Survival Curves, Prevalence Rates, and Dark Matters Therein

LOIS M. VERBRUGGE, PhD, MPH
University of Michigan

Survival curves are a visual aid to help us think about interrelationships between chronic morbidity, disability, and mortality. Prevalence rates indicate a population's morbidity and disability status at given times. The curves and rates are both residues of very dynamic processes: Chronic conditions may be alleviated as well as progress; functions may be restored as well as lost. The dynamics can be represented by transition rates between states; transition rates can vary across population groups (heterogeneity). Contemporary data and life table techniques are advancing to measure morbidity-disability-mortality dynamics and summarize them in statistical manner. Topics that remain elusive or overlooked are comorbidity, nonfatal chronic conditions, frailty, generalized symptoms, and difficulty in many activity domains; these are dark matters. Future scenarios of health depend on premises about where prevention of chronic conditions will occur. I present three basic scenarios (one includes the compression of morbidity) and note their implications for transitions between states and for morbidity and disability prevalence rates. Compression of morbidity is an intriguing notion, but to know if it occurs or not over the next century requires a deep foundation of epidemiologic data and analysis, and that is where scientific efforts must be devoted.

The compression of morbidity, first described by Fries (1980), posits a particular relationship between population morbidity and mortality over time. It represents just one of many possible relationships that

AUTHOR'S NOTE: Preparation of this article was facilitated by a Special Emphasis Research Career Award (#K01 AG00394) from the National Institute on Aging. The author thanks Mark Hayward, Richard Rogers, and the editors of this issue for critiques and education. Reprint requests should be addressed to Lois M. Verbrugge, PhD, MPH, Institute of Gerontology, 300 North Ingalls, The University of Michigan, Ann Arbor, MI 48109-2007.

JOURNAL OF AGING AND HEALTH, Vol. 3 No. 2, May 1991 217-236

can be portrayed in an economical manner by standard survival curves. The standard curves and the life table techniques from which they are derived contain simplistic notions about how people move from one health or disability state to another. I note the assumptions and how modern techniques have overcome them so that the true extent of dynamics and population heterogeneity are incorporated. I discuss three key scenarios of future health, premised on changes in onset and recovery for morbidity and disability, and I note their consequences for prevalence rates and survival curve portraits. The compression of morbidity is among them, and readers can compare and judge it in the context of other scenarios.

Survival Curves

Survival curves have their origin in life table methods, which were designed to describe the mortality experience of a birth cohort. The approach has been adapted to many other kinds of experiences (such as labor force participation, migration, marriage, and so forth) and other kinds of data (such as prevalence rates from cross-section populations). For all of these, survival curves are a simple visual device to show the chances that people have experienced an event by age X (cohort) or are in a given state at age X (cross-section). The most rudimentary methods allow one outcome state (such as death; this is called single decrement) and make a critical assumption about the process that generates it (called absorption). I shall soon note principal extensions of the methods that accommodate multiple outcomes and various movements that people make among them.

Interest in relationships between population morbidity, disability, and mortality has grown among health researchers. They have used survival curves as a device for discussion and hypothesis formation. Figure 1 shows a common portrayal of the three phenomena. The key indicates how prevalence rates are contained in the curves.

How are the *states* of ill, well, disabled, and nondisabled defined? Choosing severity thresholds is a key issue here. (a) Morbidity refers to the presence of chronic conditions (diseases or sensory/structural impairments). Acute conditions, defined by transience within several months, are excluded. Generally, chronic conditions are diagnosed

