

## AGING, HEALTH RISKS, AND CUMULATIVE DISABILITY

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**ABSTRACT**

**Background** Persons with lower health risks tend to live longer than those with higher health risks, but there has been concern that greater longevity may bring with it greater disability. We performed a longitudinal study to determine whether persons with lower potentially modifiable health risks have more or less cumulative disability.

**Methods** We studied 1741 university alumni who were surveyed first in 1962 (average age, 43 years) and then annually starting in 1986. Strata of high, moderate, and low risk were defined on the basis of smoking, body-mass index, and exercise patterns. Cumulative disability was determined with a health-assessment questionnaire and scored on a scale of 0 to 3. Cumulative disability from 1986 to 1994 (average age in 1994, 75 years) or death was the measure of lifetime disability.

**Results** Persons with high health risks in 1962 or 1986 had twice the cumulative disability of those with low health risks (disability index, 1.02 vs. 0.49;  $P < 0.001$ ). The results were consistent among survivors, subjects who died, men, and women and for both the last year and the last two years of observation. The onset of disability was postponed by more than five years in the low-risk group as compared with the high-risk group. The disability index for the low-risk subjects who died was half that for the high-risk subjects in the last one or two years of observation.

**Conclusions** Smoking, body-mass index, and exercise patterns in midlife and late adulthood are predictors of subsequent disability. Not only do persons with better health habits survive longer, but in such persons, disability is postponed and compressed into fewer years at the end of life. (N Engl J Med 1998;338:1035-41.)

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**T**HE compression-of-morbidity hypothesis<sup>1-3</sup> suggests that it may be possible to reduce cumulative lifetime morbidity. Since chronic illness and disability usually occur late in life, cumulative lifetime disability could be reduced if primary-prevention measures postponed the onset of chronic illness. However, decreases in health risks may also increase the average age at death.<sup>4-9</sup> The compression-of-morbidity hypothesis predicts that the age at the time of initial disability will increase more than

the gain in longevity, resulting in fewer years of disability and a lower level of cumulative lifetime disability.

Some contend that healthier lifestyles may actually increase morbidity (and health expenditures) late in life by increasing the number of years of chronic illness and disability.<sup>9-12</sup> Thus, cumulative lifetime disability could actually be greater in persons with lower health risks than in those with higher health risks.<sup>4-9</sup>

The data on cumulative lifetime disability are limited, particularly data on cumulative disability in persons with different levels of health risk. National trends in health behavior have been inconsistent. In recent years, for example, the prevalence of smoking has decreased, but the prevalence of obesity has increased.<sup>13,14</sup> Hence, it is difficult to evaluate the effect of changes in health behavior on the onset of disability, life expectancy, and cumulative disability. Recent studies suggest a decrease in cumulative disability over time.<sup>15-18</sup> In addition, persons with higher socioeconomic status<sup>19</sup> and higher educational levels<sup>20</sup> and those who engage in regular aerobic activity<sup>21-24</sup> have substantially better health,<sup>25</sup> suggesting the possibility of a compression of morbidity in such persons.

We tested the compression-of-morbidity hypothesis by performing a longitudinal study of cumulative disability in relation to three levels of health risk. Our hypothesis was that persons with lower health risks will have disability later in life, will have less disability at any given age, and will have less cumulative disability than persons with greater health risks.

**METHODS**

In 1986, investigators for the Arthritis, Rheumatism, and Aging Medical Information System acquired access to a unique set of data from persons attending the University of Pennsylvania in 1939 and 1940, who were studied at that time and were subsequently surveyed in 1962, 1976, and 1980.<sup>26-30</sup> Since 1986, 2841 alumni have been studied. Mailed health-assessment questionnaires have been used to obtain information on disability, medical history, and health habits in this population on an approximately annual basis. Seven surveys were performed between November 1986 and March 1994.

