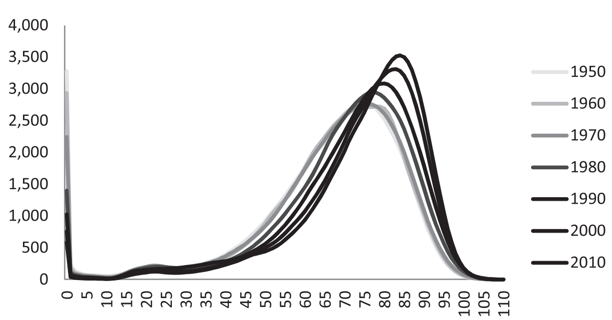

Figure 1. Number of male life table deaths by age. Source of data: Bell & Miller (2005).

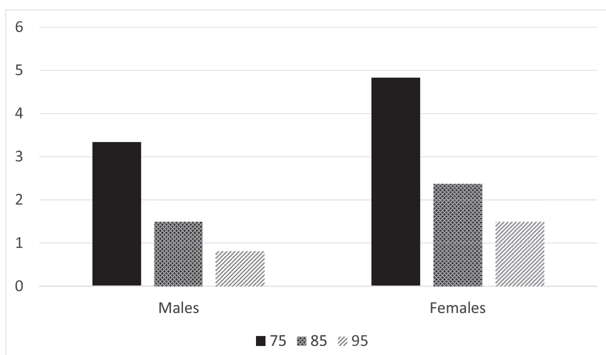

Figure 2. Years of increase in life expectancy at ages 75, 85, and 95 years between 1900 and 2010 in the United States. Source: Bell & Miller (2005)

change in future cohorts (Gavrilova & Gavrilov, 2014). Most researchers who have looked at trends in mortality at the oldest ages conclude that there is no evidence that there is an imminent wall beyond which life expectancy cannot increase; and the question for the foreseeable future is whether mortality decline and life expectancy increase will occur at a faster or a slower rate (Bongaarts, 2005, 2006; Cheung & Robine, 2007; Kannisto, 2001). Projections of future mortality change and increase in life expectancy vary considerably because they are based on very different assumptions. Some projections are based on short-run trends, some on long-run trends, some on period factors, some on cohort factors, and some make assumptions about medical and scientific progress.

Three projections for the year 2050 are shown in Figure 3. Mortality tables developed by the U.S. Social Security Administration, which is regarded as relatively conservative in their projections, estimate that we will gain about a year of life expectancy every 10 years and about half a year of life expectancy at age 65 in each of the coming decades. Bongaarts (2006) has suggested that improvement is likely to be about 50% higher, based on his approach of separating trends in senescent and non-senescent mortality. Vaupel and colleagues suggest that improvement will be about twice as fast or that life expectancy will increase about 2 years every decade (Christensen, Doblhammer, Rau, & Vaupel, 2009; Oeppen & Vaupel, 2002). Their optimistic projections are based on the assumption that recent rapid increases in life expectancy at birth will continue. Christensen, Doblhammer, Rau, & Vaupel (2009) have clarified that this projection implies that about 50% of the cohort born in 2000 will reach 100 years, or about 7 times greater than the U.S. Social Security Administration predicts for the United States.

Implications of Past Trends for Future Life Expectancy

Are we on a path to very rapid increase in life expectancies? If one uses the past as a guide to the future, it is hard to reconcile the most optimistic projections of life expectancy for the lifetimes of those currently alive or soon to be alive. Caleb Finch, Hiram Beltran-Sanchez, and I (Beltrán-Sánchez, Crimmins, & Finch, 2012; Finch, Beltrán-Sánchez, & Crimmins, 2014) have examined historical cohort patterns of mortality change for 630 birth cohorts in nine countries. For these cohorts, there is a very clear cohort pattern of mortality change, that is, the cohorts who experienced decreased mortality at young ages are the same as those who have improved in life expectancy at older ages. We think this is more than a statistical relationship; that the improvement in development of bodies at younger ages and the reduction in exposure to infection are related to the declines in mortality at older ages which occurred in the last part of the 20th century, that is, that some of the declines in cardiovascular diseases such as heart disease and stroke result from improvement in lifelong health conditions. If this is true, researchers may have overestimated the role of medical interventions and life style changes in recent decades and underestimated the effect of lifelong changes in increasing life expectancy at older ages. If there is no longer a potential for improvement in early life because mortality is already so low, projections for the future based on this history would lead to an overestimate of future life expectancy. This leads us to think that the less optimistic projections may be closer to reality.

We have also examined the parameters that describe mortality relationships across the age range of these cohorts, that is, the Gompertz parameters. Until recently, cohorts who had lower mortality early in life had higher rates of increase with age in adulthood meaning that the age-specific increase at older ages actually became steeper in later cohorts (Beltrán-Sánchez et al., 2012). This relationship between lower initial levels of mortality and faster rates of increase is the long-noted Strehler–Mildvan relationship, but in this case examined for cohorts rather than period data. If it were to continue to hold, it implies that a maximum life expectancy will be reached that is less than 100 years. This model based on long-run history indicates the potential of further increasing life expectancy, to as high as 95 years, but it does not lead us to expect large percentages of people surviving beyond 100 years.

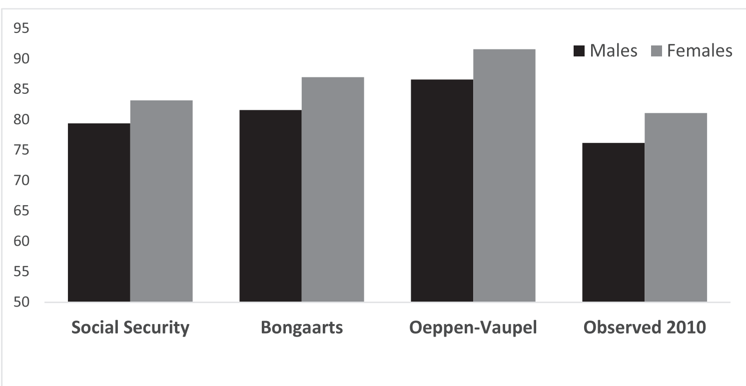

Figure 3. Projections of U.S. life expectancy for 2050. Source: Social Security Projection, Bell & Miller (2005); Bongaarts (2006); Oeppen & Vaupel (2002): U.S. life expectancy 2010, Bell & Miller (2005).

