Body mass index and mortality: the influence of physical activity and smoking

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ABSTRACT

MEYER, H. E., A. J. SØGAARD, A. TVERDAL, and R. M. SELMER. Body mass index and mortality: the influence of physical activity and smoking. *Med. Sci. Sports Exerc.*, Vol. 34, No. 7, pp. 1065–1070, 2002. **Purpose:** To study the association between body mass index (BMI) and mortality, and to evaluate the effect of physical activity during leisure time and smoking on this association in a general male population. **Methods:** During 1974–1978, all men aged 35–49 yr living in three Norwegian counties were invited to a cardiovascular screening, and 87.1% attended and had their weight and height measured. Men with recognized cardiovascular diseases, diabetes mellitus, or cancer at screening were excluded. The cohort ($N = 22,304$) was followed for an average of 16.3 yr with respect to total and cause-specific mortality. **Results:** During follow-up, 1909 men died. We found a J-shaped association between BMI and total mortality, and the form of association was similar for death from cardiovascular diseases. Although not statistically significant, a J-shaped association was also suggested in never-smokers. Irrespective of BMI level, ex- and never-smokers had lower mortality than current smokers. Obese smoking men had a relative risk of dying of 2.01 (95% CI: 1.29–3.11) compared with obese never-smokers, and a relative risk of 4.55 (95% CI: 3.34–6.20) compared with normal weight never-smokers (BMI 22–24.9 kg·m^{-2}). Within each category of physical activity during leisure time, obese men had a similar increased relative risk of death compared with normal-weight individuals. However, the U- to J-shaped association between BMI and mortality seemed to disappear by increasing level of physical activity, but this finding was not significant. **Conclusion:** This study suggests a J-shaped association between BMI and total mortality, also when stratified on smoking habits and physical activity. The suggested linear trend in the most physical active men needs to be reassessed. **Key Words:** COHORT STUDIES, OBESITY, PHYSICAL EXERCISE

The association between body weight and mortality has been assessed in many studies, and several reviews have been made (7,14,21,23,28,35). Most studies have found a U- to J-shaped association between body mass index (BMI) and mortality, but there are, however, still controversial questions connected to this issue (5,6,9,11,13,16,22,25,26,30–34). One important question still discussed in the literature is whether the reported link between increased mortality and overweight in large part results from the greater prevalence of sedentary lifestyle and low aerobic fitness in the high BMI strata (7). Some longitudinal studies indicate that the level of BMI is a minor risk factor if the level of physical activity is high (4). Thus, physical activity should be taken into account when studying the association between BMI and mortality. A number of studies have, however, not reported adjustments for or stratification on this variable (6,18,26,32), which could influence on the results. It has also been of great concern that the increased risk associated with leanness may be due to smoking and concurrent illness (33). The prevalence of smoking is greater among thin individuals, and the much higher mortality in smokers than in nonsmokers may thus confound the association between BMI and mortality. Weight loss before weight measurement may have occurred in individuals with concurrent diseases, leading to reverse causation if the underlying disease is ultimately fatal. In a few studies, such as The Harvard Alumni Study (15), The Nurses' Health Study (20), and The Seventh-day Adventist Study (17), which minimized confounding by smoking and underlying disease, a linear trend was suggested with the lowest mortality in the leanest subjects. However, other recent studies that also met the above-mentioned criteria do support the notion of a curvilinear relation in all or in some subgroups of the study population (5,6,22).

We studied prospectively the association between measured BMI and mortality in a large population-based cohort of middle-aged men attending a cardiovascular screening, excluding those with concurrent disease and early death, and adjusting for potential confounders. Specifically, we assessed the shape of the association between body mass index and mortality in strata of physical activity and smoking status.

