

# High Body Mass Index Does Not Predict Mortality in Older People: Analysis of the Longitudinal Study of Aging

David C. Grabowski, PhD,\* and John E. Ellis, MD†

**OBJECTIVE:** To determine the excess mortality associated with obesity (defined by body mass index (BMI)) in older people, with and without adjustment for other risk factors associated with mortality and for demographic factors.

**DESIGN:** Retrospective cohort analysis of the Longitudinal Study of Aging (LSOA).

**SETTING:** Nationally representative sample of community-dwelling older people.

**PARTICIPANTS:** Seven thousand five hundred and twenty-seven participants age 70 and older in 1984.

**MEASUREMENTS:** We used Cox regression to calculate proportional hazards ratios for mortality over 96 months. We tested the hypothesis that increased BMI (top 15%) increased mortality rates in older people.

**RESULTS:** Death occurred in 38% of the cohort: 54% of the thin (lowest 10% of the population, BMI <19.4 kg/m<sup>2</sup>), 33% of the obese (highest 15%, BMI >28.5 kg/m<sup>2</sup>), and 37% of the remaining participants (normal) died. Adjustment for demographic factors, health services utilization, and functional status still demonstrated reduced mortality in obese older people (hazard ratio 0.86, 95% confidence interval (CI) = 0.77–0.97) compared with normal. After adjustment, thin older people remained more likely to die (hazard ratio 1.46, 95% CI = 1.30–1.64) than normal older people. Sensitivity analyses for income, mortality during the first two years of follow-up, and medical comorbidities did not substantively alter the conclusions.

**CONCLUSION:** Obesity may be protective compared with thinness or normal weight in older community-dwelling Americans. *J Am Geriatr Soc* 49:968–979, 2001.

**Key words:** body mass index (BMI); obesity; mortality; older individuals; Cox proportional hazard regression

Recent studies document the increased prevalence of obesity in Americans,<sup>1</sup> with many studies showing an association between obesity and increased mortality. Most of these studies documenting a relationship between obesity and increased mortality have been performed in populations between adolescence and middle age. However, as people age they gain fat mass, lose muscle mass, and gain weight.<sup>2,3</sup> Studies of mortality rates in older populations have conflicting results: some suggest that mortality is increased; others, the opposite.<sup>4</sup> Importantly, obesity is not randomly distributed throughout society; many studies have shown relationships between race and socioeconomic status and the prevalence of obesity.<sup>5,6</sup> Among the studies that suggest lower mortality rates among obese older people,<sup>7</sup> some have been criticized for inappropriately controlling for the medical consequences of obesity. Obesity is associated with hypertension; diabetes mellitus, hyperinsulinemia, and insulin resistance;<sup>8</sup> hyperlipidemia;<sup>9</sup> coronary artery disease; osteoarthritis; colon cancer;<sup>10</sup> and other neoplasms. Obesity is associated with increases in many medical conditions, including diabetes mellitus and cholelithiasis and may be associated with approximately 300,000 excess deaths annually in the United States.<sup>11</sup> Other studies have suggested that older people at the very low end of the body weight scale (thin)<sup>12</sup> have increased mortality due to acute, preterminal disease<sup>13</sup> (often neoplastic), suggesting a U- or a reversed J-shaped relationship between body mass index (BMI) and mortality.

Controversy has persisted as to whether the relationship of obesity to increased mortality at younger ages persists into later life. We hypothesized that older, community-dwelling individuals who are very obese would have greater mortality than normal or thin individuals. We used data from the Longitudinal Study of Aging (LSOA) to test this hypothesis.

## METHODS

### Data Source

The LSOA is a national longitudinal study of older Americans concerning the health, social functioning, and living arrangements of its participants.<sup>14</sup> The initial survey in 1984 included 7,527 noninstitutionalized respondents age 70 and older. The baseline interview was conducted in individuals' homes, with family members interviewed when

From the \*Department of Health Care Organization and Policy, The University of Alabama at Birmingham, Birmingham, Alabama; and †Department of Anesthesia and Critical Care and Robert Wood Johnson Clinical Scholars Program, The University of Chicago, Chicago, Illinois.

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Address reprint requests to David C. Grabowski, PhD, RPHB 330, 1530 3rd Ave South, Birmingham, AL 35294-0022.

participants were unable to answer the survey. Whereas there were a series of follow-up interviews in 1986, 1988, and 1990, our analysis only used information obtained from the baseline interview in 1984.

The two key variables of interest in this analysis are mortality and obesity. Mortality information was obtained from the linked National Death Index (NDI), a computerized file of all death certificates in the United States. Thus, exact survival (to the nearest month) could be measured for the LSOA population for 96 months (8 years) from the beginning of the survey in January 1984 until December 1991.