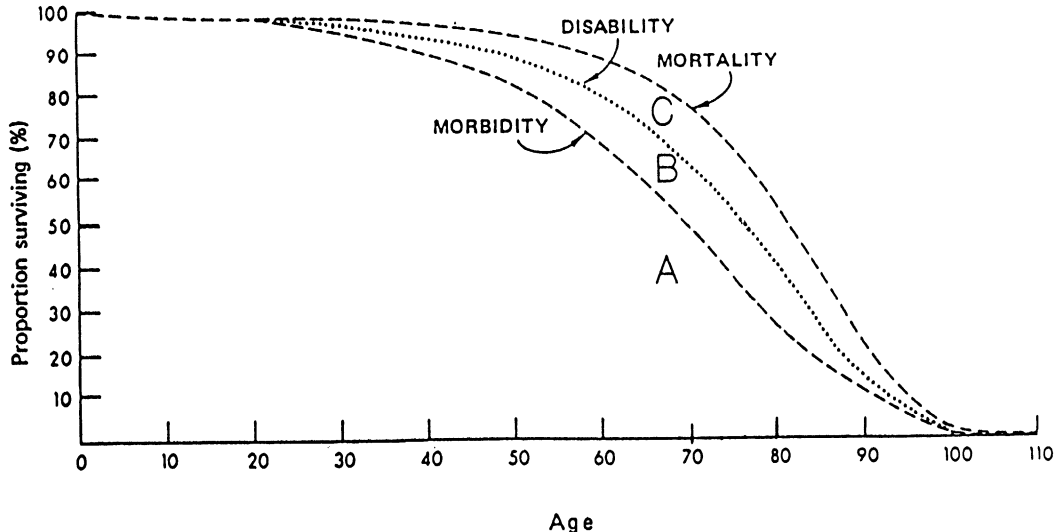


Figure 1. Survival curves of morbidity, disability, and mortality.
Source. Manton and Soldo (1985).
Key: The curves can represent probabilities for an initial cohort or prevalences for a living population—all age specific.
1. For a cohort, each curve shows probabilities of "surviving" (being free of) the event up to given ages. Probability is on the Y axis, and age on the X axis. A point on the morbidity curve means a person age X has probability Y of being well. A point on the disability curve is the probability of Y being nondisabled at age X. A point on the mortality curve is the probability of Y being alive at age X.
2. For a population, morbidity prevalence is the ratio of ill persons to all living persons (numerator is between morbidity and mortality curves, denominator is between X axis and mortality curve). Disability prevalence is the ratio of disabled persons to all living persons (numerator is between disability and mortality curves, denominator as just noted).
Zone A is well. Zone B is ill (morbidity) but not disabled. Zone C is ill and disabled.

when they reach a certain severity level, so the term *presence* means that some cutpoint along the severity continuum has been set. People who cross that threshold are scored as having a given condition, and others are scored as not having it. Global measures of morbidity, such as self-rated health, also get split into "ill" and "well." (b) Disability refers to consequences that chronic conditions have for physical and social functioning. Again, disability can be graded by degree, so cutpoints are established that separate disabled from nondisabled status.[1] In contemporary research, the usual indicator is dependency for activities of daily living (ADLs) or instrumental activities of daily living (IADLs). Dependency is needing or receiving someone's help to accomplish an activity due to a chronic health problem. ADLs are personal care activities such as bathing, eating, dressing, toileting, and transferring in and out of a bed or chair. IADLs are household management activities such as doing light housework, preparing own meals, managing own money, using a telephone, and shopping for personal items. Because dependency is assumed to reflect severe difficulty, a severity threshold is imbedded in the indicator. (c) Mortality is defined in standard, vital statistics manner. Because it is a discrete event, the issue of defining a severity cutpoint is far less troublesome (but not entirely moot).

What assumptions about *dynamics* — the transitions that individuals make between states of morbidity, disability, and mortality — are made in analyses? A key issue is which transitions are considered legal (real) on theoretical or empirical grounds and thus included, and which are considered nonlegal and excluded. In morbidity-disability-mortality discussions, two assumptions have been common: that events are absorbing (unidirectional — return to a prior state is impossible) and events are hierarchical (people in a given state have passed through all prior ones). Using Figure 1 to illustrate this, the absorption assumption means that ill people do not recover; disabled people never restore their function; and dead people are not resuscitated. The hierarchy assumption means that disabled people are also ill; and that decedents were ill and disabled at time of death. The life table procedures using these assumptions are simple, but it is quickly obvious that the assumptions are incorrect. With respect to absorption: Some chronic morbidity can be reversed, becoming clinically nonsignificant ("non-

existent") via drug, life-style, and surgical interventions. And, disability is a very dynamic situation for persons with chronic conditions; many shifts in functioning can occur over the years due to disease progression, therapies, and psychosocial factors. With respect to hierarchy: Disability can occur in the absence of a distinct disease entity, and mortality can occur without prior disease or disability.

Contemporary scientists have worked to develop statistical techniques that accommodate multiple outcomes and allow transitions to and fro across states. Ranked by complexity, there are now (a) multistate decrement models (more than one outcome state is possible; unidirectional transitions only), (b) multivariate increment-decrement models (allowing return to prior states), and (c) multivariate multistate increment-decrement models (using covariates to predict differences in transitions for age, gender, and other groups). The last model is highly flexible, allowing not only dynamics but also heterogeneity among population groups in those dynamics. Each type of model can have many specific formats, tailored to one's data and theory, for how states are arranged and which transitions are legal (nonzero) and illegal (set to zero).

Going from original to modern: The basic life table method is described in introductory demography texts (such as Pollard, Yusuf, & Pollard, 1974; Stockwell, 1976). More advanced methods are in statistics texts (Elandt-Johnson & Johnson, 1980; Manton & Stallard, 1988; Namboodiri & Suchindran, 1987). The most recently developed techniques are described in Hayward and Grady (1990), Hayward, Grady, Hardy, and Sommers (1989), Land and Rogers (1982), Rogers (1975, 1980), and Schoen (1988a, 1988b).

Figure 2 sets forth schematically the morbidity-disability-mortality transitions originally proposed and easily modeled by standard life table techniques; it also shows the transitions that actually exist and are now allowed by more advanced techniques. (Note that some transitions, such as well to ill, require pooling of detailed rates—in this instance, of four rates.)