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The survey participants were included in this study if they met three criteria. First, they had to have completed at least two consecutive questionnaires, so that at least two consecutive years of disability data would be available preceding any deaths; 397 subjects were excluded because they did not meet this criterion. Second, the subjects had to have completed all survey questionnaires since 1986 or, in the case of those who died, all questionnaires preceding their deaths; 306 participants (11 percent) were lost to follow-up and it was not known whether they were dead or alive. Third, the participants had to be between 63 and 72 years old in 1986; an additional 397 subjects did not meet this criterion. The resulting study population consisted of 1741 subjects; 77 percent were men, and 99 percent were white. Complete data on disability were available for more than 97 percent of the subjects. The mean ( $\pm$ SD) age in 1986 was  $67.0 \pm 2.8$  years.

Variables of interest included age, sex, body-mass index (the weight in kilograms divided by the square of the height in meters), smoking habits, exercise, number of chronic conditions, use of medical services, and disability index. Exercise was defined as the number of minutes per week during which the subject engaged in physical activity and became short of breath or worked up a sweat. Body-mass index was calculated by dividing the weight in kilograms by the square of the height in meters. Chronic conditions included arthritis, back pain, osteoporosis, heart disease, high blood pressure, stroke, diabetes, cancer, and lung diseases.

The health-assessment questionnaire, used to measure the dependent variable, assesses activities of daily living. Each of eight activities (dressing, rising, eating, walking, grooming, reaching, gripping, and performing errands) is scored as 0 (no difficulty), 1 (some difficulty), 2 (much difficulty), or 3 (unable to do), and the scores are averaged across the eight activities. A cumulative-disability index of 3.0 could represent the inability to perform any one of the eight activities for one year, some difficulty performing all eight activities for three years, or the inability to perform two activities for four years. The average disability index is 1.2 per year for patients with rheumatoid arthritis and 0.8 per year for those with osteoarthritis. Minimal disability (an index of 0.1) represents some difficulty in performing one of the eight activities. This disability measure has been widely used, is sensitive to change, and has been extensively validated.<sup>31-35</sup>

The three end points of the study were disability in the last year of observation, disability in the last two years of observation, and cumulative disability, which was calculated as the sum of the disability indexes since 1986. Cumulative disability was used as a surrogate measure for total disability. For the deceased participants, cumulative disability was estimated as the sum of the disability values from 1986 until the last completed questionnaire. The last disability index was the index based on the last survey before death, for the subjects who died, and the index in 1994, for the survivors. Disability in the last two years was calculated as the sum of the last two indexes.

Body-mass index, smoking, and exercise were selected as stratification variables on the basis of the known associations between these variables and disability.<sup>21,23,24,36-38</sup> Subjects were assigned scores of 0 to 3 for body-mass index ( $<22.5$ ,  $22.5$  to  $<24.0$ ,  $24.0$  to  $<26.0$ , or  $\geq 26.0$ ), number of cigarettes per day (0, 1 to 20, 21 to 30, or  $>30$ ), and minutes of vigorous exercise per week ( $>240$ , 120 to 239, 1 to 119, or 0), as determined in 1986 and also in 1962. Body-mass index had a J-shaped relation to subsequent disability in this data set, and although the power of the study may have been decreased as a result, we selected cutoff points for stratification to be consistent with those in other studies.<sup>22-24,36-38</sup> The scores for the three risk factors were totaled, and the subjects were assigned a level of risk according to the total score (low risk, 0 to 2; moderate risk, 3 or 4; high risk, 5 to 9).

To eliminate the effect of base-line disability, parallel analyses were performed with data from participants without initial disability. The postponement of disability was assessed by comparing the average age at the onset of minimal disability (score, 0.1) in the three strata. We repeated the main analyses with strata determined on the basis of the 1962 data, when the average age of the

participants was 43 years, allowing an assessment of the association between disability and the health-risk score at midlife, 32 years before the last observation (i.e., at a time when minimal disability would be expected).