METHODS

During the years 1974–1978, all men aged 35–49 yr ($N = 28,203$) residing in the three Norwegian counties of Finnmark, Sogn og Fjordane, and Oppland were invited to a cardiovascular screening carried out by the National Health Screening Service. Of all invited, 24,576 (87.1%) attended and had their weight and height measured. Details of the screening have been published (3). In brief, the participants completed a self-administered questionnaire at home, which they received together with a letter of invitation to the

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TABLE 1. Baseline characteristics in men attending a cardiovascular screening in three Norwegian counties during 1974–1978: a total of 22,304 men aged 35–49 yr without recognized cardiovascular diseases, diabetes mellitus, or cancer at screening.

	BMI Category (kg·m^{-2})					
	<18.5	18.5–21.9	22–24.9	25–26.9	27–29.9	≥30
No. of men	77	2844	8968	5419	3791	1205
Age at screening (yr)*	43.2	42.1	42.1	42.5	42.7	42.8
Systolic blood pressure (mm Hg)*	128	132	134	136	139	145
Serum total cholesterol (mmol/L)*	6.1	6.1	6.2	6.5	6.7	6.8
Serum triglycerides (mmol/L)†	1.49	1.43	1.58	1.82	2.10	2.42
Body height (cm)*	175.7	176.2	175.6	175.1	174.8	174.6
Serum glucose (mmol/L)†	6.00	5.90	5.86	5.89	5.91	6.00
Current smokers (%)	72.7	66.4	54.4	49.6	47.2	47.8
Never-smokers (%)	20.8	19.3	23.3	23.1	22.3	21.3
Sedentary during leisure time (%)	29.9	16.4	15.3	16.6	19.8	26.4
On sick leave (%)	7	4	3	3	3	3
Disability pension (%)	16	3	2	2	2	5
Married (%)	59.7	81.3	84.8	84.7	83.4	75.4
Education ≥ 11 yr (%)	14.7	17.8	19.9	16.0	12.7	10.5

* Mean values.

† Median values of triglycerides and mean values of glucose; adjustment for time since last meal did not change the results.

screening. The questionnaire included items on symptoms or history of cardiovascular disease or diabetes mellitus, sick leave, disability pension, and smoking. Subjects were asked to state the best fitting description for their usual leisure time activity in a question graded from 1 to 4 (sedentary: reading, watching television, or other sedentary activity; moderate: walking, bicycling, or moving around in other ways at least 4 h a week; intermediate: participating in recreational athletics, heavy garden work, etc., at least 4 h a week; and intensive: participating in hard training or athletic competitions, regularly and several times a week). At screening, a nurse checked the questionnaire, and blood pressure, height, and weight were measured following standardized procedures. A nonfasting blood sample was drawn for analyses of serum total cholesterol, triglycerides, and glucose. Data concerning education was collected from a compulsory nation-wide census conducted in 1970. Information concerning cancer was collected from The Cancer Registry of Norway, with all reported cancers in the Norwegian population from 1953.

The participants were followed with respect to total and cause-specific death (8th and 9th revision of the International Classification of Diseases) from the screening to December 31, 1992, by matching the data-file to the registry of death and emigration in Statistics Norway. The follow-up was complete as all Norwegians have a unique 11-digit personal identification code, by which all data linkage was done. When the screening was performed during 1974–1978, written informed consent was not asked for. However, the participants were informed that the collected data also would be used for research purposes. Approval has been given from the Data Inspectorate and the Norwegian Board of Health for using these data in mortality follow-up.

We excluded 2184 men who at the screening reported history of cardiovascular disease or diabetes mellitus or symptoms of angina pectoris or intermittent claudication. (The 188 men who reported that they had diabetes mellitus were excluded as many of these young men probably had Type I diabetes, which is not an intermediate step in the pathway between BMI and disease). Of the remaining group, 88 men with a diagnosis of any cancer in The Cancer Registry of Norway at baseline were also excluded, leaving 22,304 men for the present study. The number of observation years was calculated from screening to date of emigration ($N = 55$), date of death, or to December 31, 1992. Mean observation time was 16.3 yr. Based on weight and height measured at screening, the participants were divided into six BMI categories: <18.5 kg·m^{-2}, 18.5–21.9 kg·m^{-2}, 22–24.9 kg·m^{-2}, 25–26.9 kg·m^{-2}, 27–29.9 kg·m^{-2}, and ≥ 30 kg·m^{-2}, which correspond to the grouping suggested by WHO with the exception that we have subdivided 18.5–24.9 and 25–29.9 into two groups each (35). In analyses on cause-specific mortality, the lowest BMI group was omitted due to very few men with BMI <18.5 kg·m^{-2}.