Of course, the future can differ from the past, and the rate of increase in mortality with age may be substantially reduced. In fact, we have recently seen some hint of this in the cohorts who have completed their lives in the last two decades (Beltrán-Sánchez et al., 2012). It is also possible that the age at which mortality starts increasing markedly may get substantially older with interventions to delay "aging." If these things happen, life expectancy can exceed 100 years.

The difficulty in increasing life expectancy when mortality is as low as it is throughout much of the age range should not be underestimated. Estimates from the U.S. vital statistics are that eliminating deaths from major cardiovascular disease would add 5.5 years to life expectancy and eliminating deaths from cancer would add 3.2 years (Arias, Heron, & Tejada-Vera, 2013). So even with these accomplishments, life expectancy would be less than 90 years in the United States. In sum, I am cautious about projecting large increases in life expectancy and survival to very old ages in the coming decades but believe continued increases will occur at a modest pace unless there is an unprecedented delay in "aging."

Trends in Population Health

Changes in population health over the last century are more difficult to characterize succinctly than changes in lifespan. Health has many dimensions that do not necessarily change in the same way over time and that are not related to mortality change in the same way (Crimmins, 2004). Multiple dimensions of health are indicated by the boxes in Figure 4 outlining what has been called the morbidity process (Crimmins, Kim, & Vasunilashorn, 2010). For populations, health change related to aging begins with the physiological dysregulation indicated by a number of biological risk factors, which is followed by the subsequent diagnosis of diseases, functioning loss and disability, frailty, and death. This process is portrayed with a heuristic and simplified picture for a population, not necessarily for any individual. Any individual may skip some of the process and some of the process may be reversible and/or repeatable. We should also recognize that the link between health and mortality is not a one to one correspondence. Many diseases and conditions that cause disability and loss of functioning are not very important causes of death; examples include arthritis, osteoporosis, and affective and cognitive problems. On the other hand, cancer is a major cause of death but not of functioning loss or disability.

We can examine trends over time in each dimension of health included in the morbidity process. We begin by examining trends in disability in the older population because most of the research on trends in health among the old has focused on trends in severe disability or frailty as measured by ability to perform activities of daily living (ADLs). The trend in the United States among those aged 65 and older in inability to perform ADLs has been varied over time: the 1980s were a period of relative stability with little systematic change in ability to perform ADLs, followed by decline in reported difficulty or improvement in functioning by 1%–2.5% from the early or mid 1990s, then from 2000 up to 2008 continued improvement in functioning only for the very old (85 years and older) and stability for the younger old (65–84 years of age; Freedman et al., 2004, 2012; Seeman, Merkin, Crimmins, & Karlamangla, 2010). Younger cohorts, typically beginning with the baby boomers, have not experienced improvement in functioning over time but rather some deterioration (Crimmins, Reynolds, & Saito, 1999; Martin & Schoeni, 2014).

Trends in disability that includes less severe as well as more severe functioning problems are not the same as trends limited to more severe functioning. The prevalence of less severe disability has generally been reduced over time; this is indicated by the trends over the last 4 decades in the limitation in ability to perform normal activity (Figure 5). Positive changes in disability such as these have generally been credited to improvement in education and the reduction in physical demands of labor (Martin & Schoeni, 2014; Martin, Schoeni, & Andreski, 2010) as well as improved physical development early in life associated with reductions in infection and improved nutrition.

Changes over time in cognitive functioning or dementia are less consistent in the literature than those in physical function although the preponderance of research suggests some reduction in dementia or improvement in cognitive functioning in recent years (Freedman, Aykan, & Martin, 2001; Langa et al., 2008; Larson, Yaffe, & Langa, 2013; Manton, Stallard, & Corder, 1995, 1998). Age-specific proportions with dementia from 2000 to 2010 in the Health and Retirement Study estimated using a method of assigning dementia described by Crimmins, Kim, Langa, and Weir (2011) show decline over time (Figure 6). Generally such changes are credited to the same reasons as the improved physical functioning, increases in education, and early life nutrition and development.

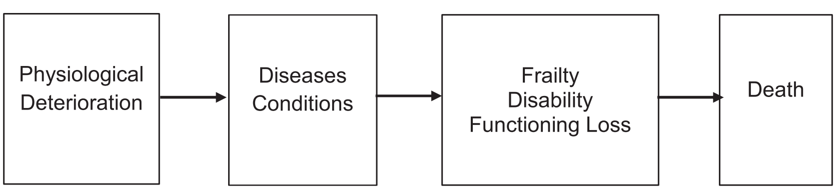

Figure 4. Dimensions of the morbidity process. Source: Crimmins et al. (2010)