Keeping pace with statistical developments, data on transitions across morbidity, disability, and mortality are increasing. Large-scale longitudinal data sets, some continuing and some completed, now exist, measuring these states at multiple time points for a fixed sample

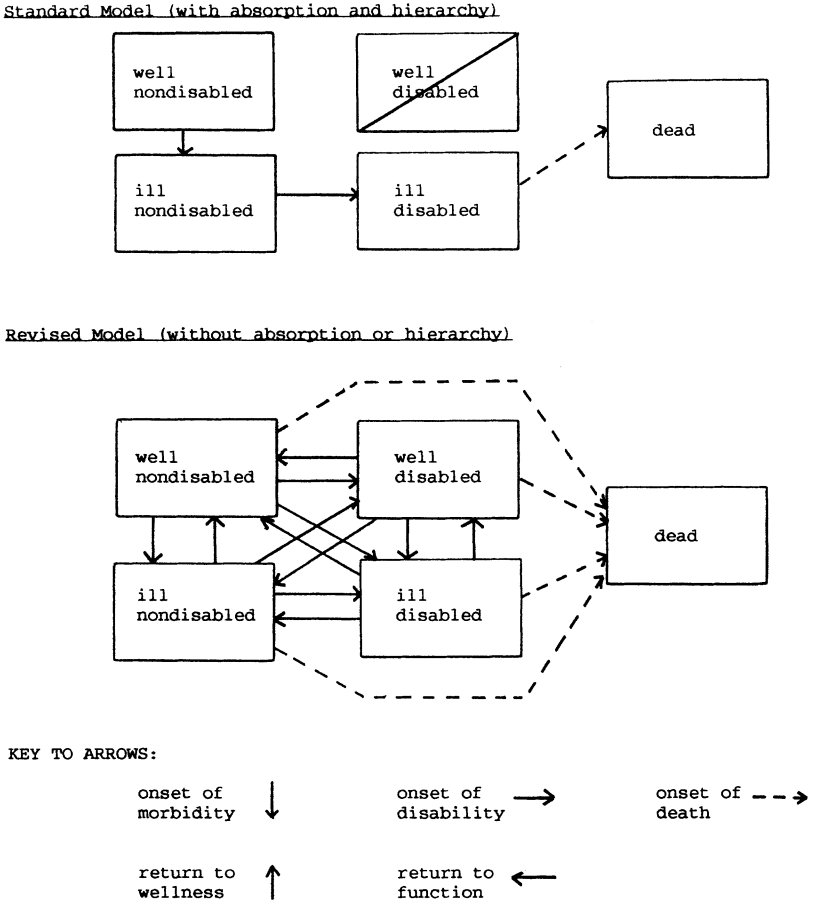


Figure 2. **Transitions between states.**
Note. Arrows represent rates of change over a time interval.

of persons. Such data readily show the fallacy of absorption and hierarchy: Sizable proportions of disabled people experience restored function over time (Branch & Ku, 1989; Katz et al., 1983; Manton, 1989; Rogers, Rogers, & Branch, 1989; Verbrugge, in press). And specific types of disability do not "scale" (are not hierarchical) for

many persons (Katz et al., 1983; Spector, Katz, Murphy, & Fulton, 1987). Transition rates among states are estimated and reported. They are used to estimate active life expectancy (years a person can expect to live without disability) and disabled life expectancy (years spent disabled). How sociodemographic characteristics influence transition rates is investigated with multistate methods or regular multivariate ones such as multiple regression. Empirical examples using multistate methods for morbidity-disability-mortality relationships may be found in Rogers, Rogers, and Belanger (1989) and Rogers, Rogers, and Branch (1989).

In summary, survival curves display the residue of highly dynamic processes for morbidity and, especially, disability. They may be derived from sparse data (prevalence rates from a cross-sectional survey) or from dense data (transition rates from a longitudinal survey). Although survival curves are convenient devices to guide discussions and prevalence rates inform us about the state of the population's health at a given point in time, they are not nearly so interesting as knowing the processes that generated them.

Dark Matters

Even with longitudinal data and modern statistical techniques, there are some features of chronic morbidity and disability that are hard to measure and incorporate. Although very important in illness and disability experiences of adults, they are elusive or overlooked in research. I call them dark matters.

Many older people have multiple chronic conditions; this is called *comorbidity*. When evaluating patients with multiple conditions, geriatricians often detect an extra disability impact due to this multiplicity (Minaker & Rowe, 1985; Rowe & Besdine, 1982). Lagging behind such clinical experience, scientific research is beginning to estimate comorbidity's impact on disability and death. Several studies show that multiple conditions exacerbate disability, increasing it in nonlinear ways (Kaplan & Feinstein, 1974; Satariano, Ragheb, & Dupuis, 1989; Verbrugge, Lepkowski, & Imanaka, 1989). Comorbidity also speeds death (Satariano et al., 1989; Seeman, Guralnik, Kaplan, Knudsen, & Cohen, 1989).

Although *nonfatal* chronic conditions dominate in late life for both prevalence and limitations (Verbrugge, 1987, 1989a), they receive far less research attention than do fatal conditions. Studies of morbidity-disability-mortality relationships that incorporate specific chronic conditions face a tug-of-war: Many common conditions cause long-term disability but not death; osteoarthritis is the best example. By contrast, some leading causes of death progress swiftly, causing shorter disability but high mortality; lung cancer is a good example. Should one choose target conditions based on disability impact or mortality impact? There is now active research to compare impacts of nonfatal and fatal conditions (Guralnik & Kaplan, 1989; Haber, 1971; Harris, Kovar, Suzman, Kleinman, & Feldman, 1989; LaPlante, 1989; Pinsky, Leaverton, & Stokes, 1987; Verbrugge et al., 1989). This brings long-deserved attention to nonfatal conditions such as osteoarthritis, hearing impairment, constipation, and low back pain, and it lets decisions about target conditions be based on information rather than on preference.