Age-adjusted rates were calculated using the direct method with the distribution of person-years of the total study cohort in age groups <40, 40–44, and ≥ 45 as the standard population. Age-adjusted and multivariate-adjusted hazard rate ratios, in the text called relative risks (RR), were estimated by Cox proportional hazards regression. Adjustment was made for age, smoking (except for the subgroup analyses in never-smokers), physical activity during leisure time (except for analyses stratified on physical activity), body height, education, and marital status. Smoking status was categorized as never-, ex-, or current-smokers (< 15 cigarettes·d^{-1} or ≥ 15 cigarettes·d^{-1}). Marital status was entered with two dummy variables, one for unmarried and one for divorced/separated. In the subgroup of never-smokers, further exclusions were made for those who died or who received a cancer diagnosis within the first 5 yr of follow-up. The quadratic effect (curvilinear relation) of BMI was tested comparing models with and without a quadratic term of BMI entered as a continuous variable.

RESULTS

Mean BMI at screening was 25.0 kg·m^{-2}. Five percent had a BMI ≥ 30.0, whereas only 4 per 1000 had a BMI < 18.5. Systolic blood pressure, serum total cholesterol, and serum triglycerides increased by increasing BMI (Table 1). There was no clear association between serum glucose (nonfasting) and the BMI categories. The prevalence of current smoking at baseline decreased by increasing BMI up to 27.0

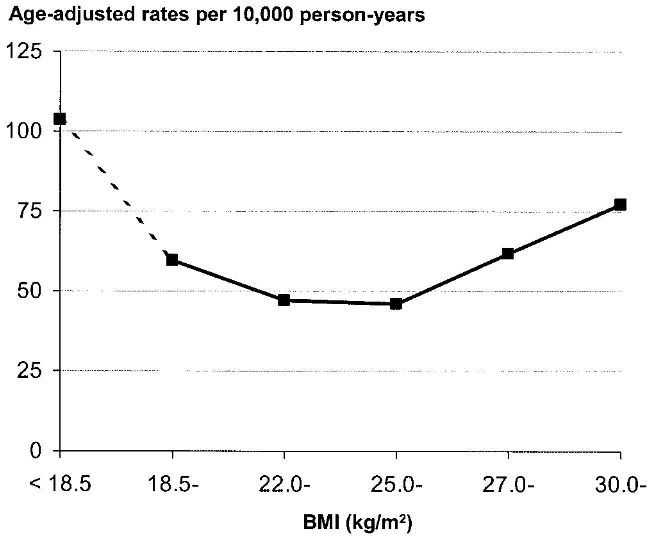

FIGURE 1—Age-adjusted rates of death from all causes according to BMI in men without recognized cardiovascular diseases, diabetes mellitus, or cancer at screening: a total of 22,304 men attending a cardiovascular screening in three Norwegian counties. The line between <18.5 and 18.5- is dotted to indicate little precision due to very few persons in the < 18.5 group

$kg \cdot m^{-2}$. Physical inactivity during leisure time showed a U-shaped pattern with the lowest prevalence in men with BMI 22.0–24.9 $kg \cdot m^{-2}$. The lowest prevalence of disability pension was found in those with BMI between 22.0 and 29.9. The proportion with more than 10 yr of education was highest in those with BMI between 22.0 and 24.9 and lowest in those with BMI $\geq$ 30.0.