We calculated BMI ( $\text{kg}/\text{m}^2$ ), a proxy for obesity, for the 98.3% of respondents in the LSOA for whom self-reported weights and heights were available. For the majority of our analyses, individuals were placed into one of three groups, depending on their BMI. Those individuals within the lowest 10% of the distribution were classified as thin ( $\text{BMI} < 19.4 \text{ kg}/\text{m}^2$ ). Individuals falling within the highest 15% of the distribution were classified as obese ( $\text{BMI} > 28.49 \text{ kg}/\text{m}^2$ ). (Note that we used a slightly higher cutoff value for obese individuals, 15% as opposed to 10%, to ensure that we were adequately representing this subgroup.) The remaining individuals were categorized as normal with regard to weight. BMI was only calculated at entry because subsequent follow-up interviews did not obtain height or weight information.

In an effort to obtain a more-precise measure of the effect of BMI on mortality, we also employed a second classification scheme that divided the cohort into seven BMI groups to calculate mortality rates for subjects outside of the extremes of the population. Following a recent study by Stevens et al.,<sup>15</sup> we divided these groups as follows: Group 1 ( $\text{BMI} < 19.0$ ), Group 2 ( $\text{BMI} 19.0\text{--}21.9$ ), Group 3 ( $\text{BMI} 22.0\text{--}24.9$ ), Group 4 ( $\text{BMI} 25.0\text{--}26.9$ ), Group 5 ( $\text{BMI} 27.0\text{--}28.9$ ), Group 6 ( $\text{BMI} 29.0\text{--}31.9$ ), Group 7 ( $\text{BMI} > 32.0$ ).

### Risk Factors

We explored the excess mortality associated with BMI in a range of models that take account of other risk factors. The LSOA provides a large set of potential variables because 1,991 questions were posed to respondents. The variables analyzed are listed in Table 1. These variables were used to construct multivariable models of mortality. In constructing this model, we were guided by the behavioral model of health services utilization first introduced by Anderson in 1968<sup>16</sup> and refined by Wolinsky<sup>17</sup> (for the special case of older adults) in our selection of variables for Model 1.

Under the behavioral model, the use of health services and subsequent mortality are conceptualized as a function of the “predisposing,” “enabling,” and “need” characteristics of the individual. The “predisposing” characteristics include demographics, social structure, and health beliefs. Demographics include standard measures such as age, sex, race, and region of the country. Social structures are measured by factors such as education or ethnicity. The “enabling” component comprises factors that help make health services available for consumption by an individual; we included only those resources available at the individual or familial level such as income, insurance, and the presence of a regular source of health care.

The final component of the behavioral model is that of “need,” which measures the health and general well-being of an individual. Objective dimensions included the need for a proxy to answer the survey, and the actual amount of health care (chronic and acute) utilized. Chronic care was measured by determining whether the individual ever utilized a nursing home facility. Acute care was measured by three variables: the number of short-stay hospital episodes, hospital bed days, and visits to the doctor in the year preceding the baseline survey. We did not include the presence of specific diseases, which are addressed in Models 4 and 5. Because income was recorded for only 82.8% of the initial LSOA sample, we elected not to include the poverty indicator in Model 1. Model 2 adds the poverty indicator to the baseline model (Model 1) described above.

Model 3 is a sensitivity analysis accounting for early mortality. It is a subset of Model 1, which excludes those individuals ( $N = 579$ ) who died in the first 24 months of the LSOA. The rationale was that these presumably sick and dying individuals might bias our results on mortality. By excluding the dying, we hoped for a more accurate picture of the effect of weight on mortality.

Model 4 adds self-reported medical conditions (including cancer, diabetes mellitus, and cardiac disease) to the baseline model (Model 1). This was not done in the baseline model because controlling for the medical consequences of obesity may reduce obesity’s apparent effects on mortality and resource utilization. Model 5, alternatively, seeks to analyze the incremental risk of obesity in the minority of respondents who reported no serious medical comorbidities at entry.

### Statistical Analyses

Statistical analyses were performed with Stata software.<sup>18</sup> We used Cox proportional-hazards analysis to assess associations between BMI and mortality. Statistical significance was assessed at the  $P = .05$  level.

The LSOA is designed to produce national estimates of the people age 70 and older living in the community in 1984. However, we relied on the unweighted data because it has been empirically shown that the complex schemes used to accommodate the disproportionately stratified multistage cluster sampling design of the LSOA have little effect on variance estimation in multivariate models (especially when age and race are included as covariates).<sup>19</sup>

## RESULTS

Descriptive statistics for persons entered into the LSOA are summarized in Table 1. The mean age at initial survey was 76.8 years; 62.0% of participants were female and 91.4% were Caucasian. Over one-third lived alone and slightly fewer than half were married. Seventeen percent were college graduates, 72% had private health insurance, and 82% were above the poverty line (\$4,979 for a single person age 65 or older in 1984). Of the 7,459 individuals who provided information to match to the National Death Index, 2,870 (38.5%) died between January 1984 and December 1991.