People vary in their overall robustness or, stated conversely, in their *frailty*. Frailty depends on both genetic characteristics and risks accumulated over life. The notion of frailty has been used in formal morbidity-mortality models, but it is still elusive for health surveys. Illustrating this point: Formal models with a frailty parameter show that when population mortality rates increase or decrease, the frailty distribution changes among the living (Alter & Riley, 1989; Manton, 1982; Vaupel, Manton, & Stallard, 1979). Specifically, as mortality declines, population frailty increases (Poterba & Summers, 1987). By contrast, survey indicators of frailty, based on clinical observation or self-report, are lacking. What we want to capture, in direct manner, is overall loss of physiological reserves, feebleness, and general vulnerability. To date, there are no empirical studies showing that frailty increases the chances of dire outcomes (falls, severe disability, institutionalization, death) for individuals or that, in the aggregate, frailty increases as mortality declines.

Generalized symptoms—such as pain, fatigue, weakness, frequent botheration from health problems, and malaise—are central to individuals' well-being and functioning. These aspects are commonly described by older persons, and they probably contribute to disability

and death. Their prediction strength may well rival that of more medical measures such as diagnosed diseases.

Disability refers to how chronic conditions affect people's ability to act in typical and personally desired ways in their society. The essential notion to be measured is how much difficulty people have doing valued activities (Verbrugge, 1990). These can be obligatory, committed, or discretionary; examples are, respectively, eating and toileting, paid job and child care, hobbies and socializing. Instead of asking about *difficulty in numerous domains*, surveys favor items on ADL and IADL dependency. (a) Dependency really measures use of certain informal and formal health services. It tells us about a buffer—an intervention aimed at reducing disability—not about disability itself. (Similarly, data on use of special aids or equipment and on structural changes at home or jobsite measure buffers to disability, not disability.) Questions that pertain directly to disability should ask about presence, and degree of, "difficulty doing *X* by yourself and without using special equipment." Because difficulty is easy to query, there should be no need to use dependency as a proxy for severe difficulty. (b) ADLs and IADLs are presumed to pose uniform physical and mental demand on people (e.g., eating is assumed to be the same task for everyone). So, disability in a given ADL or IADL activity is compared to a uniform standard. To many researchers, the assumption is quite acceptable; it is a key reason (although seldom stated) that survey questions are restricted to those domains. To illustrate this more fully, consider discretionary activities such as doing hobbies, socializing, and running errands. They vary greatly among people (e.g., some go hang-gliding for recreation and others knit), and thus pose variable physical and mental demands. Here, disability in a given domain is compared to nonuniform standards. In truth, even ADLs and IADLs vary in demand, given ethnic and personal variations in how the tasks are accomplished. Elsewhere, I discuss how accepting variable demand is far better than ignoring it (Verbrugge, 1990). Survey questions about difficulty in any activity domain are then appropriate.[2] In short, disability penetrates many life activities, and until we ask about them, the process of disability associated with chronic conditions will be poorly described.

Summing up: Comorbidity, nonfatal chronic conditions, frailty, generalized symptoms, and difficulty in many domains are all dark matters. Bringing them prominently into discussions, models, and empirical research on morbidity-disability-mortality links is recommended, although it may not be easy.

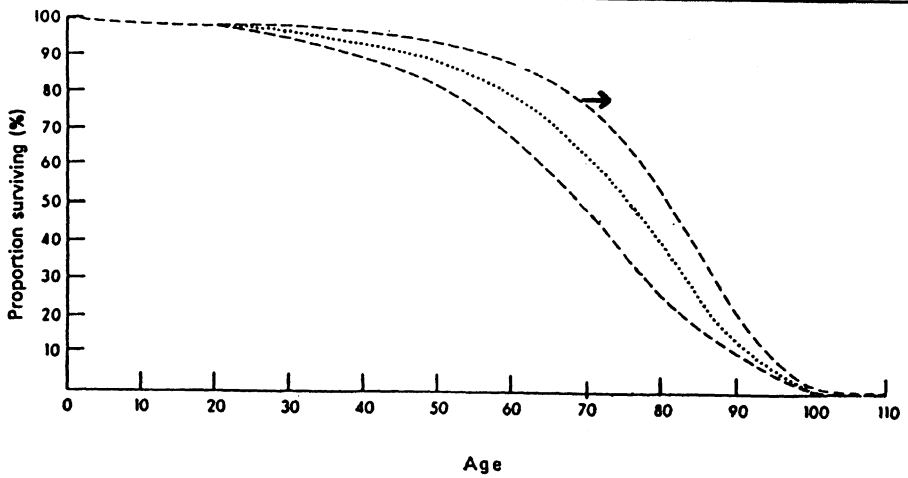
Health Prospects

The most fundamental question about morbidity-disability-mortality relationships is: How do large-scale changes in population morbidity affect disability and mortality? In more empirical terms, we ask how changes in transition rates (from well to ill, nondisabled to disabled, disabled to well, and so forth) affect morbidity and disability prevalence rates and mortality rates. Aggregate changes can be portrayed in survival curves by shifts in the lines that demarcate morbidity, disability, and mortality. In this section, I present three distinctive scenarios of future health, noting which transitions change and their implications for prevalence, incidence, severity distribution, comorbidity, and duration.