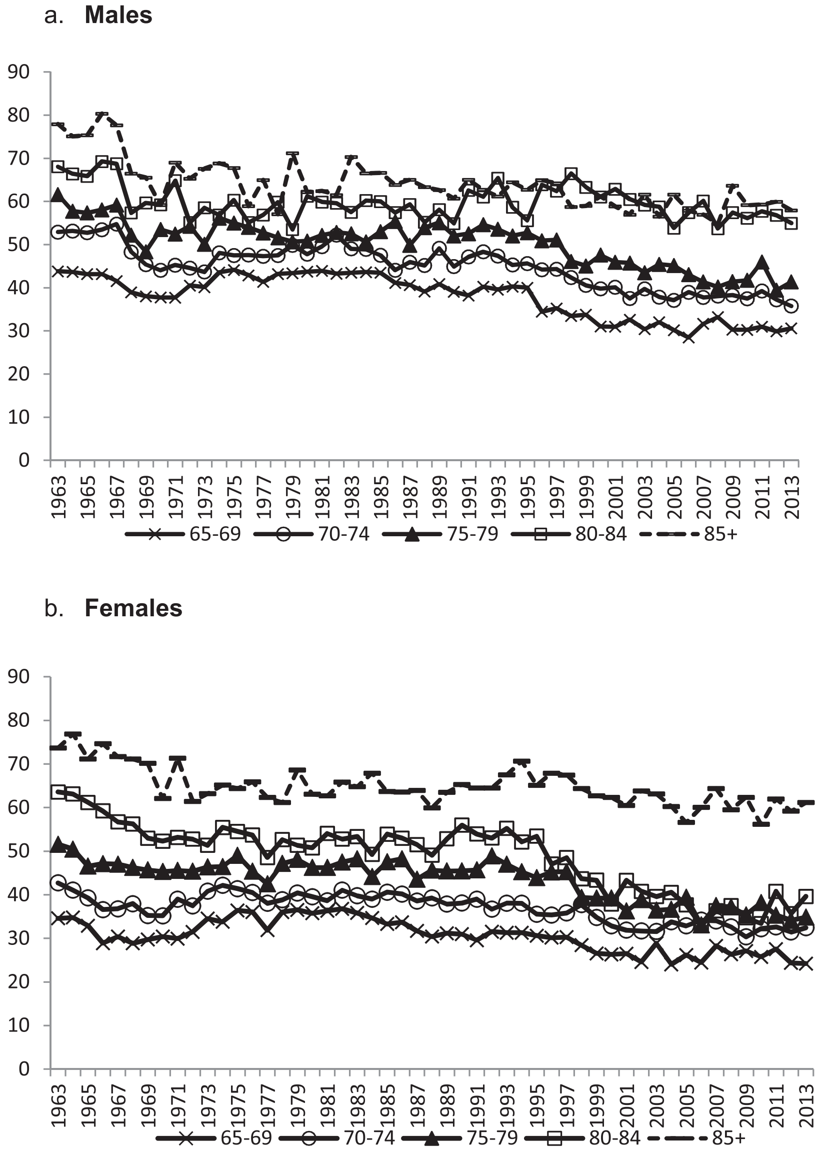

Figure 5. Trend in less severe disability among Americans aged 65 and older: Percent with any activity limitation (1963–2010) for (**A**) Males and (**B**) Females. Source: Minnesota Population Center and State Health Access Data Assistance Center, *Integrated Health Interview Series: Version 5.0.* Minneapolis: University of Minnesota, 2012. http://www.ihis.us. Trends adjusted for changes in question wording.

Let's turn to trends in the prevalence of diseases in the older population. Some have declined. For instance, fewer persons have bronchitis and emphysema, and smoking cessation is credited as the cause. On the other hand, self-reports of arthritis have generally increased (Crimmins, 2004; Freedman, Schoeni, Martin, & Cornman, 2007). Diabetes also appears to have been increasing since at least the 1950s, with more rapid increase after the 1990s (CDC, 2013). This trend reflects improved survival among diabetics as well as increased incidence due to increasing numbers of overweight persons.

The prevalence of cancer, heart disease, and stroke also increased from the 1970s through the 1990s, which may reflect both increased survival among those who have the conditions and improved diagnosis (Crimmins & Saito, 2000). More recently, cancer has continued to increase but heart disease and stroke may be beginning to decline. This has been reported from recent studies of hospitalizations for acute myocardial infarction, which indicate that the increasing trend may have ended around 1990, followed by a period of stability up to 2000 after which there were marked reductions (20%–40%; Chen et al., 2010; Fang & Alderman, 2002; Talbott, Rager, Brink, Benson, & Bilonick, 2013; Wang, Wang, Chen, & Krumholz, 2012; Yeh, Sidney, Chandra, Sorel, & Selby, 2010). Stroke incidence as indicated by hospitalizations is reported to have peaked around 1997 for those aged 65 and older and now to have declined somewhat (Fang, Alderman, Keenan, & Croft, 2006). Thus, after a long period of increase in the prevalence of many conditions, it is possible that we are beginning to see the beginning of reductions in disease presence that could reflect improvement in innate health of older persons.

What do we know about change over time in physiological status? Again, there are many indicators of physiological dysregulation and they do not all move in the same direction. Over the past 50 years, in the United States we have had remarkable declines in measured blood pressure and cholesterol (Crimmins et al., 2010; Martin et al., 2010; Ong et al., 2013) (Figure 7). Long-term improvement in cholesterol and hypertension is probably due to some combination of increased use and effectiveness of prescription drugs and diet change, and possibly reduced smoking. In recent years, most of these improvements have been attributed to the use of medications—antihypertensives and statins. For instance, in the last decade, the proportion of people with hypertension, that is, those who either have measured hypertension or who take medication, has stayed fairly constant; while the use of medications has increased markedly, resulting in rapid reductions in measured hypertension (Figure 8). The pattern for high cholesterol is relatively similar—although the numbers of people with either measured high cholesterol or on medications actually increased, the numbers with high measured cholesterol have decreased (Figure 8).

On the other hand, obesity has increased over time (Alley, Lloyd, & Shardell, 2010). There is also evidence of increase in adverse levels of related biomarkers, such as plasma glucose, which would also be related to the increase in diabetes mentioned earlier (Beltrán-Sánchez, Harhay, Harhay, & McElligott, 2013). Although it is hard to summarize all

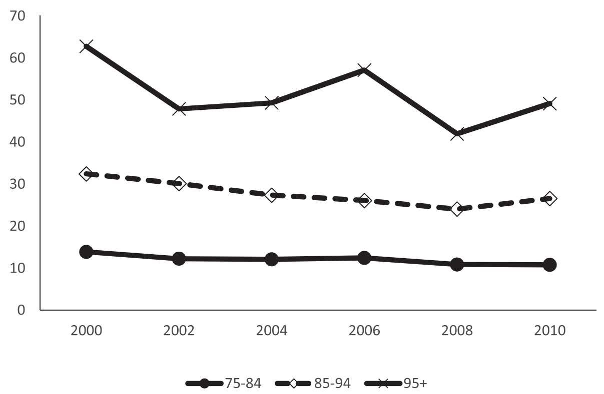

Figure 6. Percent with dementia by age (2000–2010), Health and Retirement Study, age 75 years and older. Source: Calculations from Health and Retirement Study data. Dementia based on method in Crimmins et al. (2011).