Figure 1 presents the distribution of BMI values by gender. Men had slightly, but statistically significantly,

Table 1. Descriptive Statistics for Variables Utilized from the LSOA

Variable	Definition	n	Unweighted Mean $\pm$ SD or Prevalence (%)
Mortality			
Time	Number of months survived from start of survey (max = 96)	7,459	78.4 $\pm$ 27.24
Died	Individual died during the 96 months of follow-up	7,459	38.5%
Body Mass Variables			
Thin	Individual defined as thin lowest 10% of body mass index (BMI) distribution)	7,397	9.9%
Normal weight	Individual not classified as thin or obese	7,397	75.0%
Obese	Individual defined as obese (highest 15% of BMI distribution)	7,397	15.0%
BMI	Body mass index = kg(weight)/m <sup>2</sup> (height)	7,397	24.4 $\pm$ 4.33
Predisposing variables			
Age	Age in years in 1984	7,527	76.8 $\pm$ 5.59
Old-old	Over age 85 in 1984	7,527	8.8%
Sex	Female	7,527	62.0%
Black	Individual's race is coded as black	7,527	7.4%
Other	Individual's race is coded as other	7,527	1.2%
White	Individual's race is coded as white	7,527	91.4%
Hispanic	Individual's ethnicity is coded as Hispanic	7,500	2.9%
Alone	Lives alone	7,527	36.5%
No hs graduate	Not a high school graduate	7,527	56.2%
Hs graduate	At least high school graduate, but not college graduate	7,527	24.8%
College graduate	College graduate	7,527	17.4%
Northeast	Individual lives in Northeast region of the country	7,527	23.1%
North central	Individual lives in North Central region of the country	7,527	25.8%
South	Individual lives in South region of the country	7,527	33.6%
West	Individual lives in West region of the country	7,527	17.6%
Enabling characteristics			
Private health insurance	Individual has private health insurance	7,467	71.9%
Medicaid	Individual has Medicaid card	7,510	6.1%
Married	Individual is married (as opposed to divorced, separated, never married, or widowed)	7,506	48.0%
Urban	10-point 1980 county adjacency code, ranging from 0 = thinly populated not adjacent to 9 = core SMSA county	7,527	7.4 $\pm$ 2.54
Poverty	Individual has income level below poverty threshold	6,231	17.7%
Stable	Number of years at same residential address	7,467	21.1 $\pm$ 16.41
Need characteristics			
Self rated health	Self rated health as excellent, very good or good (as opposed to fair or poor)	7,485	66.7%
Functional limitations	Number of functional limitations in 1984	7,511	2.5 $\pm$ 2.69
Proxy needed	Individual required a proxy to complete the survey	7,527	9.9%
Cancer	Individual had history of cancer	7,459	12.3%
Diabetes mellitus	Individual had history of diabetes mellitus	7,459	9.9%
Heart problems	Individual had history of heart problems	7,370	58.8%
Health services utilization			
Dr visits	Number of doctor visits in 1984	7,493	5.8 $\pm$ 13.70
Bed days	Number of hospital bed days in 1984	7,437	14.1 $\pm$ 51.59
Hospital episodes	Number of short-stay hospital episodes in 1984	7,524	0.3 $\pm$ 0.70
Nursing home use	Individual utilized a nursing home prior to 1984	7,527	11.0%

SD = standard deviation; SMSA = Standard Metropolitan Statistical Area.

higher BMI than did women (24.56  $\pm$  3.62 standard deviation (SD) vs 24.30  $\pm$  4.72 SD;  $P = .0127$ ). The values for women appeared less normally distributed, with a broader tail at high BMI values. In Figure 2, we calculated unad-

justed Kaplan Meier survival curves across the thin, normal, and obese weight categories. From these curves, mortality is highest in the thin group and lowest in the obese group.

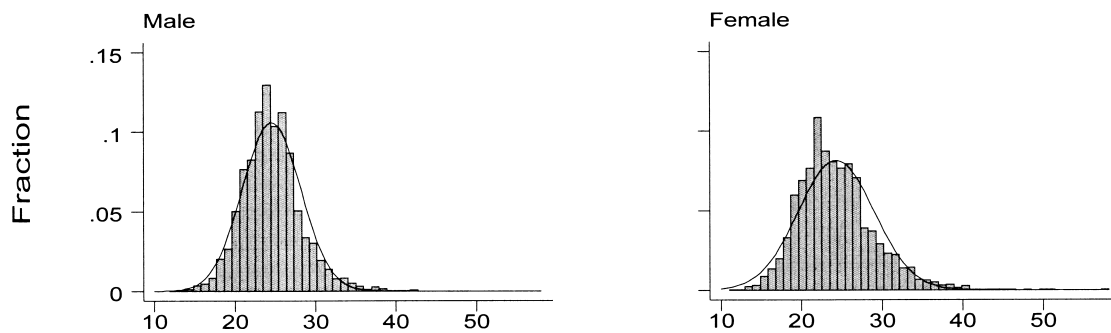


Figure 1. Body mass index distribution by gender.