The scenarios were first discussed in Verbrugge (1989b); some modifications are included here. I note that (a) all statements are age-specific. Effects of population aging, which by itself will swell rates of morbidity and disability in the total population, are therefore excluded. (b) The terms "outward" and "inward" summarize changes in the morbidity, disability, and mortality lines of survival curves. Lower incidence rates for an event move its line higher and toward the right, or "outward." Conversely, higher incidence rates move a line lower and toward the left, or "inward." (c) Figures 3a, 3b, and 3c show the scenarios in two ways: the principal transition rates that change, and how the survival curves shift.

Three basic, or pure, scenarios hinge on where prevention efforts for chronic conditions are directed.

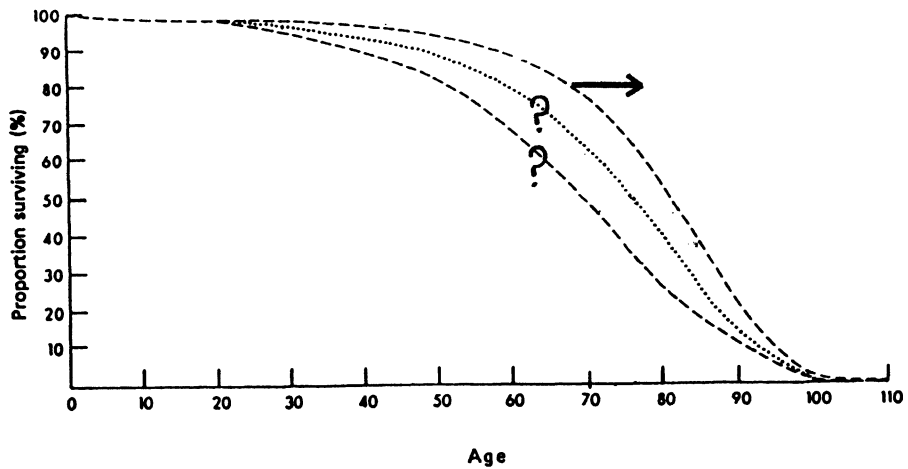
Tertiary prevention (Figure 3a) is saving people at the brink of death by costly medical measures that (a) maintain basic life processes (this is called heroic care) or (b) cure or avert fatal complications of certain diseases. Death is deterred, usually for just a short time, without influencing the principal disease process at all. Incidence rates (onsets



What happens to this transition rate?

ill →dead declines a bit

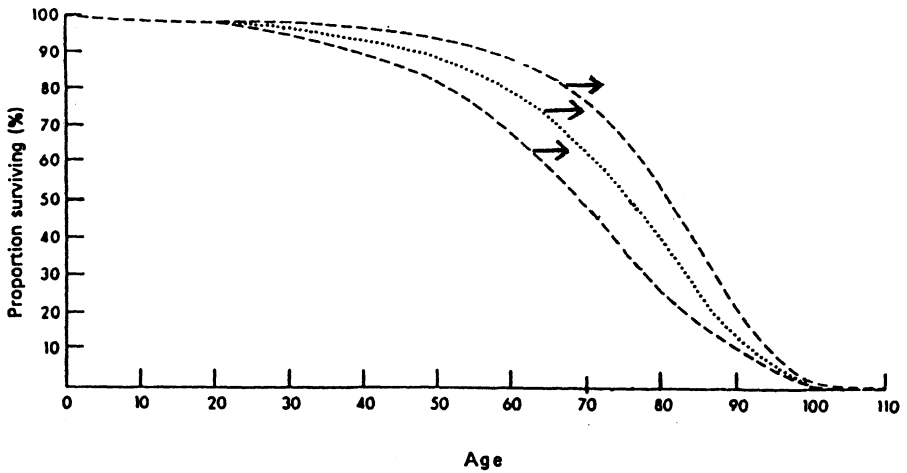
Figure 3a. **Tertiary prevention.**



What happens to this transition rate?

ill →dead	declines
ill →well AND disab →nondisab	increases due to milder conditions
BUT	
well →ill AND nondis →disab	increases due to vulnerable survivors and if diagnostic thresholds are lowered

Figure 3b. **Secondary prevention.**



What happens to this transition rate?

well →ill declines sharply

Other transition rates may stay the same but the proportions of people experiencing them are far smaller; all events are pushed forward to later ages.

Figure 3c. **Primary prevention.**

of morbidity and disability) are completely unaffected. Assuming that the "marginal survivors" are extremely ill, far more than their age peers, there will be slight increases in average severity and comorbidity for the total population.

Tertiary prevention affects relatively few people in the population for two reasons: It is costly, and most deaths occur before decisions about tertiary care are needed. With respect to survival curves, the aggregate impact of tertiary prevention is to move the mortality curve outward just a little, without any change in the morbidity and disability curves. Prevalence rates of morbidity and disability rise ever so little.

Secondary prevention (Figure 3b) is controlling chronic diseases so that they advance less rapidly. This is a cardinal feature and goal of contemporary medicine. It comes about (a) by more efficacious treatment procedures at any or all disease stages and (b) by earlier diagnosis of disease and thus earlier initiation of treatment. Considering better disease management: People are just as likely to acquire diseases as before, based on life-style and other risk factors; incidence rates remain constant on that basis. But conditions are milder; there is a broad-based "shift toward mildness." How great the shift is depends on the initial severity distribution and how much therapeutic benefit accrues at various stages. Retention of ill people, who under a prior mortality schedule would have died by age X, probably increases comorbidity rates; this assumes they are not only sicker when rescued, but also more vulnerable to new conditions during their extra years than are age peers. People avoid death longer (lower case fatality), but then have a disease for more years and a larger fraction of their lives. Considering earlier diagnosis: When the cutpoint for clinical detection and intervention is set lower, official incidence rates are likely to increase. If early intervention is actually efficacious, then the shift toward mildness described above occurs for early cases as well, a welcome compensation for their having crossed the clinical threshold sooner.