Analyses were performed with SAS software.<sup>39</sup> Pearson's correlation coefficients were calculated with cumulative disability as the dependent variable. Two-tailed t-tests were performed for the three disability end points, with comparisons of the low- and moderate-risk groups and the low- and high-risk groups. Tests for trend were performed by fitting the dependent variables to the risk-factor strata, coded as 1, 2, and 3.

## RESULTS

The mean disability index in 1986 was low ( $0.06 \pm 0.16$ ), and 74 percent of the subjects had no disability, suggesting that the disability index in 1962 (not available) would have been close to zero.<sup>37</sup> Univariate correlations between cumulative disability and the independent variables, as determined in 1986, were analyzed; initial values for the disability index had the highest correlation ( $r = 0.64$ ,  $P < 0.001$ ). Female sex and a greater number of chronic conditions were also correlated with cumulative disability ( $r = -0.16$  and  $r = 0.20$ , respectively;  $P < 0.001$  for both comparisons). Age and educational level were not significantly associated with cumulative disability ( $r = 0.02$  for both comparisons), probably because of the nearly uniform age and educational level in this population. Greater cumulative disability was associated with a larger number of cigarettes smoked per day ( $r = 0.09$ ,  $P < 0.001$ ), less exercise per week ( $r = -0.11$ ,  $P = 0.001$ ), and a higher body-mass index ( $r = 0.11$ ,  $P = 0.001$ ), suggesting approximately equal contributions from each of the three risk factors.

The results were similar in the group of subjects who were excluded from our study, although they were slightly older (70.0 vs. 68.2 years) and had a higher initial disability index (0.10 vs. 0.08) and lower exercise levels (111 vs. 133 minutes). A significantly larger proportion of deceased subjects were men (84 percent, vs. 77 percent of survivors) with a higher initial disability index (0.15 vs. 0.06), a larger number of cigarettes smoked per day (3.3 vs. 1.6), and a larger number of chronic conditions (0.66 vs. 0.46).

The disability outcomes are shown in Table 1 according to risk strata (based on body-mass index, exercise, and smoking). The initial age and the number of questionnaires completed were similar in the low-, moderate-, and high-risk groups, with an average of 6.94, 6.99, and 6.99 questionnaires completed by the surviving subjects, respectively, and 4.6, 4.5, and 4.2 completed by those who died, respectively. The subjects in the high-risk group had an average cumulative-disability index of 1.02, and the values for the subjects in the moderate- and low-risk groups were 0.71 and 0.49, respectively ( $P$  for trend,  $< 0.001$ ). There were similar differences among the three risk groups for disability in the last year and the last two years of observation. For subjects with no initial disability, the cumulative values showed a similar trend

TABLE 1. DISABILITY ACCORDING TO HEALTH RISK IN 1986.