In Table 2, estimates of survival and demographic characteristics are provided for the three separate weight categories, which showed highly significant differences across these categories ( $F = 52.34$ ,  $P < .001$ ). Once again, the thin group had the highest mortality (53.9%) of the three weight categories, whereas the obese group had the lowest (33.5%).

The Cox proportional hazards results are displayed in Table 3. In Model 1 (our baseline model), the obesity group (highest 15% BMI) had a hazards ratio for mortality of 0.86 (95% CI = 0.77–0.97). For the thin group (lowest 10% BMI), the hazards ratio was 1.46 (95% CI = 1.30–1.64), compared with the normal group (10–85% BMI). Additional factors were significantly related to increased mortality in this baseline model ( $P < .05$ , see Table 4): age, male gender, number of functional limitations, number of previous hospitalizations, not having private health insurance, not being married, number of previous doctor visits, needing a proxy to complete the survey, a lower self-health rating, and residence in the north central or western regions of the country. Eliminating acute and chronic care utilization variables did not alter these results, whereas incorporating the poverty indicator (in Model 2) strengthened these relationships between increased BMI and decreased mortality.

Model 3, a sensitivity analysis that eliminated the first 2 years of mortality, reduced the number of deaths avail-

able for modeling to 2,291. This resulted in significantly lower mortality in the obese group at 83 months of follow-up, but by 96 months, mortality in the obese was no longer significantly different (hazard ratio 0.93, 95% CI 0.82–1.06,  $P = .27$ ).

When we added self-reported medical comorbidities (diabetes mellitus, chronic heart problems, or cancer in Model 4), the results were only marginally different from Models 1 or 2. In the obese group the hazard ratio = 0.83 (95% CI = 0.74–0.94,  $P = .002$ ) and in the thin group the hazard ratio = 1.584 (95% CI = 1.41–1.78),  $P < .001$ ).

In Model 5 (those healthy at baseline), there were fewer obese people with comorbidities than in the other models (only 25.7% reported themselves free from major medical problems (cancer, heart disease, or diabetes mellitus) compared with 37.4% thin or 35.5% normal ( $F = 21.52$ ,  $P < .0001$ )). Obesity was strongly associated with lower mortality (hazard ratio = 0.67, 95% CI = 0.51–0.88), whereas the thin group had higher mortality (hazard ratio = 1.40, 95% CI = 1.13–1.74). In a further sensitivity analysis not shown in Table 3, we also limited the analysis to only those individuals who reported major medical problems (cancer, heart disease, or diabetes mellitus) at baseline and found obesity to be protective for these individuals, although the result was not statistically significant. This result held whether we analyzed the medical problems individually or collectively.

We also examined whether our result held with the inclusion of additional BMI categories. In Figures 3A and 3B, we present the hazard ratios of mortality across the seven BMI groups used in the Stevens et al. study separately for men and women after adjustment for the variables in Model 1. For both men and women, the pattern found in the model above holds with this different categorization of the predictor variable.

In an additional sensitivity analysis (not presented here because of space considerations) we included an interaction of the oldest old ( $>85$ ) with the thin and obese groups. The hazard ratio was 0.70 ( $P = .007$ ) for the thin oldest old, and 1.20 ( $P = .31$ ) for the obese oldest old. In another alternative model, we considered the potential for convexity in the relationship between BMI and mortality, and included continuous variables measuring BMI directly and a quadratic term ( $BMI^2$ ), rather than the three weight categories. This model did not change our results substantively. In alternative specifications of the model, we in-

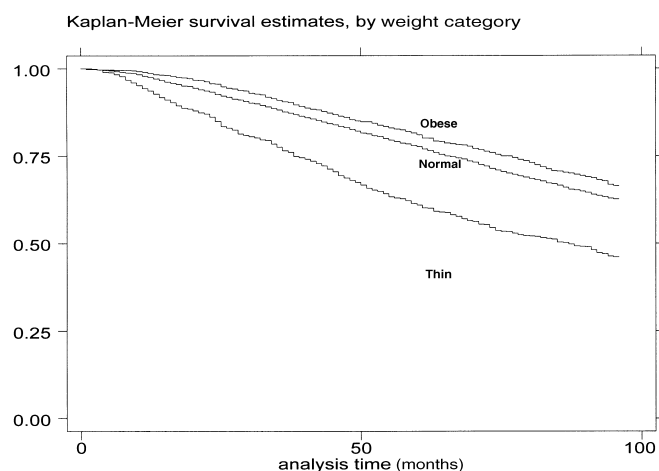


Figure 2. Kaplan Meier survival estimates, by weight category.