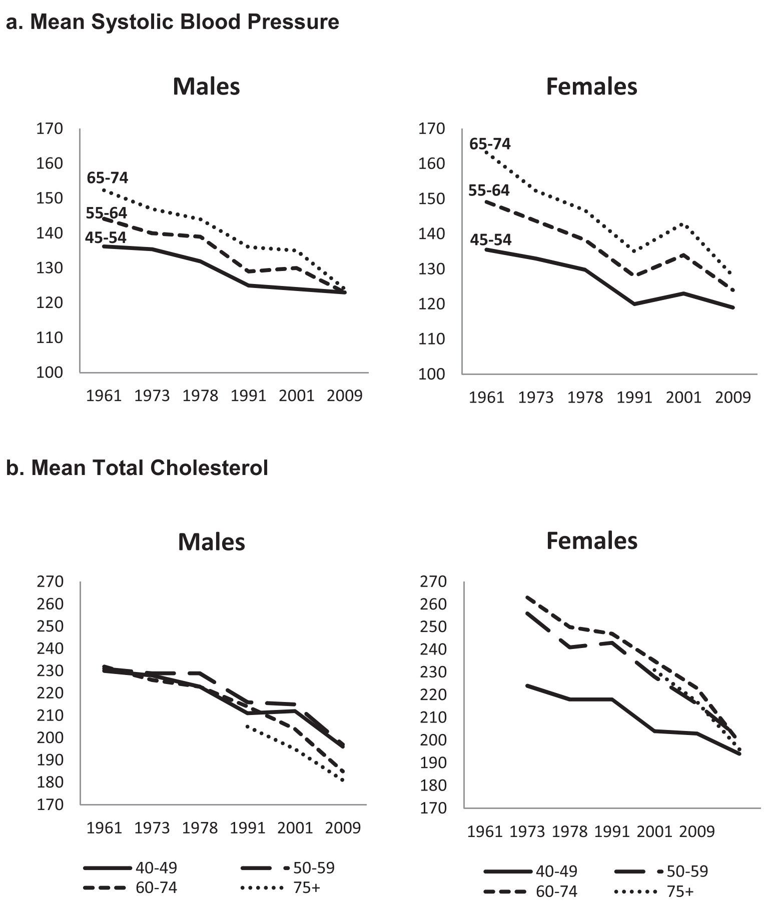

Figure 7. Trends in mean systolic blood pressure and mean total cholesterol (1960–2010). (**A**) Mean systolic blood pressure. Source: Kumanyika et al. (1998). 1960–1980. Calculated from National Health and Nutrition Examination Survey (NHANES) data: 1988–1994, 1999–2002, and 2007–2010. (**B**) Mean total cholesterol. Source: Carroll et al. (2005). 1960–2002. Calculated from NHANES data: 2007–2010. National Center for Health Statistics, Centers for Disease Control and Prevention, Hyattsville, MD 20782, USA. mdc3@cdc.gov.

physiological change succinctly, time change in a summary indicator of the average number of cardiovascular risk factors at three dates spanning almost 20 years shows that the average number of risk factors measured at clinically defined high-risk levels has been reduced to lower levels above age 50 (Figure 9). Other researchers have reported small reductions in the prevalence of metabolic syndrome in the most recent decade (Beltrán-Sánchez et al., 2013).

In sum, recent health trends are looking promising with recent declines in the prevalence of some major diseases such as heart disease and stroke, continuing declines in less severe disability, declines in the prevalence of cognitive impairment, and an overall balance of physiological status that may be starting to improve. However, other diseases (e.g., diabetes) appear to be continuing to increase, and trends in severe physical disability do not indicate continued improvement for most age groups; so the outlook for health change in the future is mixed.

Looking at each dimension of morbidity independently is not enough to clarify changes in the process of health change in a population. The links between the health dimensions may also change, that is, disease may be linked to less disability, and physiological change to less disease. In fact, the likelihood of reporting disease with risk factors appears to be recently reduced (Mehta & Chang, 2011); the likelihood of disability with disease appears lowered (Crimmins & Saito, 2000); and the likelihood of death from disease and disability has been reduced (Crimmins & Beltrán-Sánchez, 2011; Crimmins, Hayward, Hagedorn, Saito, & Brouard, 2009). So the whole morbidity process or the process of health change in the population may be being delayed or stretched out. This is the type of change that will lead to increased healthspan.

Trends in Healthspan or Length of Healthy Life

Up to this point, we have discussed primarily the prevalence of health problems, but this is not the same as healthspan that combines information on both morbidity and mortality. Emphasis on healthspan as an additional indicator of population health began about 30 years ago and was a direct result of difficulty in interpreting trends

