REVIEW ARTICLES

Physical activity, the compression of morbidity, and the health of the elderly

James F Fries MD

J R Soc Med 1996;**89**:64–68

Keywords: *compression of morbidity; physical activity; elderly; quality of life*

SUMMARY

The *Compression of Morbidity* hypothesis envisions a potential reduction of overall morbidity, and of health care costs, now heavily concentrated in the senior years, by compression of morbidity between an increasing age of onset of disability and the age of death, increasing perhaps more slowly[1,2]. For this scenario to be able to be widely achieved, largely through prevention of disease and disability, we need to identify variables which predict future ill health, modify these variables, and document the improvements in health that result[3]. Physical activity is perhaps the most obvious of the variables which might reduce overall lifetime morbidity.

INTRODUCTION

The ideal for the healthy life under the *Compression of Morbidity* scenario becomes a life which is vigorous and vital until shortly before its natural close. In the early and middle years of this century most observers believe that there was movement away from this ideal, with a steady increase in the proportion of a typical life spent ill or infirm. This phenomenon resulted as the previously prevalent acute illnesses gave way to chronic diseases with longer periods of morbidity. The first suggestion that this adverse trend might be changing came with the beginning of the decline of cardiovascular disease, the major chronic illness and major cause of death in the United States, 20 years ago. With this decline in chronic illness and in accompanying increase in life expectancy in the 1970s, the national illness burden took on an increasing domination by the problems of senescence. With these changes comes controversy as to which of the possible scenarios is likely in the future[4].

Figure 1 diagrams these alternatives. At present, as shown on the top line, morbidity is concentrated principally in the last two decades of life, beginning on average at age 55, increasing over time, and reflecting the increasing prevalence of chronic illness and the infirmities of age. Morbidity occurs between the arrows representing the first onset of chronic disease and the arrow representing the average age at death. One may imagine three future scenarios. One is a life extension scenario by which the average age at death is increased by perhaps five years, but there is no change in the age at onset of morbidity. Such a scenario, termed the 'increasing misery' scenario[4,5], will result in greater average lifetime morbidity. A more moderate scenario might hold that the age at onset of morbidity might rise as rapidly as age at death, preserving the present amount of morbid time in a typical life. The compression of morbidity scenario, on the other hand, postulates that the age at death will not move as rapidly as predicted by some, but that the age at beginning morbidity may be greatly advanced by preventive health practices and other interventions. The period of morbidity is compressed into a shorter time period and the amount of lifetime morbidity also decreased. Data over the last 15 years documents a plateauing of life expectancy increases after age 65; indeed, after age 85 female life expectancy in the U.S. has been constant since 1980[3].

The *Compression of Morbidity* paradigm presents a health policy strategy for addressing the major health care burdens of developed countries. Recognizing that most illness at present is chronic rather than acute and that the overwhelming portion of the national illness burden falls upon the elderly, the *Compression of Morbidity* strategy seeks to compress this period of ill health between an increasing age at onset of disability or illness and a stable or slowly advancing average age at death.

With few empiric data available on age-specific morbidity and the factors which influence that morbidity it has been difficult to prove conclusively that morbidity compression is possible[6–8]. Analyses of the effects of physical activity upon the health of seniors provides a unique perspective from which to view these issues of senior health[9–11].

RUNNING AND THE DEVELOPMENT OF DISABILITY WITH AGE

For the past nine years our research group at the Stanford Arthritis Center has conducted prospective longitudinal

Department of Medicine, Stanford University School of Medicine, Stanford, California, USA

Correspondence to: Dr James F Fries, 1000 Welch Road, Suite 203, Palo Alto, CA 94304-1808, USA

