Frailty, Heart Disease, and Stroke
The Compression of Morbidity Paradigm

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Abstract: Frailty, the loss of physiologic organ reserve with age, and chronic illness, such as heart disease and stroke, which may accelerate the development of frailty, become the dominant determinants of ill-health in those who escape the hazards of early and mid-life. The Compression of Morbidity paradigm holds that if the average age at first chronic infirmity is postponed, and if this postponement is greater than increases in life expectancy, then average cumulative lifetime morbidity will decrease, squeezed between a later onset and the time of death. The National Long-Term Care Survey, National Health Interview Survey, and other data document declining U.S. disability trends since 1982; accelerating recently, at about 2% per year. The decline in mortality is only 1% a year, documenting Compression of Morbidity in the U.S. population. Frailty, increasing exponentially because of linear declines in multiple organ systems, mandates converging morbidity and mortality rates as longevity increases. Longitudinal studies now link good health risk status with reduced lifetime disability; those with few health risks have only one-fourth the disability of those who have more risks, and the onset of disability is postponed from 7 to 12 years. Randomized controlled trials of senior health enhancement programs have shown reduction in health risks, improved health status, and decreased medical costs. Current health enhancement opportunities can increase health gains for seniors under the umbrella paradigm of the Compression of Morbidity. Effective interventions to prevent or postpone heart disease and stroke will decrease lifetime morbidity.

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Introduction

The Compression of Morbidity paradigm was presented as hypothesis in 1980,[1] noting that the great majority of illness was chronic and occurred in later life, and postulating that the lifetime burden of illness could be reduced if the onset of chronic illness could be postponed and if this postponement could be greater than increases in life expectancy. The concept is illustrated in Figure 1, where estimated present lifetime morbidity is portrayed along with three possible future scenarios: "life extension," "shift-to-the-right," and "compression of morbidity." The lines represent the length of life and the shaded triangle depicts lifetime morbidity; obviously a more precise depiction would include the smaller amounts of disability, which may occur before age 55, and would not assume a straight line progression thereafter.

Two arrows are shown for each scenario; the left arrow represents the median age of onset of chronic morbidity and the right arrow the median age at death. Alternative health futures are determined by the relative movement of these arrows over time. If the arrows separate, there is more lifetime morbidity, if they come closer together there is Compression of Morbidity. In each scenario some extension of life expectancy is envisioned, although this expectation is not inevitable. The illustrative use of age 55 years as the present age of morbidity onset is drawn from data showing that this approximates the median age of detectable chronic disability.[2]

Most demographers and health economists felt in 1980 that the "life extension" scenario was occurring and was the most likely, and most unfortunate, future for human health. As medical progress increasingly prolonged life, those extra months and years would be spent in poorer and poorer health. The process was termed the "failure of success."[3] Many speculated then, and a few still do, that eliminating heart disease and stroke would result in a frail, demented, elderly population and that the burden of illness would increase.

In contrast, the Compression of Morbidity represented a positive concept, with the ideal of a long life with a relatively short period of terminal decline.[4,5] It seemed reasonable in 1980 to postulate that lifetime morbidity had been rising with the emerging dominance of chronic illnesses, but it also could be argued that this period was ending, led by declining incidence of cardiovascular disease.[1]

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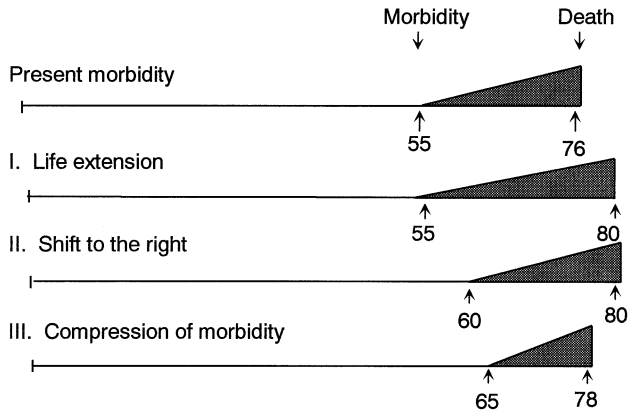

Figure 1. Possible scenarios for future morbidity and longevity. Present lifetime morbidity, portrayed as the shaded area, contrasted with three possible future scenarios. See text for discussion.