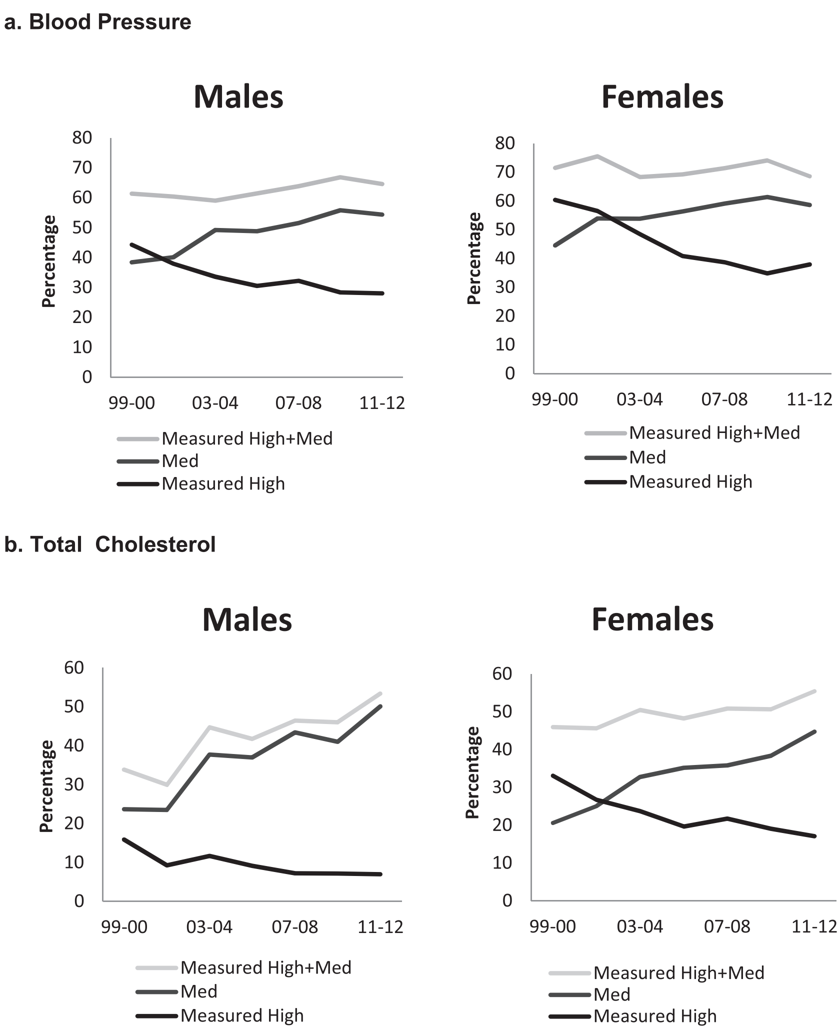

Figure 8. High blood pressure and high cholesterol (measured + medication), measured high blood pressure and high cholesterol, antihypertensive and cholesterol lowering medication use for older adults aged 65 and older. (**A**) Blood pressure, (B) total cholesterol. Source: NHANES.

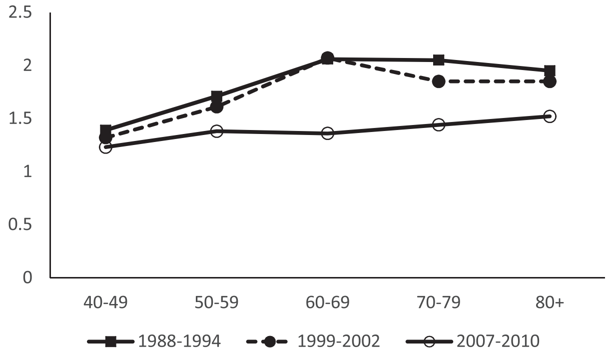

Figure 9. Average summary score of biological risk by age at three dates: Number of factors at high-risk level out of 9. Source: NHANES Data. Nine risk factors: total cholesterol, high density lipoprotein, low density lipoprotein, triglycerides, obesity, HbA1C, C-reactive protein, systolic blood pressure, and diastolic blood pressure.

in population health when the increase in life expectancy was due to a reduction in chronic disease mortality at the older ages. When life expectancy was short, death was often the result of a recent infection which was without visible long-term health consequences when survived. Now death is generally the result of chronic conditions, which develop over a long lifespan; and reduction in death rates among people who have chronic disease or disability means that more people with disease and disability survive. There were initially two opposing views on what would happen to population health and healthspan with life expectancy increases at older ages—one focused on the failure of success—noting that keeping unhealthy people alive could cause the health of the population to deteriorate (Gruenberg, 1977). The other more optimistic approach of James Fries (1980) raised the idea that the same processes that caused a lengthening in life expectancy could result in a reduction in morbidity or a delay in disability until just before death, thereby shortening the period of morbidity and resulting in a compression of morbidity (Fries, 1980). This compelling idea has resulted in a generation of research on trends in population morbidity and healthy life expectancy.

In response to some initial empirical findings for the 1970s and 1980s indicating lengthening life but worsening health in populations, Crimmins, Hayward, and Saito (1994) performed simulations to clarify how potential changes in mortality and morbidity interact to affect the length of healthy life and the health of populations. Some of these findings are not intuitive. Reductions in mortality alone, without changing morbidity onset rates, led to longer unhealthy life and worse population health; and these effects are more pronounced if mortality decline is concentrated among the sick. On the other hand, reducing morbidity incidence and improving recovery rates, without reducing mortality, lead to an increasing length of healthy life and improving population health. If mortality and morbidity change together, there is an increase in the length of both healthy and unhealthy life, and the proportion of life healthy remains constant, but the proportion of the population unhealthy can decrease (Crimmins, Hayward, & Saito, 1994).

What is the evidence on how observed changes in mortality and morbidity have affected the length of healthy life? It appears that life expectancy among the older people has been increased by reducing mortality among older persons with disease and disability in the United States (Crimmins et al., 2009). We have saved people from dying who had a disease, an accomplishment that leads to more years of life with heart disease, diabetes, and cancer (Crimmins & Beltrán-Sánchez, 2011). Whether the increases in disability-free life expectancy have kept pace with the increases in life expectancy has depended on the definition of disability employed and the period studied. Generally, improvements in disability have been in categories that include relatively mild disability. Among the older people, some reduction in life with ADL dependency and some increase in ADL-free life expectancy, or more severe disability, were reported for the 1990s (Crimmins et al., 2009); however, this finding may be limited to men (Solé-Auró, Beltrán-Sánchez & Crimmins, 2014). In the United States, repeated cross-sectional studies have shown that healthy or disability-free life expectancy did not increase in the 1970s but appeared to increase in the 1980s (Crimmins & Saito, 2001). Thus, we really have not experienced much compression of morbidity to date because we have reduced mortality more than we prevented morbidity. Healthspan will be increased when morbidity is decreased, most effectively through raising the age of onset.

Future

Life expectancy will continue to increase through steady improvements in reducing mortality from chronic disease, which should continue for the foreseeable future. I believe that in order for life expectancy to increase so that the majority of people live to be older than 95 years, extremely dramatic interventions would be needed at younger ages, not just interventions after adulthood or at the end of life. This means that interventions will take years to play out; so changes would have to be underway now for rapid change to occur among those alive now.

How we reduce mortality will determine whether we live longer healthy lives. We are now at a stage where we can focus on delaying the onset of and progression of chronic conditions and associated disabilities. As indicated earlier, there are some signs that positive changes are beginning to occur that point to reduction in physiological risk factors and reduction in some disease and disability onset.

