ELSEVIER

Changes in Health Status Among Participants of The Framingham Heart Study from the 1960s to the 1990s: Application of an Index of Cumulative Deficits

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PURPOSE: Health of the general population is improving along a number of major health dimensions. Using a cumulative deficits approach, we investigated whether such improvements were evident at the level of minor health traits.
METHODS: We selected 37 small-effect traits consistently measured in the 9th (performed in 1964) and 14th (1974) Framingham Heart and 5th (1991–1995) Offspring Study exams to construct indices of cumulative deficits (DIs).
RESULTS: We identified deficits-specific DIs characterizing health dimensions associated with no health changes (DI_{NHC}), health worsening (DI_{WRS}), and health improving (DI_{IMP}) between the 1960s and 1990s. The risks of death attributable to the DI_{NHC} dominate within shorter time horizons. For longer time horizons, both the DI_{NHC} and DI_{IMP} provide the same contribution to the risks of death. The mortality risks associated with the DI_{WRS} are the weakest and least significant.
CONCLUSIONS: The analyses show that the cumulative deficits approach might be an efficient tool for analyzing the effects of a large number of health characteristics for which the individual effects are small, inconsistent, or non-significant. They show favorable trends such that health of the Framingham studies participants either did not change or improved over time for the most serious small-effect traits.
Ann Epidemiol 2008;18:696–701.

KEY WORDS: Trends in Health, Population Characteristics, Age Patterns.

INTRODUCTION

Numerous studies have documented improvements in the health of the general population during the 20th century (reviewed in Crimmins [1]). These improvements were documented along a number of dimensions of health reflecting the process of population health change (e.g., a simplified pathway is: risk factors → disease → loss of functioning → disability → death) (1). Most studies of health trends (apart from mortality changes) in recent years have emphasized positive changes in disability prevalence among older individuals (e.g., Freedman et al. [2] and Freedman, Martin, and Schoeni [3]). Improvements in physical, cognitive, and sensory limitations were recently summarized by Freedman, Martin, and Schoeni (3). Trends in diseases are not so positive; most studies suggest an increasing chronic disease burden, including consistent estimates of upward trends in heart disease prevalence during the period 1970 to 1990 from several major studies (e.g., National Health Interview Survey, Framingham Heart [FHS] and Offspring [FHSO] Studies, Minnesota Heart Survey) (1). Studies of temporal changes in disease risk factors were largely focused on heart diseases and cancer and provided mixing evidences (1, 4).

Another approach to the assessment of health status is based on global health characteristics. One such characteristic is self-rated health, which is viewed as a summary of overall health status because of its high predictive power of death. Measures of self-rated health show a consistent decline in the prevalence of individuals who rate their health as poor during the 1980s and 1990s, a trend that was more pronounced among the elderly than among the younger population (5–7).

Major health dimensions provide some indications of trends in severe health conditions (e.g., disease, disability, self-perceived health). Will these trends continue in the future? To answer this question, a mechanism driving changes in severe health conditions has to be understood. This is a motivation for studies of trends in risk factors. Understanding the importance of trends in minor health conditions leads to yet another focus of recent research which is not simply on risk factors but on symptoms and signs (8). Insights on changes in these factors might provide more precise clues on future changes in population health. The challenge facing such studies is the large number of various symptoms and signs and the small or inconsistent effect of

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Received March 3, 2008; accepted June 6, 2008.

1047-2797/08/$–see front matter
doi:10.1016/j.annepidem.2008.06.005

Selected Abbreviations and Acronyms

FHS = The Framingham Heart Study
FHSO = The Framingham Heart Study Offspring
DI = deficit index
MA = mean age
IAPD = increased anteroposterior diameter
VV = venous insufficiency or varicose veins
ECG = electrocardiogram

each on health/mortality risks. The aggregate effect of several such small-effect factors, however, might be more informative. This is an underlying paradigm of recent developments of a new promising instrument which is called a *frailty index* (9–11) or an index of *cumulative deficits* (12, 13). The concept of a *cumulative health deficits index* (DI) also appears to be useful in studies of aging, health, and survival for which the DI is a promising alternative to chronological age for characterizing aging-associated processes in individuals and for improved predictions of chances of adverse events (11–20). Consequently, the DI can be an indicator of changes in health on the level of small-effects traits (e.g., signs, symptoms) and, simultaneously, can serve as a characteristic of global health/well-being.