GROUP	No. OF SUBJECTS	AGE IN 1986	DISABILITY INDEX			
			IN 1986	IN LAST YEAR	IN LAST TWO YEARS	CUMULATIVE
			mean ±SD			
		yr				
All subjects						
High risk	455	66.9	0.10±0.22	0.28±0.48*	0.45±0.88*	1.02±1.8*
Moderate risk	675	67.0	0.059±0.15	0.19±0.42†	0.29±0.64†	0.71±1.5†
Low risk	611	67.0	0.039±0.11	0.14±0.36	0.20±0.55	0.49±1.1
Survivors						
Total						
High risk	401	66.8	0.080±0.16	0.22±0.38*	0.34±0.66*	0.91±1.7*
Moderate risk	608	67.0	0.053±0.13	0.17±0.36‡	0.25±0.56‡	0.68±1.4‡
Low risk	563	67.0	0.036±0.10	0.12±0.32	0.17±0.49	0.45±1.1
Subjects without disability in 1986						
High risk	288	66.8	0	0.11±0.23	0.16±0.36	0.35±0.72
Moderate risk	467	66.9	0	0.087±0.24	0.12±0.35	0.28±0.75
Low risk	466	66.9	0	0.084±0.25	0.10±0.37	0.24±0.71
Subjects who died						
Total						
High risk	54	67.4	0.25±0.44	0.065±0.83‡	1.2±1.6†	1.8±2.5‡
Moderate risk	67	67.0	0.11±0.25	0.43±0.75	0.60±1.0	0.93±1.9
Low risk	48	67.4	0.074±0.19	0.31±0.65	0.50±0.97	0.86±1.8
Subjects without disability in 1986						
High risk	26	67.2	0	0.34±0.51	0.50±0.84	0.75±1.5
Moderate risk	48	66.7	0	0.29±0.61	0.32±0.66	0.40±0.82
Low risk	38	67.1	0	0.24±0.62	0.34±0.75	0.51±1.0
Women						
High risk	75	66.5	0.14±0.25	0.45±0.62†	0.80±1.1†	1.9±2.3†
Moderate risk	149	66.7	0.083±0.17	0.29±0.45	0.46±0.71	1.1±1.6
Low risk	162	66.5	0.046±0.11	0.22±0.46	0.36±0.77	0.86±1.7
Men						
High risk	380	66.9	0.093±0.21	0.24±0.44*	0.38±0.79*	0.85±1.6*
Moderate risk	526	67.1	0.053±0.14	0.17±0.41†	0.24±0.61†	0.59±1.4†
Low risk	449	67.2	0.036±0.11	0.11±0.30	0.14±0.44	0.35±0.86

\*P<0.001 for the comparison with the low-risk group.

†P<0.01 for the comparison with the low-risk group.

‡P<0.05 for the comparison with the low-risk group.

(P<0.01). For all comparisons, there was substantially more disability with higher risk than with lower risk. For the total study population, the disability indexes in the high- and low-risk groups differed by approximately a factor of two. Mortality rates also differed among the three groups, although the differences were smaller: 11.9 percent in the high-risk group, 9.9 percent in the moderate-risk group, and 7.9 percent in the low-risk group. Thus, the high-risk group had approximately a 50 percent higher mortality rate and approximately 100 percent greater disability than the low-risk group.

Surviving subjects in the high-risk group had a cumulative-disability index of 0.91, whereas those in the moderate- and low-risk groups had values of 0.68 and 0.45, respectively (P for trend, <0.001). For the subjects without initial disability, the differences persisted but were somewhat less striking. Among deceased subjects, the high-risk group had a cumu-

lative-disability index of 1.8, whereas the moderate- and low-risk groups had average values of 0.93 and 0.86, respectively (P for trend, <0.05). In the group of deceased subjects without initial disability, the most striking difference in cumulative disability was in the high-risk group as compared with the other two groups.

Since men were overrepresented in the high-risk group, sex-specific analyses were performed. Women had substantially more disability by all measures; however, the differences among the three health-risk groups were similar for men and women (Table 1).

Table 2 shows the results of analyses of disability according to the health risk in 1962 (similarly determined according to body-mass index, exercise, and smoking in subjects for whom these data were available). These data, obtained when the average age of the subjects was 43 years, are assumed to represent minimal disability, given an average disability index