During follow-up, 1909 of the 22,304 men died. In 36.2% of the cases, coronary heart disease was the underlying cause of death, in 9.3% other cardiovascular diseases, in 28.4% cancers, and in 26.1% other diseases. Mean age at death was 54.5 yr (range 36.5–67.8 yr). The lowest total mortality rates were found in men with BMI between 22 and 26.9 $kg \cdot m^{-2}$, and disregarding the very few men with BMI <18.5, there was a J-shaped association between BMI and total mortality (Fig. 1). Men with BMI $\geq$ 30.0 had more than 50% increased mortality compared with those with BMI between 22.0 and 24.9 $kg \cdot m^{-2}$ (Table 2). Men in the two lowest BMI groups combined had a multivariate adjusted RR of 1.16 (95% CI: 1.01–1.34) compared with men with BMI between 22 and 24.9 $kg \cdot m^{-2}$. After excluding those with BMI <18.5, there was still a quadratic effect of BMI (P = 0.0003). When stratifying on smoking status, a J-shaped form of the curve was suggested in never-smokers, ex-smokers, and current smokers (Fig. 2). In each category of BMI, the mortality among smokers was much higher compared with ex-smokers and never-smokers, and irrespective of BMI level, ex- and never-smokers had lower mortality than current smokers. Smoking obese men had RR of dying of 2.01 (95% CI: 1.29–3.11) compared with obese never-smokers, and a RR of 4.55 (95% CI: 3.34–6.20) compared with normal weight never-smokers (BMI 22–24.9 $kg \cdot m^{-2}$). An interaction term between smoking status and BMI was not significant (P = 0.39). As can be seen in Table 2, the number of persons left in the analysis was greatly reduced when excluding current and ex-smokers, and the J-shaped association did not reach statistical significance in never-smokers assessed by BMI entered as a quadratic term in the regression model (P = 0.07). Additional exclusion of men who died or had a diagnosis of cancer within the first 5 yr of follow-up also suggested a J-shaped association (Table 2), and so did additional exclusion of all who received disability pension or who were on sick leave (data not shown).

The association between BMI and mortality was long-term. Plots from Cox proportional hazards regression (cumulative hazard and log minus log survival curves) indicated that the relative risks between the BMI groups were constant throughout follow-up.

As can be seen in Table 3, obese men had a similar increased relative risk of death compared with normal weight individuals in all categories of physical activity during leisure time. The U- to J-shaped association between BMI and mortality seemed to disappear by increasing level of physical activity. There was a quadratic effect of BMI in

TABLE 2. All-cause mortality in men attending a cardiovascular screening in three Norwegian counties during 1974–1978: a total of 22,304 men aged 35–49 yr without recognized cardiovascular diseases, diabetes mellitus, or cancer at screening.

	BMI Category ($kg \cdot m^{-2}$)					
	<18.5	18.5–21.9	22–24.9	25–26.9	27–29.9	≥30
All men (N = 22,304)						
No. of deaths	13	272	673	412	387	152
Person years	1193	46 331	146 886	88 737	61 484	19 349
Age-adjusted relative risk† (95% CI)	2.24 (1.29–3.88)	1.27 (1.10–1.46)	1.00 (ref.)	0.98 (0.86–1.10)	1.31 (1.16–1.48)	1.64 (1.37–1.95)
Multivariate-adjusted relative risk† (95% CI)	1.88 (1.06–3.34)	1.14 (0.99–1.32)	1.00 (ref.)	1.00 (0.88–1.13)	1.33 (1.17–1.51)	1.60 (1.33–1.91)
Never smoking men (N=5260)						
No. of deaths	2	24	69	62	52	25
Person years	269	9392	35 751	21 528	14 885	4 661
Age-adjusted relative risk† (95% CI)	3.63 (0.89–14.8)	1.34 (0.84–2.14)	1.00 (ref.)	1.42 (1.01–2.00)	1.65 (1.15–2.37)	2.49 (1.58–3.95)
Multivariate-adjusted relative risk† (95% CI)	3.37 (0.82–13.9)	1.30 (0.82–2.07)	1.00 (ref.)	1.35 (0.96–1.90)	1.53 (1.06–2.20)	2.20 (1.38–3.50)
Never smoking men, excluding deaths and cancer during the first 5 yr of follow-up (N = 5209)						
No. of deaths	2	23	55	55	41	22
Person years	269	9373	35 636	21 479	14 767	4638
Age-adjusted relative risk† (95% CI)	4.53 (1.11–18.6)	1.62 (0.99–2.63)	1.00 (ref.)	1.58 (1.09–2.03)	1.64 (1.10–2.47)	2.78 (1.69–4.57)
Multivariate-adjusted relative risk† (95% CI)	4.51 (1.09–18.6)	1.60 (0.98–2.61)	1.00 (ref.)	1.49 (1.03–2.17)	1.51 (1.00–2.27)	2.47 (1.49–4.09)