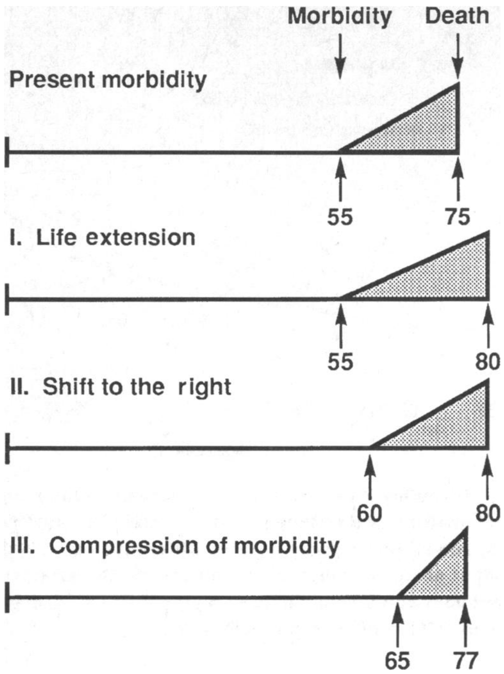

Figure 1 **Scenarios for future morbidity and longevity. Four average lives are graphically presented. Schematically, most lifetime morbidity (shaded) occurs between the age of onset of first chronic disability (first arrow) and the average age at death (second arrow). The lower three future scenarios show the difference in average lifetime morbidity (and medical costs) depending upon the relative future movements of the two arrows**

studies of the effects of long distance running, a popular form of physical activity, on patient outcomes in 537 members of a runner's club with participants at least 50 years old and 423 age-matched community controls[9,12,13]. The study was designed as a test of the *Compression of Morbidity* hypothesis, with the intention to study whether those who were physically active in fact deferred the onset of disability, or on the other hand sustained repetitive traumatic injury to joints and periarticular structures resulting in accelerated disability.

The principal analytic problem of observational studies of this type is the difficulty in removing self-selection bias from the data. The best approach toward removing selection bias is to perform longitudinal study, as here. With longitudinal study, one can assume that a difference in disability between groups at the study beginning might have resulted from self-selection bias in which the healthiest people were more likely to be exercisers. With longitudinal study, however, if the exercise activity were detrimental through a mechanism of repetitive trauma, then as exposure to this trauma increased the differences between the groups should narrow and the lines eventually cross with time as the deleterious effects of the physical activity eventually overcame the self-selection bias[13].

In addition to a longitudinal approach, we considered and tried to control for six specific types of self-selection bias. Firstly, we tried to identify covariates that were different at study outset between groups and found many. Generally, the differences were not unexpected, with fewer reports of arthritis, chronic disease, or smoking and with lower body mass in the runners. We adjusted statistically for all identified variables that were different between the groups, and the overall results were not changed by this adjustment. Second, a bias could be present in which runners reported their functional abilities as better than they were, whereas the less enthusiastic controls reported more accurately. We ruled out this possibility of bias by doing validation studies comparing the two groups. Third, we considered that there might have been differences in genetic characteristics, such as family history of arthritis or congenital abnormality. Here, however, there were few differences between the groups. Fourth, we considered that those persons who had begun to run at some intermediate point in their lives but who had experienced pain or excessive difficulty might then have stopped running, leaving the runner's club to inherit a self-selected group who are comfortable with continued running activity. To eliminate this effect, we created 'ever-runner' and 'never-runner' groups, so that those in either group who had ever run for more than one month would be included as 'runners', although they may have stopped running many years before. This approximates an 'intention to treat' analysis and might generally be considered conservative. Fifth, we considered that with time, selective dropouts might bias the results. But there was no difference when including or excluding data from individuals who dropped out during the study. Dropouts were similar in initial characteristics to completers, except for controls, for whom the most disabled initially tended to drop out. Had these persons not dropped out, presumably the results reported below would have been strengthened. Sixth, we compared radiographs of knees, lumbar spine, and hands in order to investigate differences in the rates of development of osteoarthritis. Radiographs between the groups showed nearly identical levels of progression, suggesting neither a detrimental nor a beneficial effect of exercise upon progression of osteoarthritis by radiograph. Hand radiographs, included as 'controls' to assess a possible greater tendency toward osteoarthritis in the community group, were also identical between the groups in the rate of progression. These radiographs were postulated not to be effected by the physical activity.

With this study design we attempted to identify study groups with such large differences in the independent variable of interest, vigorous physical activity, so as to greatly magnify, for good or ill, the effects of that variable. The typical runner's club member had run 16 869 miles during an average of 12.4 years before entering the study.