**Table 2. Estimates of Characteristics of Older People Across Weight Categories**

	Total	Thin	Normal Weight	Obese
Months survived or until end of study (96 months)	78.4	67.9	79.2	82.1
Died (%)	38.5	53.9	37.4	33.5
BMI (kg (weight)/m <sup>2</sup> (height))	24.4	17.8	23.8	31.8
Age (years)	76.8	79.2	76.7	75.8
Sex (% female)	62.0	78.0	58.2	68.8
Black (%)	7.4	5.8	6.3	13.1
White (%)	91.4	93.1	92.6	86.2
Other race (%)	1.2	1.1	1.2	0.7
Hispanic (%)	2.9	2.0	2.6	4.3
Did not graduate high school (%)	56.2	50.9	54.5	67.3
Private health insurance (%)	71.9	67.3	73.8	68.2
Married (%)	48.0	37.5	50.3	44.9
Number of functional limitations at baseline	2.5	3.3	2.2	3.1
Needed a proxy to complete the survey (%)	9.9	17.8	9.2	7.6
Cancer, self-reported (%)	12.3	15.8	12.3	10.7
Diabetes mellitus, self-reported (%)	9.9	4.3	9.3	16.8
Heart disease, self-reported (%)	58.8	55.3	57.2	67.4

*Note:* The total sample is 7,527 people although there are missing observations for certain variables. Analysis of variance revealed that comparisons among the thin and normal groups were all statistically significantly different, except for black, white, other race, Hispanic, no high school graduation, and heart disease. In addition, comparisons between the obese and normal groups were all statistically different, except for other race, proxy needed, and cancer. BMI = body mass index.

cluded other interaction terms, but the results did not differ materially from those presented.

## DISCUSSION

In contrast to many studies showing increased mortality in younger obese populations, our analysis of the LSOA suggests a decreased mortality in obese older people. Lower mortality in obese older people persisted despite controlling for many different confounders. These results seem robust, given the multiplicity of conceptual models used in analysis (Table 3). Additionally, whether examining the extremes (by BMI) of the population, or in a more continuous manner (Steven et al.'s seven groups, Figure 3), obesity in older people is associated with decreased mortality.

We believe the construction of the LSOA database supports the robustness of our results. The matched records from the National Death Index provide 96 months of mortality information (longer than in many studies of the elderly). Importantly, there was almost no loss to follow-up. Data from less than 1% of the respondents ( $n = 68$ ) could not be matched with the National Death Index and thus had to be eliminated from our analysis. The similarity of results after adjustment for potential confounders and sensitivity analyses also strengthened the conclusions.

Although obesity had a protective effect across all the different model specifications, we did not obtain a statistically significant effect of obesity on mortality for Model 3, in which we eliminated those individuals who died during the first 2 years of the LSOA. By eliminating those sick and dying individuals, we had hoped to obtain a truer picture of the effect of obesity on mortality. With this sensitivity analysis, we must acknowledge that the relationship between weight and mortality may be confounded by weight loss among individuals nearing death. Future stud-

ies should perform similar analyses to measure the robustness of this result.

The only other study we have found that utilizes the LSOA to examine the relationship between BMI and mortality is Allison et al.<sup>20</sup> In comparison with this current study, these authors employ a more limited set of covariates within their statistical models and perform alternative sensitivity analyses. In contrast to our study, they conclude that there is a U-shaped relationship between BMI and mortality in older people. We feel the use of a richer set of covariates generated by the behavioral model, the most widely used framework for studying health services utilization, and the sensitivity analysis eliminating early mortality (Model 3) are two examples of important features that differentiate our study from this previous analysis and help to account for their alternative findings.

The biggest limitation of this study is the inability to control for cigarette smoking. Cigarette smoking is a confounder because it is associated with increased mortality and lower body weight. Unfortunately, the LSOA did not ask respondents questions about their smoking histories. Some community-based estimates of the prevalence of cigarette smoking in this age group range from 5% to 12%.<sup>21-23</sup> In one study of older people residing in the community (median age = 73 at initial survey), all-cause mortality rates were higher among current smokers; compared with never smokers, the age-adjusted relative risks (and 95% CI) were 1.67 (1.46-1.92) for women and 1.95 (1.66-2.30) for men.<sup>24</sup> Investigators have debated whether the confounding and/or modifying effects of smoking should be addressed statistically or by using nonsmoking cohorts. Because smokers vary in the number of cigarettes and the depth of inhalation, statistical adjustment may be inadequate.<sup>25,26</sup>

Recently, Stevens et al.<sup>15</sup> published a study not subject to the confounding effects of cigarette smoking; all sub-