† Age-adjusted and multivariate-adjusted (age, smoking (where applicable), physical activity during leisure time, body height, education, and marital status) relative risk with 95% confidence interval (95% CI) by Cox proportional hazards regression.

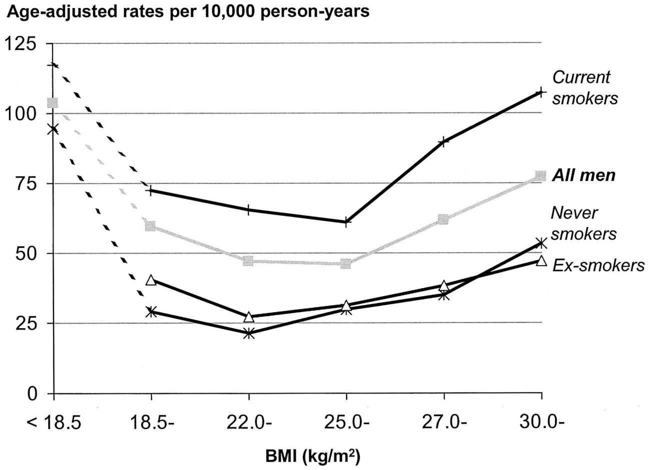

FIGURE 2—Age-adjusted rates of death from all causes according to BMI and smoking status in men without recognized cardiovascular diseases, diabetes mellitus, or cancer at screening: men attending a cardiovascular screening in three Norwegian counties during 1974–1978. The lines between <18.5 and 18.5- are dotted to indicate little precision due to very few persons in the < 18.5 groups

the sedentary ($P = 0.0016$) and in those reporting moderate physical activity ($P = 0.0030$) but not in the intermediate/intensive physical active ($P = 0.66$). However, an interaction term between physical activity and BMI was not statistical significant ($P = 0.15$). Additional analyses showed that also compared with sedentary men with BMI between 22 and 24.9 kg·m^{-2}, increased risk was seen in obese men reporting moderate physical activity (multivariate adjusted RR 1.66, 95% CI: 1.25–2.20) and in obese men reporting intermediate and intensive physical activity (multivariate adjusted RR 1.66, 95% CI: 1.06–2.61).

A J-shaped association was suggested for cardiovascular diseases and for causes other than cardiovascular diseases and cancer but was not present for cancer deaths (Fig. 3). Concerning cardiovascular diseases, a statistical significant quadratic effect of BMI was present in all men ($P = 0.008$) but not in the group of never-smokers ($P = 0.12$).

DISCUSSION

In this study, we found a J-shaped association between BMI and total mortality, and the form of association was similar for death from cardiovascular diseases. In all categories of physical activity during leisure time, obese men had a similar increased mortality compared with normal-weight individuals in the same category of physical activity. However, the data suggest that the J-shaped association found in the sedentary group was changed to a linear association in the most physical active ones. In all strata of smoking, we found a J-shaped association between BMI and total mortality although the addition of a quadratic term did not significantly improve the fit in never-smokers.