Secondary prevention can affect many people, so its impact on aggregate health and mortality can be great. The more successful and widespread that secondary prevention is, the more the mortality curve shifts outward. What happens to the morbidity and disability curves is less certain because there are opposing factors: Milder cases (people

cross back over the threshold from ill to well and from disabled to nondisabled) make the curves push outward. But some forces push the curves inward: Marginal survivors, who may be numerous, have increased vulnerability to new conditions; and lower diagnostic thresholds, if they have occurred, draw people over to ill status. How morbidity and disability prevalence rates change in these circumstances is hard to predict. The best bet is that prevalences will increase (mortality curve outward, morbidity and disability curves inward). In sum, some aspects of population health are likely to show worsening (increases in morbidity and disability prevalences, duration, comorbidity) and others improvement (shift toward mildness, decreased mortality). This situation of "longer life but worsening health" is not in the least contradictory or anomalous.

Primary prevention (Figure 3c) means keeping people free of a disease (a) for their entire lifetimes by disease eradication or (b) until late in life by delayed onset. Rates of incidence and duration fall sharply for morbidity and disability. In the situation of delayed onset, people who do develop diseases tend to have milder cases than did prior cohorts; what delays onset deters progression as well. Comorbidity diminishes; as chances of acquiring each disease fall, so do chances of their co-occurrence.

All three survival curves shift strongly outward, giving people more years free of morbidity, disability, and death. Prevalence rates decrease at all ages, except possibly the very oldest in the situation of delayed onset.

The compression of morbidity (Fries, 1980, 1983, 1989) is one version of this third scenario. It is premised on greatly delayed onset for fatal diseases, plus some intrinsic limits to life expectancy. Stated another way, mortality rates "bump up" against some intrinsic limits to life expectancy, while primary prevention continues to speed forth. People are well for most of their long lives, then ill for a short time before dying. In terms of survival curves, the zone between morbidity and mortality narrows over time; that is, gains in morbidity survival exceed those for mortality.

Fries' scenario is not the only way that morbidity gains can exceed mortality gains. Readers familiar with multistate methods will be able to concoct some reasonable ways that involve spells of illness and

disability over a lifetime. So the notion of intrinsic limits to life expectancy is not a prerequisite feature of compression; it is the particular condition that Fries has chosen. The ultimate scenario he describes is possible only if we know disease risk factors thoroughly and convince people to avoid such risks throughout their lives; that is a tall order. The compression of morbidity, as proposed by Fries, is not near at hand.

(It should be noted that the compression of disability is really a separate concept from compression of morbidity, although it is seldom distinguished. Its discussion is parallel to the one above.)

The three scenarios of tertiary, secondary, and primary prevention are not mutually exclusive. Advances in all three kinds of prevention can occur at the same time, with greater or lesser emphasis on each. The past several decades have been dominated by secondary prevention. This accounts for observed rises in disease and disability prevalences (Colvez & Blanchet, 1981; Feinleib & Wilson, 1985; Feldman, 1983; Rice & LaPlante, 1988; Verbrugge, 1984, 1989b; Ycas, 1987), combined with substantial declines in mortality rates, especially at older ages (Crimmins, 1981, 1984; Rosenwaike, Yaffe, & Sagi, 1980; Verbrugge, 1989a; Wilkin, 1982). Secondary prevention is likely to continue as a key focus and outcome of medical care and life-style behaviors. For some time, then, we should expect to see rising morbidity and disability prevalences joined with falling mortality. Lacking survey data on severity and comorbidity, we will not know their trends with certainty. If biomedical research and medical therapies remain focused on fatal diseases, with less attention to nonfatal conditions, we will slowly see a redistribution of health problems—with increasing prominence of arthritis and other nonfatal diseases, sensory and structural impairments, and physiological frailty.

Opinions and theories about how population health will change in coming decades, however well based, are not demonstrated truths. Their value is to guide the discussions and research that generate empirical truths. My opinion is that the scenario of longer life but worsening health is most likely, but other scenarios such as compression of morbidity are strongly promulgated as well. Convincing empirical evidence will be hard to come by, not only for what has happened in the past 50 years, but also what lies ahead for the next 50.

This is because our main national health surveys focus on prevalence and are seldom designed to address questions of incidence, severity, comorbidity, and duration.

Scientific labor should be devoted to the key issues noted here: (a) data that measure dynamics (transition rates) among morbidity, disability, and death; (b) analyses that reveal heterogeneity in those dynamics (such analyses provide empirical grist for health policies and programs); (c) attentiveness to severity thresholds that define the states of being ill and disabled; and (d) considerations and measurement of the "dark matters." Further development and dissemination of statistical models that relate risks, morbidity, disability, and mortality are desirable. Theoretical models of morbidity-mortality relationships will also advance (Manton & Stallard, 1984; Vaupel et al., 1979; Vaupel & Yashin, 1987). And ingenious uses of existing data (as in Manton, 1982; Myers & Manton, 1984a, 1984b; Olshansky & Ault, 1986) should be applauded.