**Table 3. Relationship of Obesity and Thinness to Mortality in Different Multivariable Models with Varying Conceptual Foundations**

Model	Hazard Ratio and 95% CI in the Obese Group; <i>P</i> Value  Z	Hazards Ratio and 95% CI in the Thin Group; <i>P</i> Value  Z
Model 1: baseline* (N = 7,048)	0.86 (0.77–0.97) (0.011)	1.46 (1.30–1.64) (0.000)
Model 2: baseline plus poverty data† (N = 5,916)	0.84 (0.74–0.95) (0.007)	1.55 (1.36–1.75) (0.000)
Model 3: beginning with those alive 2 years after initial survey‡ (N = 6,510)	0.93 (0.82–1.06) (0.268)	1.38 (1.20–1.57) (0.000)
Model 4: baseline plus controls for self-reported serious medical conditions§ (N = 6,888)	0.83 (0.74–0.94) (0.002)	1.58 (1.41–1.78) (0.000)
Model 5: subset of Model 1, including only those without serious medical comorbidities¶ at baseline (N = 2,378)	0.67 (0.51–0.88) (0.004)	1.40 (1.13–1.74) (0.002)

\*Variables included:

Continuous: age, number doctor visits, number hospital bed days, number short-stay hospital episodes, number functional limitations, residential stability, urbanization.

Categorical/binary: gender, race, private health insurance, region of the country, ever in a nursing home, education, self-rated health, lives alone, need for proxy, married, Medicaid.

†Available for only 82.8% of respondents; included as a categorical variable (above or below poverty level).

‡Eliminates the thin dying older people by removing those individuals (n = 579) from the sample who died in the first 2 years of the survey (poverty variable is not included).

§Analysis controls for self reported diabetes mellitus (present in 9.9%), cancer (12.3%), and heart disease (58.7%).

¶Self-reported cancer, diabetes mellitus, or heart disease.

CI = confidence interval.

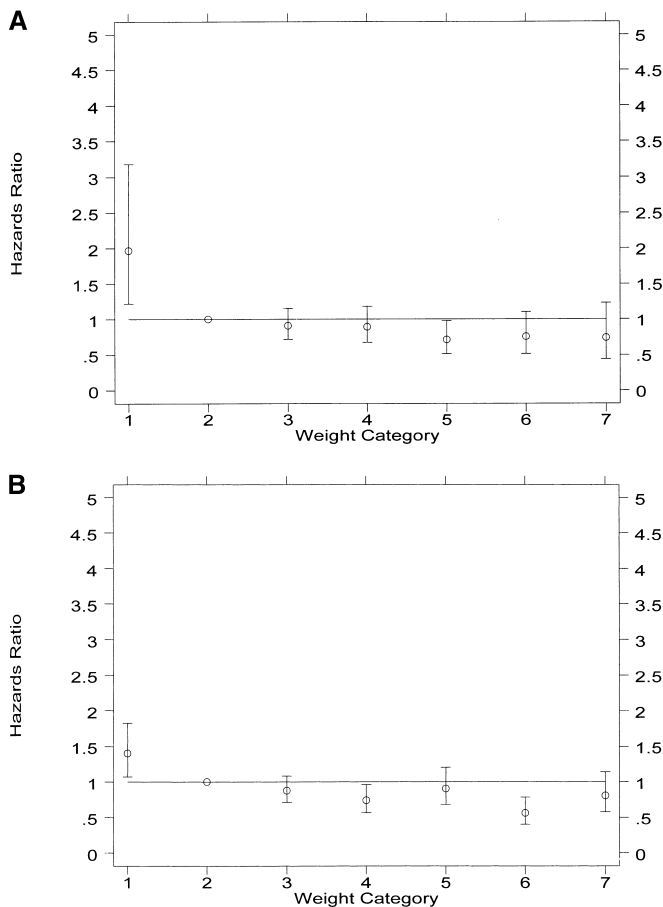
jects were nonsmokers. In this study, mortality was studied over 12 years in Caucasian men (n = 62,116) and women (n = 262,019) who participated in the American Cancer Society’s Cancer Prevention Study I. However, the

proportion of older subjects was small, with 7,683 subjects age 75–84 and only 553 age 85 and older, not much larger than the LSOA cohort that we have analyzed here (n = 7,527, mean age 76.8). In that study, excess mortal-