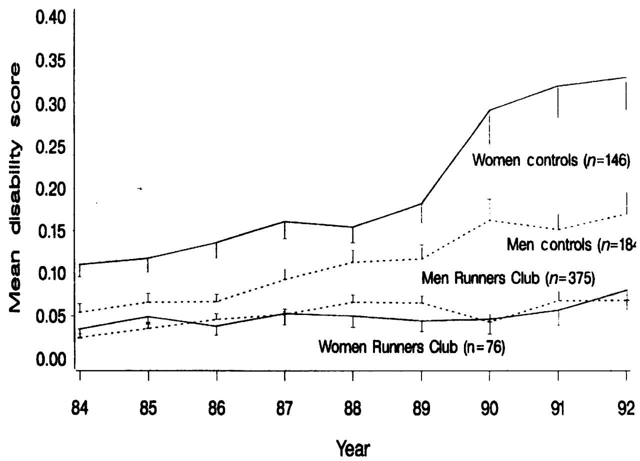

Figure 2 **Progression of disability over time by sex in 1992 participants runner's club compared with community controls. Disability progression is less in the runner's club members. Significant differences are noted for men and women, with effects more pronounced in women. Bars represent 95% confidence limits — women; - - - men**

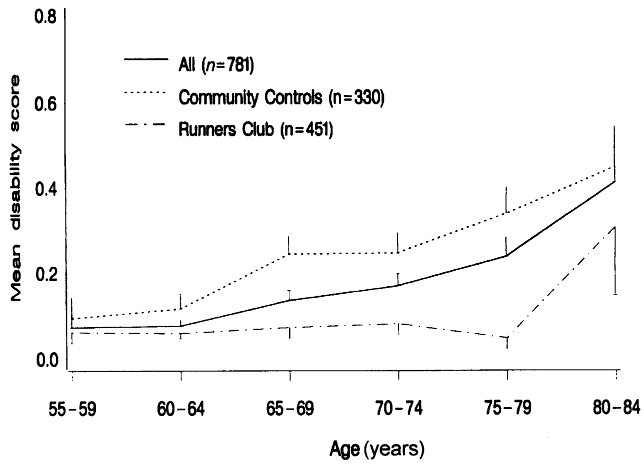

Figure 3 **Disability levels by age. The figure presents a cross-sectional analysis of disability in runner's club, community controls, and all participants in 1992. Differences are significant (*P*<0.005) at all ages except for the oldest and the youngest. Bars represent 95% confidence limits — All (*n*=781); - - - Community controls (*n*=330); and --- Runners Club (*n*=451)**

Throughout the study they continued with running and other vigorous exercise on an average of 280 min per week. Community controls only averaged six running minutes per week at study close, and their reported total of vigorous exercise was 123 min per week. At study close only 56% of the ever-runners and 63% of the runner's club members were still running after eight years. The frequency of other vigorous exercise, however, had increased substantially in the runner's club group. Hence, this study is best viewed as a study of vigorous physical exercise rather than solely a study of long-distance running. Dropouts from running very seldom reported injury as the reason for stopping, usually they had become bored with the activity, had moved to a less convenient place, or had other similar reasons for discontinuing running.

Figure 2 demonstrates progression of disability over 8 years in men and women from the runner's club and community control groups. Disability was measured by the Disability Index of the Health Assessment Questionnaire (HAQ), a widely used and thoroughly validated instrument[14–17]. Disability is estimated on a scale of 0–3. Both male and female runner's club participants maintain low disability levels throughout the study. In contrast, female controls have far greater degrees of disability compared with female runners ($P<0.001$), and male controls also have significantly greater disability than do the men in the runner's club ($P<0.05$). To control for baseline differences in disability, we repeated these analysis for those runners (325 men, 64 women) and community controls (130 men, 84 women) who did not report any disability at initial assessment in 1984. Again, runners maintained low disability levels for all eight years of follow-up but the controls showed increasing disability, so that differences became and remained statistically significant after five years ($P<0.05$).

We adjusted these differences for age, initial disability, educational level, smoking behaviour, body mass index, history of arthritis, and presence of comorbid disease. After adjustment, male runners increased disability at an average adjusted rate of 0.004 disability units per year, only one-third of the rate of the male community controls at (0.012). Women runners had adjusted rates of progression of disability of 0.009, again one-third of the adjusted rate for the community controls (0.027). Dividing all runners from the runner's club or community into three groups based on the amount of running plus initial assessment in 1984 (1–5 miles per week, 6–25, and 26+) showed a trend toward a 'dose-response' effect, with 1992 disability levels of 0.18, 0.07, and 0.06, respectively.

Figure 3 shows cross-sectional data for disability levels by age at the final data point in 1992. Disability increased progressively with age in all groups, with the slope of the disability curve increasing for the oldest participants. Overall, differences exist between community controls and runners at all ages, and these differences are maximal at ages 75–79 years. The curves in the runner's club, with essentially no progression of disability until very advanced years, are consistent with the occurrence of *Compression of Morbidity* in this group.