The major epidemiologic health transitions in developed nations may be considered as (1) an initial stage of acute infectious disease (prior to 1950) that gives way to (2) a second stage dominated by especially burdensome chronic illness (1950–1980), and then (3) a third stage of Compression of Morbidity (after 1980), where the illness burden is postponed and ultimately reduced. For developing states, the second stage of dominant chronic illness is a potentially devastating one, requiring resources not likely to be available. Consequently, health efforts in such states must simultaneously focus on prevention and postponement of chronic illness as well as improved medical care, moving through both the second and third stages at the same time in order to keep the resource burden within manageable limits.

The Compression of Morbidity paradigm focuses attention on the quality-of-life over its quantity, and considers morbidity as a lifetime cumulative area-under-the-curve concept rather than a cross-sectional view at a particular point of time, such as a specific age. Thus, the national illness burden, which will tend to increase with the increasing absolute number of seniors, may be offset, at least in part, by a decreased average illness burden for the individual, with positive consequences for the health of the public and the stability of national healthcare systems. This paper draws on recent data from national surveys, longitudinal studies, and randomized controlled trials to bring together the present evidence for Compression of Morbidity in the United States and explores the implications of continuing reductions in the incidence of heart disease and stroke through reductions in health risk factors.

Trends in Mortality and Life Expectancy

Since morbidity compression depends on the relative trends in morbidity rates and in mortality rates it is necessary to examine trends in both. From 1980 to 1998 life expectancy (U.S. data, both sexes) rose at a rate of 0.150 years per year, for an increase of 2.7 years, to 76.6 years; somewhat slower than in the two prior decades.[6] The more relevant numbers, however, are life expectancy increases from age 65 (or even 85), since these exclude the large effects of early life mortality. From age 65, life expectancy rose at a rate of only 0.066 per year, for an increase of 1.2 years over 18 years, to a life expectancy of 82.7 years; this is a slightly lower rate of increase than in prior decades. From age 85, life expectancy rose by only 0.017 years per year for an increase of 0.3 years or only about 4 months over the past 18 years. Similar data are available from other developed nations. If present trends continue, gains in average life expectancy above age 65 will remain modest for the individual. However, because of larger birth cohorts and an increasingly frequent survival to age 65, the absolute number of persons over 65 years will increase markedly.

Furthermore, present trends will not continue indefinitely. Barring discovery and dissemination of a breakthrough in understanding of the basic science of aging, the rate of increase in human life expectancy from advanced ages will continue to slow. Constant decreases in mortality rates, about one percent a year, yield diminishing increases in terms of life expectancy over time because of the exponential mathematical relationship between the two statistics; the effect of constant mortality rate decreases yields smaller increases in life expectancy over time.[7]

Trends in Declining Disability Rates

Over the past 2 decades, preventive programs have not been systematically implemented, even though the problems were recognized. As a result, while smoking prevalence did decrease significantly in the U.S., obesity and the "metabolic syndrome" greatly increased in prevalence, and there has been a trend toward more sedentary lifestyles. Over the last two decades, therefore, lifestyle changes are not likely to have played a dominant role in the Compression of Morbidity.