**Table 4. Full Results for Baseline Cox Proportional Hazards Model of Death**

	Hazard Ratio	SE	<i>P</i> >  t	95% CI	
Obese	0.860	0.051	0.011	0.766	0.966
Thin	1.460	0.086	0.000	1.301	1.638
Sex	0.515	0.023	0.000	0.471	0.562
Self health rating	0.752	0.034	0.000	0.687	0.823
Hospitalizations	1.234	0.030	0.000	1.176	1.295
Functional limits	1.096	0.0094	0.000	1.0779	1.1146
Age	1.0664	0.0037	0.000	1.0591	1.0737
Proxy	1.223	0.076	0.001	1.084	1.380
Doctor visits	1.0027	0.0010	0.009	1.0007	1.0046
North central	1.142	0.059	0.01	1.033	1.263
Private health insurance	0.891	0.042	0.014	0.813	0.977
Married	0.872	0.051	0.019	0.778	0.978
West	1.124	0.067	0.049	1.0004	1.263
College graduate	0.894	0.052	0.053	0.798	1.001
Urban	1.0155	0.0081	0.054	0.9997	1.0314
Ever in nursing home	0.911	0.052	0.1	0.815	1.018
Medicaid	0.885	0.073	0.139	0.752	1.041
Lives alone	0.931	0.053	0.21	0.833	1.041
Black	0.908	0.074	0.233	0.774	1.064
Northeast	1.069	0.060	0.235	0.958	1.193
Hispanic	0.879	0.108	0.295	0.691	1.118
Stable living environment	0.9989	0.0012	0.367	0.9966	1.0012
Other race	1.11	0.21	0.584	0.77	1.61
Bed days	0.99991	0.00035	0.8	0.99922	1.00060
High school graduate	1.009	0.050	0.855	0.916	1.111

SE = standard error; CI = confidence interval.



**Figure 3.** (A) Adjusted hazard ratios (with 95% CI) of death for men, adjusted for the variables in Model 1. (B) Adjusted hazard ratios (with 95% CI) of death for women, adjusted for the variables in Model 1. Group 1 (BMI <19.0); Group 2 (BMI 19.0–21.9); Group 3 (BMI 22.0–24.9); Group 4 (BMI 25.0–26.9); Group 5 (BMI 27.0–28.9); Group 6 (BMI 29.0–31.9); Group 7 (BMI >32.0). CI = confidence interval; BMI = body mass index.

ity was seen in obese younger subjects, but not in those age 75 to 84. Patients in this study were all Caucasian and an unspecified number were excluded from the analysis because of medical comorbidities. Other limitations include questionable generalizability because baseline data were collected in 1959 and 1960. In contrast, our analysis uses data collected starting at baseline in 1984, making it perhaps more relevant. Additionally, we analyzed the data with and without comorbid conditions, the treatment and outcomes of which may have improved in the interim.

Calle et al. examined prospectively more than one million adults over 14 years in the American Cancer Society's Cancer Prevention Study II.<sup>27</sup> They determined that the relationship between BMI was U-shaped at all ages, including an unspecified number of respondents greater than 75 years. For example, BMI between 30 and 32 was associated with a multivariate relative risk of death of 1.16 for men and 1.25 for women for those who never smoked and were without coexisting disease. The authors point out that, although the increased relative risk of death for obesity declined with increasing age, the absolute number of deaths attributed to overweight is greatest among older

people because death rates are highest in the oldest groups. In reviewing work in this field, they note that "obesity was most strongly associated with an increased risk of death among those who had never smoked and who had no history of disease, whereas leanness was most strongly associated with an increased risk of death among current or former smokers with a history of disease."

The Cardiovascular Health Study<sup>28</sup> collected clinical and demographic information for 5,201 men and women age 65 and older. Higher weights (BMI data were not reported) were not associated with different 5-year mortality in either unadjusted or multivariable models, although low weights were associated with higher-than-normal mortality.<sup>29</sup> Analysis of the first National Health and Nutrition Examination Survey (NHANES), a cohort study that included 3,339 noninstitutionalized civilians age 65 to 74, suggested a U-shaped relationship between BMI and mortality.<sup>30</sup> However, the increased mortality was more striking for underweight respondents, prompting Tayback et al.<sup>31</sup> to conclude that "the accepted definition of overweight . . . lacks specificity and may be inappropriate for older persons who do not have weight-related medical conditions." A Finnish community-based cohort study of 674 people age 85 and older found that those with BMI greater than 30 had the lowest mortality during 5 years of follow-up.<sup>32</sup> However, analysis of survival after age 65 in nonsmokers from the Framingham study suggests increased mortality in the obese, before and after adjustment for medical comorbidities.<sup>33</sup>