Whereas the majority of the recent studies assessing the BMI mortality relation are performed in selected groups of the population (15,17,20), the present study comprised the vast majority of all men in a defined age group. Many studies also rely on self-reported weight and height (5,15,17,20). We used weight and height measured in a standardized way at screening. Although self-reported weight and height is fairly reliable, obese individuals tend to underestimate their weight, resulting in an underestimated BMI (5). At the time of screening, concurrent diseases might have influenced the individual's weight. Thus, we excluded men with recognized cardiovascular disease or cancer at baseline. However, other chronic diseases were not recorded. As can be seen in Table 1, sick leave and disability pension was more prevalent in thin individuals, but exclusion of all men on sick leave or disability pension did not weaken the association between underweight and mortality. In addition, excluding deaths and cancer during the first 5 yr of follow-up did not change the association. It would thus be surprising if any concurrent diseases not accounted for would change the J-shaped association completely. This is in line with a recent Danish study where a U- to J-shaped association between BMI and all cause mortality was indicated also after exclusion of subjects with a broad variety of chronic diseases at baseline and during the first 4 yr of follow-up (identified by linkage to the Danish National Patient Register) (22).

The excess mortality related to obesity may be explained by an increasing prevalence of diabetes mellitus and risk factors like hypertension and hypercholesterolemia by increasing BMI (33). The excess risk associated with underweight, reported in the present and the majority of other studies (5,6,9,11,16,22,25,26,30–32), is more difficult to explain except for the proposed effects of preexisting diseases and smoking. It could be speculated that in the group

TABLE 3. Relative risk of death by BMI at different levels of physical activity during leisure time: men aged 35–49 yr without recognized cardiovascular diseases, diabetes mellitus, or cancer at screening.

	Sedentary (N = 3830)			Moderate Physical Activity (N = 11,907)			Intermediate and Intensive Physical Activity (N = 6557)		
BMI (kg·m^{-2})	Relative Risk*	Relative Risk†	95% CI‡	Relative Risk*	Relative Risk†	95% CI	Relative Risk*	Relative Risk†	95% CI
< 18.5	4.71	4.98	2.30–10.8	1.25	1.13	0.42–3.04	0.96	0.75	0.10–5.36
18.5–21.9	1.46	1.35	0.97–1.87	1.27	1.17	0.97–1.41	1.08	0.93	0.67–1.28
22–24.9	1.00	1.00	(ref)	1.00	1.00	(ref)	1.00	1.00	(ref)
25–26.9	0.91	0.98	0.72–1.32	0.97	1.01	0.86–1.20	1.03	1.01	0.79–1.29
27–29.9	1.57	1.68	1.27–2.22	1.17	1.24	1.04–1.48	1.34	1.29	0.98–1.68
≥ 30	1.58	1.75	1.22–2.51	1.59	1.57	1.23–1.99	1.62	1.62	1.04–2.51

* Adjusted for age.
† Adjusted for age, smoking, body height, education, and marital status.
‡ CI, confidence interval.