However, Compression of Morbidity has been occurring, and at a relatively rapid rate.[8,9] In the National Long-Term Care Survey (NLTCS) data (Figure 2), disability over age 65 decreased from 26.2% to 19.7% from 1982 to 1999, a decrease of approximately 2% per year and substantially greater than decreases in mortality rates, which declined at about 1% per year, their historic rate of decline over the past century.[10] The decline was seen both in activities of daily living disability and instrumental (more complex) activities of daily living disability. It has been argued that a decline of 1.5% per year would be sufficient to maintain solvency of the U.S. Medicare Program for at least 70 years.[11] Moreover, declines in disability have accelerated in the

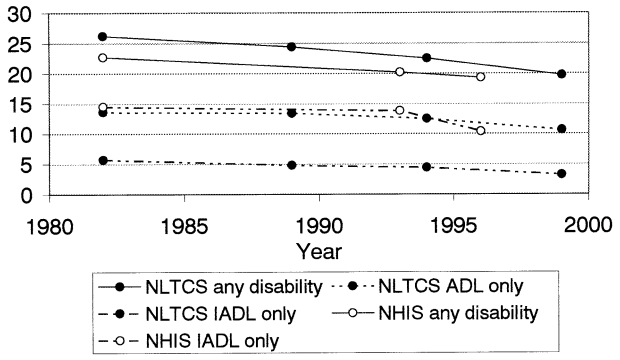

Figure 2. Recent trends in disability among older Americans. Disability rates decline at about 2% per year, with the declines accelerating in the most recent time period in the National Long-Term Care Survey (NLTCS) and the National Health Interview Survey (NHIS). Declines are in both Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL) in the NLTCS. In the NHIS, declines were similar for IADL but not significantly changed for ADL.

last 5 years of observation and have begun to be seen in minority as well as white sub-populations.[8] Data from the National Health Interview Survey from 1982 to 1996 show strikingly similar declines, again with accelerated declines in more recent years.[9] Freedman et al.[12] performed a systematic review of 16 studies of trends in disability in the U.S. and noted that all found declining trends in disability. Thus, the literature shows consensus.[13] Compression of morbidity and the consequent improvement in lifetime health now has been documented. Remarkably, these improvements have occurred absent systematic approaches toward postponement of disability and further improvements appear achievable.

Multiple causes for the decline in disability to date appear likely. Contributions may include reduction in smoking, medical advances such as better treatment of hypertension, diabetes, hypercholesterolemia and coronary artery disease, total joint replacements, and medical preventive measures such as colon cancer screening, influenza and pneumococcal vaccines, and cardioprotective-dose aspirin.[10] It might be that rising expectations for healthier aging became self-fulfilling, perhaps through a mechanism of perceived self-efficacy.[14] Access to medical care in the U.S. has not improved, and access to prescription drugs may have become more difficult.[10] Whatever the reasons, however, compression of morbidity is currently occurring at the population level in the United States.

Frailty as the Ultimate Competing Risk for Morbidity and Mortality

The concept of frailty, often difficult to define and describe, provides the explanation for why improving health, as with eliminating heart disease and stroke, will not lead to increasing human misery. To a physician/biologist, frailty equates with the loss of organ reserve in each of multiple organ systems, beginning at or before age 30, at a roughly linear decline of 1.5% per year in the individual organ and with an exponential decline in the ability to withstand a perturbation.[15] Incipient frailty results in a doubling of vulnerability to both mortality and morbidity approximately each eight years, known somewhat inaccurately as "Gompertz's Law."

The frailty phenomenon is perhaps first observed when the champion sprinter or swimmer begins to post slower race times, absent injury or reduction in training effort. The halfback becomes unable to "get around the corner." In middle life any of us might observe that despite a consistent exercise program and the absence of any apparent disease our time required to run a mile (or performance of some other activity) has steadily increased. When the sporting pages report results of a large marathon by 5-year age groups we observe that the winner in each successive age group posted a slower time than the winner in the immediately younger age group, although we would not conclude that these older marathoners had diseases. Or we might observe that our dog is growing older and slower. Or when visiting the retirement institution for healthy seniors we note the slow pace of even the spryest 85 year olds as they walk to lunch. Frailty is physiologic decline, and inevitably it must lead to morbidity, infirmity, and eventually death, as organ reserve is no longer adequate to withstand even a small perturbation.