**TABLE 2.** DISABILITY ACCORDING TO HEALTH RISK IN 1962.

GROUP	NO. OF SUBJECTS	AGE IN 1962	DISABILITY INDEX			
			IN 1986	IN LAST YEAR	IN LAST TWO YEARS	CUMULATIVE
			yr			
			mean ±SD			
All subjects						
High risk	469	42.9	0.086±0.18	0.25±0.48*	0.40±0.81*	0.91±1.1*
Moderate risk	519	42.9	0.066±0.18	0.20±0.45†	0.30±0.73†	0.74±1.6†
Low risk	335	42.6	0.039±0.11	0.14±0.31	0.21±0.52	0.50±1.1
Survivors						
High risk	424	42.9	0.067±0.14	0.21±0.40‡	0.31±0.65‡	0.81±1.6*
Moderate risk	464	42.9	0.056±0.14	0.16±0.35	0.24±0.54	0.67±1.4†
Low risk	310	42.6	0.036±0.09	0.12±0.28	0.18±0.45	0.45±0.99
Subjects who died						
High risk	45	43.5	0.26±0.37	0.70±0.84‡	1.2±1.4‡	1.8±2.5
Moderate risk	55	42.9	0.15±0.38	0.53±0.90	0.85±1.5	1.3±2.4
Low risk	25	42.7	0.085±0.19	0.29±0.56	0.50±1.0	0.99±2.1

\*P<0.001 for the comparison with the low-risk group.

†P<0.05 for the comparison with the low-risk group.

‡P<0.01 for the comparison with the low-risk group.

of only 0.06 in 1986, and to reflect health risks at midlife. The results of these analyses are consistent with those shown in Table 1, with disability scores in the high-risk group that were approximately twice those in the low-risk group (P<0.001).

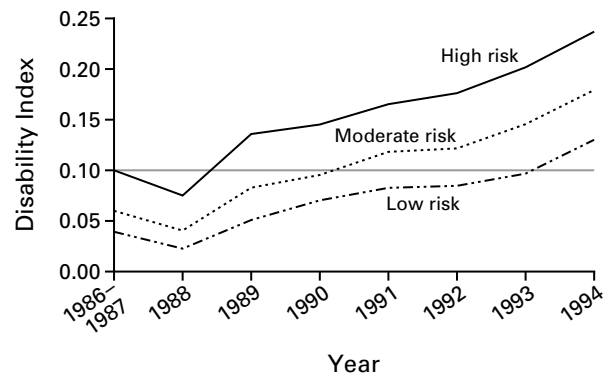
Figure 1 shows the disability index in the three risk groups according to the year. The rates of progression were similar in the three groups although slightly more rapid in the high-risk group than in the other two groups. The onset of minimal disability (an index of 0.1) was postponed by approximately five years in the low-risk group as compared with the high-risk group. An analysis of disability according to age (Fig. 2) showed that the onset of minimal disability was postponed by approximately seven years in the low-risk group as compared with the high-risk group.

Figure 3 shows the cumulative disability in all subjects, those without disability in 1986, those who survived, and those who died, according to the level of risk. The results are robust and consistent for the study end points and for the subgroups of subjects.

### DISCUSSION

This study shows that persons with lower health risks (defined in terms of smoking, body-mass index, and exercise) have initial disability at an older age and have lower levels of cumulative disability and disability at any given age than do persons with higher health risks. These findings suggest that for the average person, efforts to reduce modifiable health risks may result in a postponement of initial disability and decreased lifetime disability.

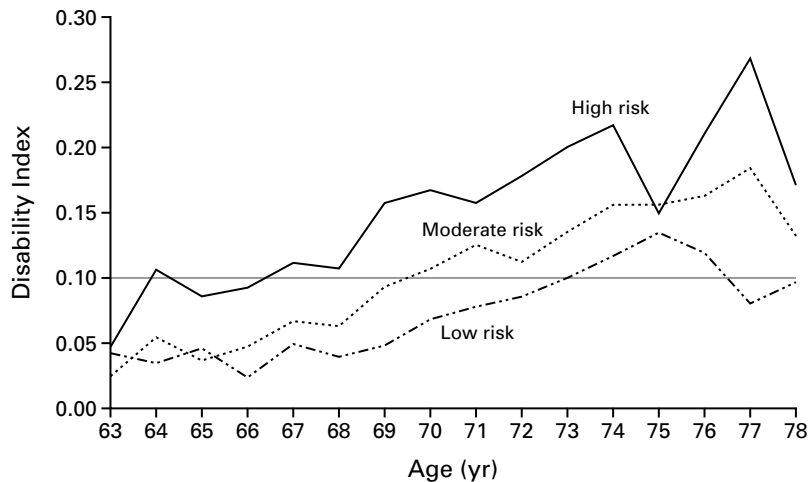
The main results of the study were similar in men



**Figure 1.** Disability Index from 1986 to 1994 in 1741 Subjects, According to the Year and Level of Health Risk in 1986.