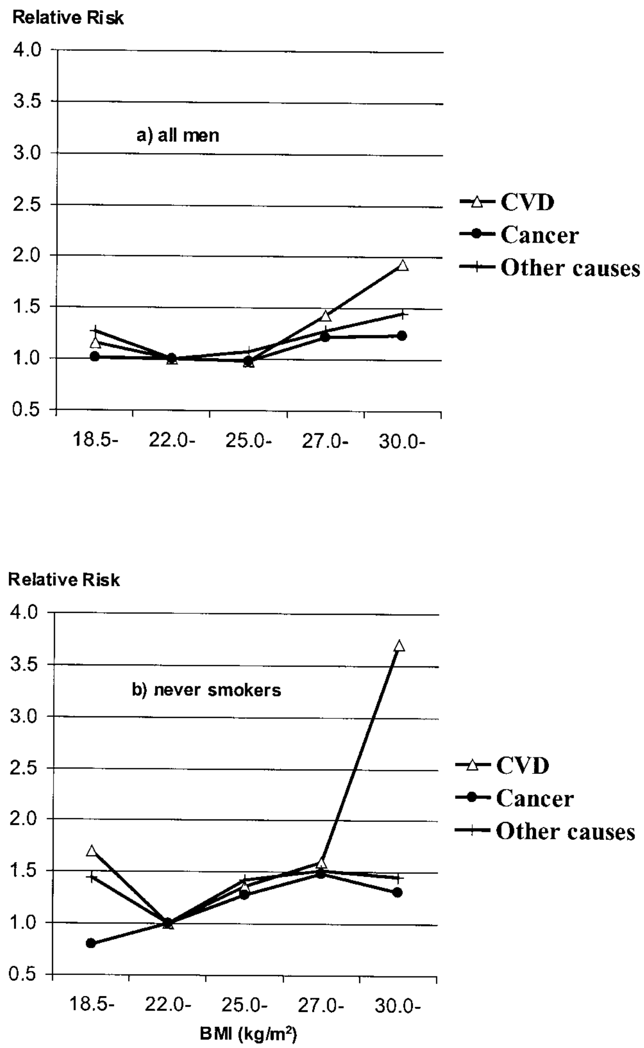

FIGURE 3—Relative risk of death from cardiovascular diseases (CVD), cancer, and other causes by BMI in men without recognized cardiovascular diseases, diabetes mellitus, or cancer at screening: men attending a cardiovascular screening in three Norwegian counties during 1974–1978, adjusted for age, smoking (where applicable), physical activity during leisure time, body height, education and marital status; a) all men, b) never-smokers.

with low BMI there is a higher prevalence of people who have a lower than recommended intake of beneficial food constituents, like antioxidants, mono- and poly-unsaturated fatty acids, etc. This could well differ between different study populations, for example, in selected groups with great awareness of health issues compared with a general population such as ours. It is interesting to note that studies that have reported a linear association between BMI and mortality are performed in health-conscious groups, like American nurses, Adventists, etc. (17,20). It has also been hypothesized that the U- to J-shaped association between BMI and mortality is the result of a linear association between fat mass and mortality, and an inverse linear association between fat free mass and mortality, giving a curvilinear relation in combination (2).

We did not adjust for cholesterol and blood pressure in the main analyses because these may be regarded as intermediate steps in the pathway between BMI and disease. However, additional adjustment for serum total cholesterol and systolic blood pressure reduced, but did not eliminate, the excess risk associated with overweight. This applies both for total death and deaths from cardiovascular diseases (data not shown).

The question we used about physical activity in leisure time was constructed in Sweden 40 yr ago (27). The answer correlates to physical fitness (19) and is a statistically significant predictor of high-density lipoprotein cholesterol (10), breast cancer (29), fracture in weight-bearing skeleton (12), and Type II diabetes (Bjarne K. Jacobsen, University of Tromsø, personal communication). In an evaluation of physical activity assessment methods in breast cancer epidemiology applying the criteria put forth by Powell et al. (24), this four-level ranking question got the score of 8 of a maximum of 10 (1). If comparing with other studies, it should be remembered that even the moderate physical activity level might imply considerable physical activity and that in our study population nearly one third reported a higher level than this (intermediate or intensive physical activity). We found that, even among men who reported a high level of physical activity, obesity was associated with increased total mortality. This is somewhat in contrast to the conclusion of a recent review suggesting that persons with the highest fitness levels have the lowest death rates, regardless of BMI (4). Our data also suggest a J-shaped association between BMI and mortality in sedentary and moderate physical active men, but interestingly there seemed to be a linear association between BMI and mortality in those with the highest level of physical activity. This might be in concert with the described linear associations in subgroups of health-conscious people discussed above. However, as the interaction between physical activity and BMI did not reach statistical significance in our study, this finding needs to be reassessed, not least in data with more sophisticated measures of physical activity.

Our finding that ex- and never-smokers had lower mortality than current smokers, irrespective of BMI level, is in agreement with other studies (8,25,31), stressing the point that smoking is a greater health hazard than obesity and that the absolute risk associated with obesity increases markedly if it is combined with smoking.

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