Loss of organ reserve can of course be accelerated by disease or accident, so the relationship between frailty and medical problems is often not completely obvious. The cigarette smoker accelerates loss of pulmonary organ reserve through disease; the morbidly obese person has accelerated loss of organ reserve in several organs; and paraplegia, Parkinson disease, and coronary artery disease, among many others, accelerate loss of organ reserve.[15,16] Some entities often considered diseases, the "degenerative diseases," seem very close to physiologic frailty. Thus, conditions from cataracts to osteoarthritis to benign memory loss do not have causes or cures as the prototypic diseases may, but represent a loss of organ reserve. The frailty observed clinically is the sum of natural physiologic declines in organ reserve function and disease-related declines in organ reserve, including in this sum those conditions that may be in part disease and in part physiologic decline.

Physiologic declines, like disease-related declines, can be slowed or even reversed, in substantial measure, but not without limit. In general, exercise at a particular activity can improve personally sub-optimal performance toward optimal at any age. This conclusion holds for mental, physical, and social activities; few persons practice or exercise sufficiently to reach their personal limits, and those that do not are capable of improvement.[17–20] At optimal performance, the princi-

ple of the decline of 1.5% per year resumes. These concepts become important especially when considered in the context of "competing risks."

Risks for death and risks for morbidity compete with other risks for death and for morbidity. This principle is not controversial and is not in dispute, but it is regularly ignored in modeling frailty/morbidity and mortality. Competing risks mandate a dynamic and not a static approach to modeling. People with higher than average levels of risk for one condition tend to have higher than average levels of risk for other conditions. Risks for both mortality and morbidity, including the increasing risks from physiologic frailty, increase exponentially with age. Linear declines in individual organ reserves become exponential when multiple organ systems are considered together. Thus, if you were to remove all risk factors for heart disease and stroke you reduce both morbidity and mortality rates, but other risk factors and risks of other diseases increase exponentially over time to take their place. Static modeling postulates that if you could remove all diseases and all accidents an individual or a population could live forever. After considering the dynamic role of competing risks one can appreciate that the actual effect would be rather less. Increasing physiologic frailty with age (intrinsic causes) gradually replaces specific diseases (external causes) for mortality and morbidity as a person or a population ages, and these trends have been recognized for many years.[16,17]

After acute disease is eliminated, and after chronic disease eliminated in turn, the limits of the organism begin to be reached. The differences between the mortality and morbidity curves with age begin to narrow, not in terms of the rates themselves, but in terms of the increases in life expectancy and disease-free life expectancy that result. Physiologic frailty is the ultimate competing risk. The limits that it imposes, because of its exponential increases with age, accentuate the compression of morbidity. Reductions in disease incidence permit good health further into the life span.

Longitudinal studies of risk factors and subsequent disability provide an additional perspective on the amount of disability postponement, which may result from population-wide lifestyle changes. Studies of populations with good education levels, relative affluence, and good access to medical care are particularly instructive, since socioeconomic class is otherwise a strong alternative explanatory variable. An important issue is whether prevention can provide improvement "at the margin," after medical and social support are already near optimal. The ARAMIS (Arthritis, Rheumatism, and Aging Medical Information System) research group is conducting two such ongoing studies; a study of University of Pennsylvania alumni since 1986 when they were enrolled at age 68 and a study of Fitness Club members and controls begun in 1984 at an average age of 58.