Aging is what sets the morbidity process into action. To improve healthy life, we need to better understand the beginning of the process; and to focus on slowing and delaying this process (Goldman et al., 2013). We need to focus on prolonging health rather than only preventing death. To delay the process, we need to keep people healthy, not just treat people with disease. We now know that a number of health outcomes linked to age—mortality, heart disease, functioning loss, cognitive loss—have very similar risk factors. They are all rooted in the physiological changes related to aging. In order to monitor health, we need to define the markers that indicate where we are on the pathway to physiological aging more precisely and try to delay this process.

We need clinical trials where delaying "aging" or physiological change associated with age is the desired outcome. These trials will need to begin early in life and proceed over many decades. This requires major changes in how we run clinical trials among people who do not yet have any diagnosable condition except "aging." We also need a focus on preventing and delaying disability as much as disease in order to improve healthspan. There are a number of signs in the population data that we may be at the beginning of the century of improving healthspan, not just lifespan. It is timely that scientific advances have begun to suggest the paths to improving healthspan (Kennedy et al., 2014; Longo et al., 2015).

Discussion

Before concluding that all signs point to future improvement, we need to acknowledge that there is much that can be done to improve lifespan and healthspan in the United States that does not require scientific discovery. Health is determined by social conditions as well as physical conditions. Risky health behaviors, lack of access to medical care, and poor life circumstances may account for up to half of premature mortality and morbidity (Rhodes, 2015). Behavioral changes, changes in social and economic situations, and changes in policies can provide a substantial improvement in the length of healthy life in the United States. Our current life expectancy in the United States is dramatically below its scientific potential (Crimmins, Preston, & Cohen, 2011). The United States not only ranks very poorly in life expectancy among all countries with incomes like ours; but since 1950 our rank is falling relative to other countries. For women, we have had decades of stagnation in life expectancy leaving us at the bottom of the group of wealthy and long-lived countries (Crimmins et al., 2011). It is not because of mortality among the older adults that we rank so poorly; in fact, among those older than 70 years, mortality in the United States is relatively good; surviving to old age is where the United States does relatively poorly (Crimmins et al., 2011). Among 17 comparison countries, mortality in the United States ranks as worst or second from the bottom at every age up into the 70s (Ho & Preston, 2010; Woolf & Aron, 2013). In addition to having high mortality, the United States has extraordinarily poor health according to a wide variety of indicators before old age. We approach the older ages with much more risk for the diseases of old age than our peers in other countries.

In addition, within U.S. population subgroups there are large differences and differential trends in life expectancy and health expectancy. There have been significant declines in life expectancy for women in many areas of the country over the last 30 years (Ezzati, Friedman, Kulkarni, & Murray, 2008). This reduction in life expectancy for women has been concentrated among those with low education (Olshansky et al., 2012). Evidence for recent increases in healthy life expectancy shows that these have been limited to those with higher education and to men (Crimmins & Saito, 2001; Solé-Auró et al., 2014)

The causes of the differences between the United States and other countries and between socioeconomic groups in the United States are not unknown; the roots are in behaviors, social conditions, and policies (Crimmins et al., 2011; Woolf & Aron, 2013). Americans behave relatively poorly in terms of smoking, eating, exercise or movement, inappropriate use of drugs, and violence. The relative health of the poor and the uneducated is worse than in other countries. Many of our health policies do not help build healthy minds and bodies in the children who are the aged of the future. A focused effort to improve health, increase life expectancy, and remove social differentials through improved behavior and social policies would lead to increased life expectancy and heath expectancy and allow us to reach our current scientific potential at the same time that we use science to improve that potential.

Funding

Research reported on in this article was supported by the National Institute on Aging (NIA): P30AG017265 and T32AG0037.

References

Alley, D. E., Lloyd, J., & Shardell, M. (2010). Can obesity account for cross-national differences in life-expectancy trends? In E. M. Crimmins, S. H. Preston, & B. Cohen (Eds.), *International differences in mortality at older ages: Dimensions and sources, panel on understanding divergent trends in longevity in high-income countries*. Washington, DC: National Academies Press.

Arias, E., Heron, M., & Tejada-Vera, B. (2013). United States life tables eliminating certain causes of death, 1999–2001. *National Vital Statistics Reports*, **61**.

Bell, F. C., & Miller, M. L. (2005). Life tables for the United States social security area 1900–2100. Social Security Administration, Office of the Chief Actuary, SSA Pub. No. 11-11536.

Beltrán-Sánchez, H., Crimmins, E. M., & Finch, C. E. (2012). Early cohort mortality predicts the rate of aging in the cohort: A historical analysis. *Journal of Developmental Origins of Health and Disease*, **3**, 380–386. doi:10.1017/S2040174412000281

Beltrán-Sánchez, H., Harhay, M. O., Harhay, M. M., & McElligott, S. (2013). Prevalence and trends of metabolic syndrome in the adult

US population, 1999–2010. *Journal of the American College of Cardiology*, **62**, 697–703. doi:10.1016/j.jacc.2013.05.064

Bongaarts, J. (2005). Long-range trends in adult mortality: Models and projection methods. *Demography*, **42**, 23–49. doi:10.1353/dem.2005.0003

Bongaarts, J. (2006). How long will we live?. *Population and Development Review*, **32**, 605–628. doi:10.1111/j.1728-4457.2006.00144.x

Carroll, M., Lacher, D., Sorlie, P., Cleeman, J., Gordon, D., Wolz, M., … Johnson, C. L. (2005). Trends in serum lipids and lipoproteins of adults, 1960–2002. *The Journal of American Medical Association*, **294**, 1773–1781. doi:10.1001/jama.294.14.1773

CDC. (2013). CDC's Diabetes Program: Data and Trends. www.cdc.gov/diabetes/statistics/prev/national/figbyage.htm

CDC/NCHS. (2012). *CDC/NCHS National Vital Statistics Reports*, **61**.

CDC/NCHS. (2013). *CDC/NCHS National Vital Statistics Reports*, **61**.