The rate of progression in average disability as assessed on the basis of the disability index (on a scale of 0 to 3) was similar in the three risk groups, but the progression to a particular level of disability was postponed by approximately five years in the low-risk group as compared with the high-risk group. The horizontal line indicates a disability index of 0.1, which corresponds to minimal disability (some difficulty in performing one of eight activities of daily living, such as walking).

and women, in persons with no initial disability and those with initial disability, and in persons who survived and those who died during the study period. The marked differences in the degree of disability among the three risk groups persisted throughout nearly eight years of follow-up, to an average age of 75 years. The results were similar whether the risk strata were defined on the basis of midlife (1962) data or 1986 data. Disability indexes in the low- and



**Figure 2.** Disability Index According to Age at the Time of the Last Survey and Health Risk in 1986.

Average disability increased with age in all three risk groups, but the progression to a given level of disability was postponed by approximately seven years in the low-risk group as compared with the high-risk group. The horizontal line indicates a disability index of 0.1, which corresponds to minimal disability.

high-risk groups differed by a factor of approximately two, and the differences were statistically significant. Disability was postponed by more than five years in the low-risk group as compared with the high-risk group. Among the subjects who died, both cumulative disability and disability in the one or two years before death were much lower in the low- and moderate-risk groups than in the high-risk group. Similarly, among the survivors, cumulative disability was much lower in the low-risk group than in the other two groups.

Caveats apply to the results. The study population had a high educational level, was relatively homogeneous in terms of age and socioeconomic status, and was almost entirely white. Over three fourths of the subjects were men, but separate analyses of men and women had similar results. In addition, since the study end points were determined on the basis of responses to a questionnaire, there is the possibility of bias. However, the health-assessment questionnaire used to determine disability has been repeatedly validated.<sup>31-35</sup> In a study of runners and controls, for example, we found no differences between the two groups in reliability or in correlations with spousal estimates of disability.<sup>21</sup> However, for the subjects in our study, the time of greatest disability (after the age of 85 years) is still in the future. As the study continues, it will be possible to assess the effects of changes in specific risk factors such as cessation of smoking.

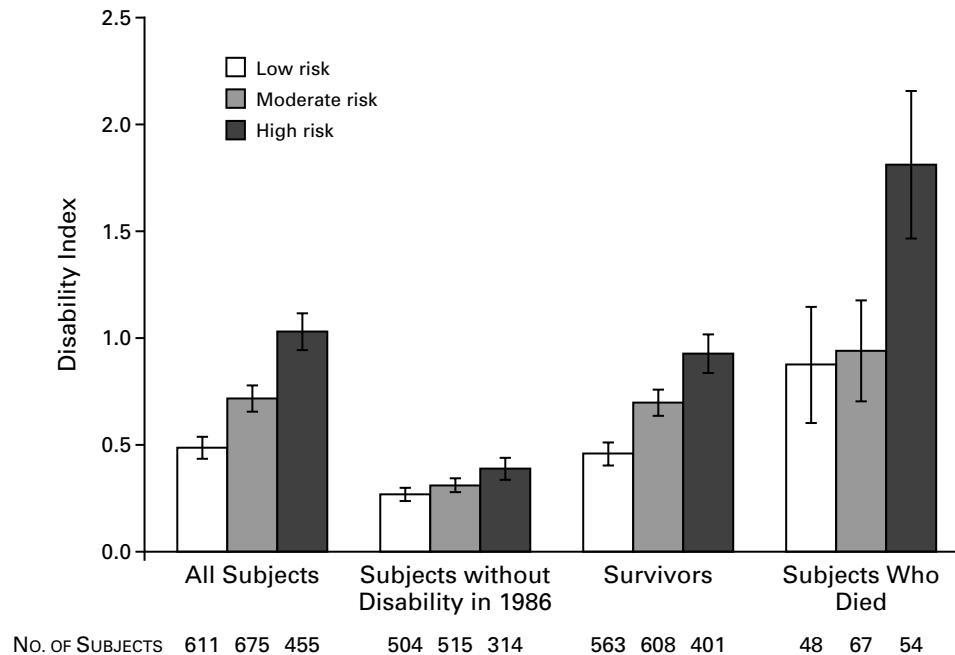
Eleven percent of the subjects were lost to follow-up and their status (dead or alive) was not known, which is another potential source of bias. These subjects were slightly older and more disabled and had