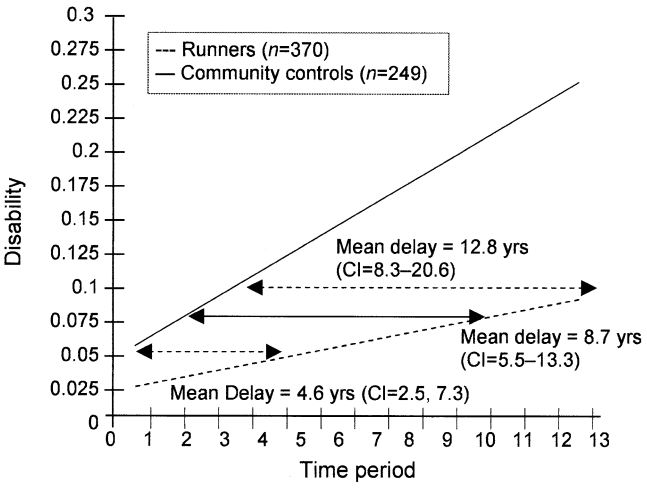

Figure 3. Regression of disability on time period (based on bootstrap). Development of disability over a 13-year period from an average age of 58 in Runner's Club and community control groups, with linear regression lines adjusted for covariates, documenting postponement of disability in the Fitness Club group compared with controls, with differences increasing over time.

The effects of good health habits on subsequent disability were extremely large. In the alumni study, after adjustment for a wide range of possible confounding variables, the cumulative lifetime disability since 1986 was four times as great in those who smoked, were obese, and did not exercise as in lean, exercising nonsmokers. The onset of initial disability was postponed by 7.75 years in those with the best health habits as compared with the worst.[18] Moreover, in those 418 who had died and whose true total lifetime disability could be computed, those with low health risks had lower disability levels at each year prior to death. Those with higher levels of health risks had more disability throughout and also showed a surge to higher disability levels in the 2 years prior to death.[19] In the Fitness Club study the initial cohort, using intent-to-treat analyses and after adjustment for covariates, had postponement of disability as measured by the Health Assessment Questionnaire of 12.8 years as compared with the more sedentary controls (Figure 3).[20] Other investigators have found similar results. This amount of postponement of disability far exceeds any increases in life expectancy resulting from the better health habits.

Health Enhancement Interventions

A final metric is the examination of the effects of interventions. Is it possible to intervene in senior populations, improve risk factor profiles, and observe improved health and reduced medical care costs? Or would such intervention be "too little, too late?" Large, randomized controlled trials of health promotion pro-

grams in seniors or retirees,[21,22] in particular those that use complex "tailored print interventions" very specific to the participant, have been able to document substantial health improvement. Risk reductions have approximated 10% per year of intervention, and improved self-reported health, decreased disability and pain,[23] and reduction in medical care utilization, both by self-report and claims analysis, of about 10% yearly have been reported.[14,24]

Health Policy Initiatives

Current trends in morbidity and mortality encouragingly suggest that we must be doing something right. This seems to have occurred even though we have not systematically implemented the most promising approach, postponing disability through primary prevention, into healthcare systems. We now have serial data documenting health improvement over time, and we have monitoring systems in place to observe future trends. We have solid underlying theory from the Compression of Morbidity paradigm, proof of concept by longitudinal epidemiologic studies, and proven interventions, which may be broadly applied. We can reassure those health policy makers who fear that elimination of heart disease and stroke will create an unaffordable society of frail demented elders. This will not happen. Frailty, competing risks, and the Compression of Morbidity will prevent it.

Arguably, both our greatest national health problem and our greatest economic problem is the health of seniors. There is an urgent need to find and implement solutions.[14,24,25] In the U.S. a number of health policy initiatives now target postponement of senior illness and frailty. Several bills have now been introduced in the Congress. This is unprecedented activity and a remarkable opportunity for major health improvement.

The Compression of Morbidity research agenda includes the following: (1) more accurate monitoring of disability trends with addition of more quantitative disability measures and inclusion of quality-of-life measures, and improved sampling frames[26]; (2) more precise quantification of the causes behind the trends, possibly using econometric techniques; (3) systematic studies of specific primary prevention interventions, with the goal of identifying those population-based approaches which are most effective and most cost-efficient. This agenda, discussed previously[27,28] and elaborated here, has immense implications for the improvement of human health. Among the goals are a financially stable (if perhaps postponed) social security system, a solvent Medicare system, and healthier seniors.

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