Chen, J., Normand, S. L. T., Wang, Y., Drye, E. E., Schreiner, G. C., & Krumholz, H. M. (2010). Recent declines in hospitalizations for acute myocardial infarction for medicare fee-for-service beneficiaries progress and continuing challenges. *Circulation*, **121**, 1322–1328. doi:10.1161/CIRCULATIONAHA.109.862094

Cheung, S. L. K., & Robine, J. M. (2007). Increase in common longevity and the compression of mortality: The case of Japan. *Population Studies*, **61**, 85–97. doi:10.1080/00324720601103833

Christensen, K., Doblhammer, G., Rau, R., & Vaupel, J. W. (2009). Ageing populations: The challenges ahead. *The Lancet*, **374**, 1196–1208. doi:10.1016/S0140-6736(09)61460-4

Crimmins, E. M. (2004). Trends in the health of the elderly. *Annual Review of Public Health*, **25**, 79–98. doi:10.1146/annurev.publhealth.25.102802.124401

Crimmins, E. M., & Beltrán-Sánchez, H. (2011). Mortality and morbidity trends: Is there compression of morbidity?. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **66**, 75–86. doi:10.1093/geronb/gbq088

Crimmins, E. M., Hayward, M. D., & Saito, Y. (1994). Changing mortality and morbidity rates and the health status and life expectancy of the older population. *Demography*, **31**, 159–175. doi:10.2307/2061913

Crimmins, E. M., Hayward, M. D., Hagedorn, A., Saito, Y., & Brouard, N. (2009). Change in disability-free life expectancy for Americans 70 years old and older. *Demography*, **46**, 627–646. doi:10.1353/dem.0.0070

Crimmins, E. M., Kim, J. K., & Vasunilashorn, S. (2010). Biodemography: New approaches to understanding trends and differences in population health and mortality. *Demography*, **47**, S41–S64. doi:10.1353/dem.2010.0005

Crimmins, E. M., Kim, J. K., Langa, K. M., & Weir, D. R. (2011). Assessment of cognition using surveys and neuropsychological assessment: The health and retirement study and the aging, demographics, and memory study. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **66**(Suppl. 1), i162–i171. doi:10.1093/geronb/gbr048

Crimmins, E. M., Preston, S. H., Cohen, B. (Eds.); Panel in Understanding Divergent Trends in Longevity in High-Income Countries, Committee on Population, Division of Behavioral and Social Sciences Education. (2011). *Explaining divergent levels of longevity in high-income countries*. Washington, DC: National Academies Press.

Crimmins, E. M., Reynolds, S. L., & Saito, Y. (1999). Trends in health and ability to work among the older working-age population. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **54**, S31–S40. doi:10.1093/geronb/54B.1.S31

Crimmins, E. M., & Saito, Y. (2000). Change in the prevalence of diseases among older Americans: 1984–1994. *Demographic Research*, **3**, 3–9. doi:10.4054/demres.2000.3.9

Crimmins, E. M., & Saito, Y. (2001). Trends in healthy life expectancy in the United States, 1970–1990: Gender, racial, and educational differences. *Social Science & Medicine*, **52**, 1629–1641. doi:10.1016/S0277-9536(00)00273-2

Ezzati, M., Friedman, A. B., Kulkarni, S. C., & Murray, C. J. (2008). The reversal of fortunes: Trends in county mortality and cross-county mortality disparities in the United States. *PLoS Medicine*, **5**, e66. doi:10.1371/journal.pmed.0050066

Fang, J., & Alderman, M. H. (2002). Dissociation of hospitalization and mortality trends for myocardial infarction in the United States from 1988 to 1997. *The American Journal of Medicine*, **113**, 208–214. doi:10.1016/S0002-9343(02)01172-5

Fang, J., Alderman, M. H., Keenan, N. L., & Croft, J. B. (2006). Declining US stroke hospitalization since 1997: National Hospital Discharge Survey, 1988–2004. *Neuroepidemiology*, **29**, 243–249. doi:10.1159/000112857

Finch, C. E., Beltrán-Sánchez, H., & Crimmins, E. M. (2014). Uneven futures of human lifespans: Reckonings from Gompertz mortality rates, climate change, and air pollution. *Gerontology*, **60**, 183–188. doi:10.1159/000357672

Freedman, V. A., Aykan, H., & Martin, L. G. (2001). Aggregate changes in severe cognitive impairment among older Americans 1993 and 1998. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **56**, S100–S111. doi:10.1093/geronb/56.2.S100

Freedman, V. A., Crimmins, E. M., Schoeni, R. F., Spillman, B. C., Aykan, H., Kramarow, E., … Waidmann, T. A. (2004). Resolving inconsistencies in trends in old-age disability: Report from a technical working group. *Demography*, **41**, 417–441. doi:10.1353/dem.2004.0022

Freedman, V. A., Schoeni, R., Martin, L. G., & Cornman, J. (2007). Chronic conditions and the decline in late-life disability. *Demography*, **44**, 459–477. doi:10.1353/dem.2007.0026

Freedman, V. A., Spillman, B. C., Andreski, P. M., Cornman, J. C., Crimmins, E. M., Kramarow, E., … Waidmann, T. A. (2012). Trends in late-life activity limitations in the United States: An update from five national surveys. *Demography*, **50**, 661–671. doi:10.1007/s13524-012-0167-z

Fries, J. F. (1980). Aging, natural death, and the compression of morbidity. *New England Journal of Medicine*, **303**, 1369–1370. doi:10.1056/NEJM198012043032317

Gavrilova, N. S., & Gavrilov, L. A. (2014). Biodemography of old-age mortality in humans and rodents. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*. doi:10.1093/gerona/glu009

Goldman, D. P., Cutler, D., Rowe, J. W., Michaud, P. C., Sullivan, J., Peneva, D., & Olshansky, S. J. (2013). Substantial health and economic returns from delayed aging may warrant a new focus for medical research. *Health Affairs*, **32**, 1698–1705. doi:10.1377/hlthaff.2013.0052

Gruenberg, E. F. (1977). The failures of success. *Milbank Memorial Fund Quarterly/Health and Society*, **55**, 3–24. doi:10.2307/3349592

Ho, J. Y., & Preston, S. H. (2010). US mortality in an international context: Age variations. *Population and Development Review*, **36**, 749–773. doi:10.1111/j.1728-4457.2010.00356.x

Kannisto, V. (2001). Mode and dispersion of the length of life. *Population: An English Selection*, 159–171.