We studied mortality data in the runner's club and community control groups. Although only 38 deaths had occurred through 1992, the crude mortality rates were substantially different between the two groups, consistent with other studies. Overall, eight-year mortality was 1.5%

in the runner's club compared with 7% in the control group. Life table analyses showed statistically significant differences between the curves, after adjustment for age, sex, body mass, smoking behaviour, alcohol intake, comorbid conditions, educational level, and mean blood pressure. There were 30 deaths in the community controls and only 8 deaths in the runner's club. The conditional risk ratio for community controls compared with runner's club members in the Cox proportional hazards model is 4.27 (95% CI, 1.78 to 10.26) (P=0.002) after adjusting for covariates.

In ongoing studies, we are looking at additional health outcomes of global health assessment estimated by analog scale, musculoskeletal pain and stiffness, total direct medical costs, and indirect costs. In each of these, results after nine years favour the physically active group. There is a reduction in musculoskeletal pain of approximately 20% in the exercising group. There are reductions of approximately one-fourth in total medical costs and a reduction of about the same amount in global health self-assessment.

Thus, we found striking, persistent, increasing differences between runners and non-runners after eight and nine years of longitudinal study. We anticipate, from previous studies, that the overall differences in longevity between physically active and less active individuals will approximate two years[18,19]. In the context of the *Compression of Morbidity* scenario, the additional morbidity accumulated during those additional two years of life will constitute only a trivial percentage of the differences in lifetime morbidity between exercising and non-exercising groups.

CONCLUSIONS

This discussion has centred around our longitudinal studies of the effects of exercise upon quality of life variables. The mechanisms by which these outcome variables are affected are suggested by a large literature[10,11,20–23]. Thus, aerobic exercise is associated with decreased cardiovascular disease, lower smoking rates, lower body weight, lower cholesterol levels, higher HDL cholesterol levels, lower pulse and blood pressure, and many positive physiologic effects. The remaining area for dispute about the overall positivity of the health effects of exercise was the issue of repetitive physical trauma and the possibility of increased osteoarthritis and musculoskeletal disability in heavily exercising groups[24–27]. This does not occur. An extensive literature by a number of major investigators confirms and supports our findings[28–32]. These effects can be seen in population sample data such as the National Health and Nutrition Survey as well as in more selected populations[33]. Unusual for major medical and epidemiologic issues, there is no counter-literature which presents empiric data that regular, sustained, long-term physical activity is not associated with improved long-term health outcomes.

The *Compression of Morbidity* thesis predicts that 'favoured groups' in society should show increasingly 'rectangular' disability curves, with a longer period without disability and a steeper terminal decline. This prediction has now been confirmed in at least three areas. House *et al.*[8] have presented data showing much less disability in higher socio-economic classes as compared with lower, with the upper classes showing a more 'rectangular' disability curve. We confirmed these findings using education levels as the marker for a 'favoured' group in a study with the National Health and Nutrition Survey data. In this study, we documented approximately twice as much lifetime morbidity in those with lower educational levels as compared with those with higher, again, the curves were more 'rectangular' in those with college educations and higher[5].

The studies reported here use exercise levels to characterize the 'favoured' groups, and again, appear to support a more 'rectangular' disability curve with age, with much less overall life time disability in exercise groups compared with more sedentary comparison groups. Morbidity thus is already being compressed in some subclasses of the population. If increasing misery theorists, those postulating ever longer life and ever worsening health, were correct, these longer-surviving subgroups should have had more lifetime disability[4,34–36]. These data confirm the often ignored if obvious points; if you get a problem later in life, you will have it and its residua for a shorter period of time. Morbidity will have been compressed. There is now ample evidence that the compression of morbidity is possible. If it is already approximated by average lives in certain definable societal groups, then it should be able to be accomplished more broadly. Like the problems of chronic illness, the problems of senescence are multi-disciplinary, and include biologic, disease, life style, psychological, and social inputs. Public policies to improve health must be directed at each of these inputs, with the dominant goal of the prolongation of disability-free life expectancy. Exercise will be a cornerstone toward accomplishment of this goal.

Acknowledgments This work was supported in part by a grant from the National Institutes of Health to ARAMIS (AM2 1393) and a grant from the National Institute of Health to the Stanford Arthritis Center (2 P60 AR20610)

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(Accepted 8 March 1995)