This study investigates trends in the health status in a sample of adult and elderly individuals participating in the FHS/FHSO using a new instrument, the DI, which aggregates small-effect variables routinely collected during the period 1960 to 1990. Unlike other studies, the focus of this work is on a broad spectrum of such traits.

METHODS

The FHS and FHSO Data

Beginning in 1948, 5,209 respondents (46% male) aged 28–62 years residing in Framingham, Massachusetts were enrolled in the famous FHS. The FHSO data set consists of a sample of 3,514 biological descendants of the FHS Cohort, 1,576 of their spouses and 34 adopted offspring for a total sample of 5,124 subjects (48% male). The FHSO subjects were enrolled in the period 1971–1975 using research protocols similar to those of the FHS so that comparisons of the results from the FHSO and the FHS could be made. Selection criteria and study design have been described (21, 22). These cohorts have been followed for the occurrence of certain diseases (e.g., heart disease, cancer, diabetes mellitus) and death. Examination also included an interview, physical examination, and laboratory tests.

The Cumulative Deficits Approach

In traditional analyses, traits with small, inconsistent, or non-significant contributions to risks of adverse health outcomes are usually ignored. When the number of such traits is large enough, however, their cumulative effect on chances of future adverse events may become significant and, thus, an integrative or cumulative measure (i.e., the DI) might be more informative compared to individual traits (12–15, 20). Therefore the DI is designed to gather different manifestations of health deterioration with aging (regardless of their individual significance) from a wide set of deficits into a single measure. An important advantage of the DI is that it can be constructed using the set of deficits typically collected in majority of the aging-related studies. This is because such studies collect wide sets of the aging-related traits and statistical properties of the DI (e.g., age patterns) and its effect on other outcomes (e.g., mortality) are weakly sensitive to the selection of specific set of deficits. Robustness of the DI is confirmed in several studies using different sets of deficits (11, 15, 17, 18). In addition, the DI might be a good characterization of the level of aging-associated decline in health status at this age (12–15, 20). If the DI is constructed from a set of small-effect traits, it can capture small decrements in declining health with aging, hopefully, informing about health problems long before clinically manifested conditions.

The conceptual framework behind the DI can be summarized in a simplified scheme in which the individual's vulnerability state can be characterized by a proportion of failed units out of a large number, N, of such units (subsystems). The failure of each unit is associated with a "deficit". The proportion of deficits accumulated by age x characterizes individual's health/well-being status and affects chances of further health deterioration and death. The data often do not allow for observing failures of all the N units. Therefore, an empirical estimate of this proportion in a given individual, that is, the $DI(x)$, can be calculated by selecting a set of M units out of a list with N units, summing the number of failed units from the selected set M up to age x, $m(x)$, and dividing this sum by M, that is, $DI(x) = m(x)/M$ (15, 23–25). Prior studies suggest that the properties of the DI are weakly sensitive to the choice of the subset M (18).

Analyses

The evaluation of trends in the age patterns of DI is constrained by several factors. First, ideally, the DIs have to be constructed using a wide set of heath-related conditions (see section "The Cumulative Deficits Approach"). Second, survey instruments have to be comparable over time. Third, the range of intersecting ages should be as large as possible. Fourth, the surveys/exams should be well separated in time. Finally, selected samples have to be of adequate size. To address all these constraints, the same sets of 37 deficits (Table 1) with comparable diagnostic procedures across all years was selected from two representative exams of the FHS (9th FHS exam performed in 1964: $N = 3{,}833$; age range, 44–78 years; mean age [MA] $\pm$ standard error $= 59.0 \pm 0.13$ years and