The compression of morbidity is a distilled product of many specific changes in morbidity, disability, and mortality. The enterprise and pleasure of science need to focus on those specific changes. They are the foundation for answering many, many questions. Compression of morbidity happens to be a particularly intriguing one, but it is neither preeminent in the scientific agenda on morbidity-disability-mortality relationships nor temporally proximate for our society.

NOTES

1. In some analyses, several disability outcomes are used and arranged in hierarchical manner (see Branch & Ku, 1989; Manton, 1989; Soldo & Manton, 1985).

2. People can also be asked how they have changed activities over time to reduce demand; this is called accommodation.

REFERENCES

Alter, G., & Riley, J. C. (1989). Frailty, sickness, and death: Models of morbidity and mortality in historical populations. *Population Studies, 43*, 25-45.

Branch, L. G., & Ku, L. (1989). Transition probabilities to dependency, institutionalization, and death among the elderly over a decade. *Journal of Aging and Health, 1*, 370-408.

Colvez, A., & Blanchet, M. (1981). Disability trends in the United States population 1966-76: Analysis of reported causes. *American Journal of Public Health, 71*, 464-471.

Crimmins, E. M. (1981). The changing pattern of American mortality decline, 1940-77, and its implications for the future. *Population and Development Review, 7*, 229-254.

Crimmins, E. M. (1984). Life expectancy and the older population. *Research on Aging, 6*, 490-514.

Elandt-Johnson, R., & Johnson, N. L. (1980). *Survival models and data analysis*. New York: Wiley.

Feinleib, M., & Wilson, R. W. (1985). Trends in health in the United States. *Environmental Health Perspectives, 62*, 267-276.

Feldman, J. J. (1983). Work ability of the aged under conditions of improving mortality. *Milbank Quarterly/Health and Society, 61*, 430-444.

Fries, J. F. (1980). Aging, natural death, and the compression of morbidity. *New England Journal of Medicine, 303*, 130-135.

Fries, J. F. (1983). The compression of morbidity. *Milbank Quarterly/Health and Society, 61*, 397-419.

Fries, J. F. (1989). The compression of morbidity: Near or far? *Milbank Quarterly/Health and Society, 67*, 208-232.

Guralnik, J. M., & Kaplan, G. A. (1989). Predictors of healthy aging: Prospective evidence from the Alameda County Study. *American Journal of Public Health, 79*, 703-708.

Haber, L. D. (1971). Disabling effects of chronic disease and impairment. *Journal of Chronic Diseases, 24*, 469-487.

Harris, T., Kovar, M. G., Suzman, R., Kleinman, J. C., & Feldman, J. J. (1989). Longitudinal study of physical ability in the oldest-old. *American Journal of Public Health, 79*, 698-702.

Hayward, M. D., & Grady, W. R. (1990). Work and retirement among a cohort of older men in the United States, 1966-1983. *Demography, 27*, 337-356.

Hayward, M. D., Grady, W. R., Hardy, M. A., & Sommers, D. (1989). Occupational influences on retirement, disability, and death. *Demography, 26*, 393-409.

Kaplan, M. H., & Feinstein, A. R. (1974). The importance of classifying initial co-morbidity in evaluating the outcome of diabetes mellitus. *Journal of Chronic Diseases, 27*, 387-404.

Katz, S., Branch, L. G., Branson, M. H., Papsidero, J. A., Beck, J. C., & Greer, D. S. (1983). Active life expectancy. *New England Journal of Medicine, 309*, 1218-1224.

Land, K., & Rogers, A. (Eds.). (1982). *Multidimensional mathematical demography*. New York: Academic Press.

LaPlante, M. P. (1989). *Disability risks of chronic illnesses and impairments* (Disability Statistics Report, No. 2). San Francisco: University of California, Institute for Health and Aging.

Manton, K. G. (1982). Changing concepts of morbidity and mortality in the elderly population. *Milbank Quarterly/Health and Society, 60*, 183-244.

Manton, K. G. (1989). A longitudinal study of functional change and mortality in the United States. *Journal of Gerontology: Social Sciences, 43*, S153-161.

Manton, K. G., & Soldo, B. J. (1985). Dynamics of health changes in the oldest old: New perspectives and evidence. *Milbank Quarterly/Health and Society, 63*, 206-285.

Manton, K. G., & Stallard, E. (1984). *Recent trends in mortality analysis*. New York: Academic Press.

Manton, K. G., & Stallard, E. (1988). *Chronic disease modelling: Measurement and evaluation of the risks of chronic disease processes*. New York: Oxford University Press.

Minaker, K. L., & Rowe, J. W. (1985). Health and disease among the oldest old: A clinical perspective. *Milbank Quarterly/Health and Society, 63*, 324-349.

Myers, G. C., & Manton, K. G. (1984a). Compression of mortality: Myth or reality? *Gerontologist, 24*, 346-353.

Myers, G. C., & Manton, K. G. (1984b). Recent changes in the U.S. age at death distribution: Further observations. *Gerontologist, 24*, 572-575.

Namboodiri, K., & Suchindran, C. M. (1987). *Life table techniques and their applications*. New York: Academic Press.