more hospitalizations in 1986 than the subjects who were followed, and it is possible that many of them died or were institutionalized. If more low-risk persons than moderate- or high-risk persons were lost to follow-up, the imbalance could produce a bias. However, the proportions of persons lost to follow-up were similar in the low-, moderate-, and high-risk groups and in the groups of patients with and without disability in 1986.

This study documents a strong association between the level of health risk and subsequent disability but does not prove causality. It is possible that other, unmeasured variables are correlated both with risk-factor scores and with cumulative disability. However, with age, education, and race essentially held constant in our study, and with prior studies indicating that smoking, obesity, and level of exercise are independently related to disability, it is difficult to think of additional causal variables.

Initial disability might have been a confounding variable, since it is strongly associated with cumulative disability and since health habits might have been modified in response to early disability. In the group of subjects without initial disability, the results were less robust. It is more likely, however, that the early disability was the result of a high health risk before the study began. We examined this issue both by performing a separate analysis of the subjects without initial disability and by assigning the subjects to risk groups at an average age of 43 years, when disability should have been minimal. In both instances, the results were consistent with those in the overall study population.

Our data base contains serial data on disability,



**Figure 3.** Mean ( $\pm$ SE) Cumulative Disability According to Health Risk in 1986.

Cumulative disability was assessed after an average age of 67 years. The data represent approximately eight years of follow-up for subjects who were alive at the end of the study period and five years of follow-up for subjects who died. The disability index in the high-risk group was approximately twice that in the low-risk group for all subjects, those with no disability in 1986, those who survived, and those who died. A score of 1.0 corresponds to moderate disability in performing two of eight activities of daily living, such as walking and rising from a chair, for two years or mild disability in performing all eight activities for one year.

which are available in few other data bases. Previous longitudinal studies have not examined the relation between cumulative disability or mortality and health risks, despite the relevance of such studies to health policy issues.<sup>23,40,41</sup> None of these previous studies have reported on disability until the end of life, which permits a direct estimation of total lifetime disability.

Our study provides evidence that persons with lower health risks have less lifetime disability, as well as less disability at any given age. The results are consistent with the hope that future increases in the number of elderly persons will be offset in part by greater vitality on the part of the elderly, if there are improvements in modifiable health risks. Thus, the implications for public health are important. Primary prevention is a positive approach to reducing mortality and morbidity.<sup>42,43</sup> Some have feared that preventive measures may lead to an expanding population of frail, disabled persons. This study suggests instead that lower health risks will result, on average, in less lifetime disability.

Supported by grants from the National Institute of Child Health and Human Development (R01 HD35641-01), the National Institute of Arthritis and Musculoskeletal and Skin Diseases (AR43584), and the Donald and Delia Baxter Foundation.

We are indebted to Daniel A. Bloch, Ph.D., and Raymond Balise, Ph.D., for statistical assistance and to Dena Ramey for editorial assistance.

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