Kennedy, B. K., Berger, S. L., Brunet, A., Campisi, J., Cuervo, A. M., Epel, E. S., … Sierra, F. (2014). Geroscience: Linking aging to chronic disease. *Cell*, **159**, 709–713. doi:10.1016/j.cell.2014.10.039

Kumanyika, S. K., Landis, J. R., Matthews-Cook, Y. L., Almy, S. L., & Boehmer, S. J. (1998). Systolic blood pressure trends in US adults between 1960 and 1980: Influence of antihypertensive drug therapy. *American Journal of Epidemiology*, **148**, 528–538. doi:10.1093/oxfordjournals.aje.a009678

Langa, K. M., Larson, E. B., Karlawish, J. H., Cutler, D. M., Kabeto, M. U., Kim, S. Y., & Rosen, A. B. (2008). Trends in the prevalence and mortality of cognitive impairment in the United States: Is there evidence of a compression of cognitive morbidity? *Alzheimer's & Dementia*, **4**, 134–144. doi:10.1016/j.jalz.2008.01.001

Larson, E. B., Yaffe, K., & Langa, K. M. (2013). New insights into the dementia epidemic. *New England Journal of Medicine*, **369**, 2275–2277. doi:10.1056/NEJMp1311405

Longo, V. D., Antebi, A., Bartke, A., Barzilai, N., Brown-Borg, H. M., Caruso, C., … Fontana, L. (2015). Interventions to slow aging in humans: Are we ready? *Aging Cell*, **14**, 497–510. doi:10.1111/acel.12338

Manton, K. G., Stallard, E., & Corder, L. (1995). Changes in morbidity and chronic disability in the US elderly population: Evidence from the 1982, 1984, and 1989 National Long Term Care Surveys. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **50**, S194–S204. doi:10.1093/geronb/50B.4.S194

Manton, K. G., Stallard, E., & Corder, L. S. (1998). The dynamics of dimensions of age-related disability 1982 to 1994 in the US elderly population. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, **53**, B59–B70. doi:10.1093/gerona/53A.1.B59

Manton, K. G., Stallard, E., & Tolley, H.D. (1991). Limits to human life expectancy: Evidence, prospects and implications. *Population and Development Review*, **17**, 603–637. doi:10.2307/1973599

Martin, L. G., & Schoeni, R. F. (2014). Trends in disability and related chronic conditions among the forty-and-over population: 1997–2010. *Disability and Health Journal*, **7**, S4–S14. doi:10.1016/j.dhjo.2013.06.007

Martin, L. G., Schoeni, R. F., & Andreski, P. M. (2010). Trends in health of older adults in the United States: Past, present, future. *Demography*, **47**, S17–S40. doi:10.1353/dem.2010.0003

Mehta, N. K., & Chang, V. W. (2011). Secular declines in the association between obesity and mortality in the United States. *Population and Development Review*, **37**, 435–451. doi:10.1111/j.1728-4457.2011.00429.x

Oeppen, J., & Vaupel, J. W. (2002). Broken limits to life expectancy. *Science*, **296**, 1029–1031. doi:10.1126/science.1069675

Olshansky, S. J., Antonucci, T., Berkman, L., Binstock, R. H., Boersch-Supan, A., Cacioppo, J. T., … Rowe, J. (2012). Differences in life expectancy due to race and educational differences are widening, and many may not catch up. *Health Affairs*, **31**, 1803–1813. doi:10.1377/hlthaff.2011.0746

Ong, K. L., Allison, M. A., Cheung, B. M., Wu, B. J., Barter, P. J., & Rye, K. A. (2013). Trends in C-reactive protein levels in US adults from 1999 to 2010. *American Journal of Epidemiology*, **177**, 1430–1442. doi:10.1093/aje/kws443

Robine, J. M. (2011). Age patterns in adult mortality. In R. Rogers & E. M. Crimmins (Eds.), *International handbook of adult mortality* (pp. 207–226). Netherlands: Springer. doi:10.1007/978-90-481-9996-9_10

Robine, J. M., & Saito, Y. (2003). Survival beyond age 100: The case of Japan. *Population and Development Review*, **29**, 208–228.

Rhodes, H. G. (2015). *Measuring the risks and causes of premature death: Summary of a Workshop*. Washington, DC: The National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=21656

Seeman, T. E., Merkin, S. S., Crimmins, E. M., & Karlamangla, A. S. (2010). Disability trends among older Americans: National health and nutrition examination surveys, 1988–1994 and 1999–2004. *American Journal of Public Health*, **100**, 100–107. doi:10.2105/AJPH.2008.157388

Solé-Auró, A., Beltrán-Sánchez, H., & Crimmins, E. M. (2014). Are differences in disability-free life expectancy by gender, race, and education widening at older ages? *Population Research and Policy Review*, **34**, 1–18. doi:10.1007/s11113-014-9337-6

Talbott, E., Rager, J., Brink, L., Benson, S., & Bilonick, R. (2013). Trends in acute myocardial infarction hospitalization rates for US States in the CDC tracking network. *PLOs One*, **8**, e64457. doi:10.1371/journal.pone.0064457

Vaupel, J.W., & Jeune, B. (1995). The emergence and proliferation of centenarians. In B. Jeune & J. W. Vaupel (Eds.), *Exceptional longevity: From prehistory to the present*. Rostock, Germany: Odense University Press.

Wang, O. J., Wang, Y., Chen, J., & Krumholz, H. M. (2012). Recent trends in hospitalization for acute myocardial infarction. *The American Journal of Cardiology*, **109**, 1589–1593. doi:10.1016/j.amjcard.2012.01.381

Woolf, S. H. & Aron, L. (Eds.). (2013). *US health in international perspective: Shorter lives, poorer health*. Washington, DC: National Academies Press.

Yeh, R. W., Sidney, S., Chandra, M., Sorel, M., & Selby, J. V. (2010). Population trends in the incidence and outcomes of acute myocardial infarction. *New England Journal of Medicine*, **362**, 2155–2165. doi:10.1056/NEJMoa0908610