Olshansky, S. J., & Ault, A. B. (1986). The fourth stage of the epidemiologic transition: The age of delayed degenerative diseases. *Milbank Quarterly/Health and Society, 64*, 355-391.

Pinsky, J., Leaverton, P., & Stokes, J. (1987). Predictors of good function: The Framingham Study. *Journal of Chronic Diseases, 40*(Suppl. 1), 159S-167S.

Pollard, A. H., Yusuf, F., & Pollard, G. N. (1974). *Demographic techniques*. Rushcutters Bay, NSW, Australia: Pergamon.

Poterba, J. M., & Summers, L. H. (1987). Public policy implications of declining old-age mortality. In G. Burtless (Ed.), *Work, health, and income among the elderly* (pp. 19-58). Washington, DC: Brookings Institution.

Rice, D. P., & LaPlante, M. P. (1988). Chronic illness, disability, and increasing longevity. In S. Sullivan & M. Ein Lewin (Eds.), *The economics and ethics of long-term care and disability* (pp. 9-55). Washington, DC: American Enterprise Institute.

Rogers, A. (1975). *Introduction to multiregional mathematical demography*. New York: Wiley.

Rogers, A. (1980). Introduction to multistate mathematical demography. *Environment and Planning, A-11*, 489-498.

Rogers, A., Rogers, R. G., & Branch, L. G. (1989). A multistate analysis of active life expectancy. *Public Health Reports, 104*, 222-226.

Rogers, R. G., Rogers, A., & Belanger, A. (1989). Active life among the elderly in the United States: Multistate life table estimates and population projections. *Milbank Quarterly/Health and Society, 67*, 370-411.

Rosenwaike, I., Yaffe, N., & Sagi, P. C. (1980). The recent decline in mortality of the extreme aged: An analysis of statistical data. *American Journal of Public Health, 70*, 1074-1080.

Rowe, J. W., & Besdine, R. W. (1982). *Health and disease in old age*. Boston: Little, Brown.

Satariano, W. A., Ragheb, N. E., & Dupuis, M. H. (1989). Comorbidity in older women with breast cancer: An epidemiologic approach. In R. Yancik & R. Yates (Eds.), *Cancer in the elderly: Approaches to early detection and treatment* (pp. 71-107). New York: Springer.

Schoen, R. (1988a). Practical uses of multistate population models. In W. R. Scott & J. Blake (Eds.), *Annual review of sociology* (Vol. 14, pp. 341-361). Palo Alto, CA: Annual Reviews.

Schoen, R. (1988b). *Modeling multigroup populations*. New York: Plenum.

Seeman, T. E., Guralnik, J. M., Kaplan, G. A., Knudsen, L., & Cohen, R. (1989). The health consequences of multiple morbidity in the elderly: The Alameda County Study. *Journal of Aging and Health, 1*, 50-66.

Soldo, B. J., & Manton, K. G. (1985). Health status and service needs of the oldest old: Current patterns and future needs. *Milbank Quarterly/Health and Society, 63*, 286-319.

Spector, W. D., Katz, S., Murphy, J. B., & Fulton, J. P. (1987). The hierarchical relationship between activities of daily living and instrumental activities of daily living. *Journal of Chronic Diseases, 40*, 481-489.

Stockwell, E. G. (1976). *The methods and materials of demography*. New York: Academic Press.

Vaupel, J. W., Manton, K. G., & Stallard, E. (1979). The impact of heterogeneity in individual frailty on the dynamics of mortality. *Demography, 16*, 439-454.

Vaupel, J. W., & Yashin, A. I. (1987). Repeated resuscitation: How lifesaving alters life tables. *Demography, 24*, 123-135.

Verbrugge, L. M. (1984). Longer life but worsening health? Trends in health and mortality of middle-aged and older persons. *Milbank Quarterly/Health and Society, 62*, 475-519.

Verbrugge, L. M. (1987). From sneezes to adieux: Stages of health for American men and women. In R. A. Ward & S. S. Tobin (Eds.), *Health in aging: Sociological issues and policy directions* (pp. 17-57). New York: Springer.

Verbrugge, L. M. (1989a). Gender, aging, and health. In K. S. Markides (Ed.), *Aging and health: Perspectives on gender, race, ethnicity, and class* (pp. 23-78). Newbury Park, CA: Sage.

Verbrugge, L. M. (1989b). Recent, present, and future health of American adults. In L. Breslow, J. E. Fielding, & L. B. Lave (Eds.), *Annual review of public health* (Vol. 10, pp. 333-361). Palo Alto, CA: Annual Reviews.

Verbrugge, L. M. (in press). Disability transitions for older persons with arthritis. *Journal of Aging and Health.*

Verbrugge, L. M. (1990). The iceberg of disability. In S. M. Stahl (Ed.), *The legacy of longevity* (pp. 55-75). Newbury Park, CA: Sage.

Verbrugge, L. M., Lepkowski, J. M., & Imanaka, Y. (1989). Comorbidity and its impact on disability. *Milbank Quarterly/Health and Society, 67*, 450-484.

Wilkin, J. C. (1982). Recent trends in mortality of the aged. *Transactions of the Society of Actuaries, 33*, 11-62.

Ycas, M. A. (1987). Recent trends in health near the age of retirement: New findings from the Health Interview Survey. *Social Security Bulletin, 50*(2), 5-30.