Others have examined the relationship between obesity and mortality at advanced ages. Stevens et al.<sup>15</sup> reviewed a number of studies examining age-related changes in the relationship between obesity and mortality. They concluded that "Taken together, these studies support the hypothesis that the relative risk of death associated with excess adiposity is lower for older than for younger adults. Variation in specific findings may be attributable to differences in exclusion criteria, in cutoff points for categories of body-mass index, or in the variables controlled for in the analysis, or to unmeasured characteristics of the study subjects." Diehr et al.<sup>29</sup> provide further discussion of the relative merits of other epidemiological studies of obesity and mortality in older people, including the National Health and Nutrition Examination Survey Epidemiological Follow-up Study (NHEFS), the Framingham Study, the Cardiovascular Health Study (CHS), and Established Populations for Epidemiologic Studies of the Elderly (EPES).<sup>34</sup> They reported that "all found significant excess mortality in the lowest BMI group, with and without control for covariates," including smoking. They also note that "in the highest BMI group, the Framingham study found significantly elevated mortality and NHEFS found marginally elevated risk, whereas EPES and CHS found no significant risk. EPES and CHS had shorter follow-ups than the other two studies, suggesting that studies with longer follow-up periods might yet find high BMI to be a risk factor. . . . CHS and EPES also had the largest number of subjects and the most extensive set of covariates and so might be expected to have less bias and more power. . . . All studies found that weight loss was associated with higher mortality. . . ." Table 5 summarizes a number of other studies that examine the relationship between obesity and mortal-

Table 5. Summary of Previous Studies Examining the Effect of Obesity on Mortality

Study Author, Year	Population	Effect of Obesity on Mortality	Study Design	Definition of Obesity	Length of Follow-Up	Size of Older Cohort (Mean Age)	Smoking	Fitness/Exercise	Strengths	Weaknesses	Comments
Stevens J et al. (1998) <sup>15</sup>	American Cancer Society's Cancer Prevention Study I (1960-1972)	In 75-84 yo men, BMI = 30.5 (vs mean 24.0) confers 20% mortality increase	Cohort	BMI in 1 unit intervals	12 years	1,899 males 75+ yo 6,337 females 75+ yo	No present or former smokers in the cohort	4 levels	Exclude smoking as a confounder	Excluded those with chronic heart disease, stroke, or cancer; proportion of such exclusions in older come common in older populations	Participants had no history of heart disease, stroke, or cancer; proportion of such exclusions in older subgroup not provided
Calle EE et al. (1999) <sup>27</sup>	Cancer Prevention Study II (1982-1996)	In men and women > 75 yo; BMI > 28 increased mortality	Cohort	BMI in 12 categories	14 years	N/A (entire cohort > 1 million, mean age = 57 yo)	Analyzed by smoking status overall, but older cohort analysis only in smokers	Used as a covariate	Includes blacks	Unknown # of older people, with wide CIs for mortality RRs	Obesity most strongly associated with death in those without disease who never smoked
Singh, Lindsted (1998) <sup>51</sup>	Adventist Mortality Study	Effect on all-cause mortality N/A HR for CV dz = 1.2 (1.1, 1.4) HR for Ca = 1.0 (0.7, 1.4) HR for other = 1.0 (0.8, 1.4)	Cohort	Quintiles of the population; highest BMI > 27.4	26 years	N = 12,576 women SDA 30-74 yo; # in older groups N/A	None (excluded)	N/A	26-year follow-up. Low prevalence of many chronic risk factors in SDA limits confounding. Weight change from baseline to year 17 included as variable	Limited generalizability to other populations	U-shaped at lower ages (57-79 yo), despite no smokers; obesity perhaps protective against respiratory disease

Table 5. Continued

Study Author, Year	Population	Effect of Obesity on Mortality	Study Design	Definition of Obesity	Length of Follow-Up	Size of Older Cohort (Mean Age)	Smoking	Fitness/Exercise	Strengths	Weaknesses	Comments
Diehr et al. (1998) <sup>29</sup>	Cardiovascular Health Study	None	Cohort	9 BMI groups; highest = >34	5 yrs	N = 5,201 >65 yrs (mean = 73.0 yo)	None	N/A	Started recently (1989). Past year weight change as a covariate. Analyzed with and without confounders (DM, CV dz)	Data collected from only four counties limits generalizability	Low BMI <20 associated with higher mortality for women
Bender et al. (1999) <sup>52</sup>	Dusseldorf Obesity-Mortality Study (6,193 pts referred to obesity clinic 1961–1994)	Only increased in 50–74 yo when BMI > 36; significantly lower SMR than in younger groups	Prospective cohort	BMI 25–32, 32–36, 36–40, and >40	Median 14.8 yrs	758 50–74 yo	Smoking data collected only after 1977	N/A	Height weight measured, not self-reported. Allows examination of effects of extreme obesity	Only 93.3% ascertainment of mortality. Small study.	Examines extreme obesity. Women over-represented
Corroni-Huntley et al. (1991) <sup>30</sup>	National Health and Nutrition Examination Survey (NHES) I	RR = 1.6 (CI 1.2–2.1) in upper 15% BMI women RR = 1.7 in upper 15% nonsmoking men	Prospective cohort	Upper 15% BMI (>29.5 for men, ~32 for women)	7–13 yrs	N = 3,339 65–74 yo	Included as covariate	N/A	Includes blacks. Height and weight measured.	Old data limits generalizability	10% weight loss in past decade increases mortality. Skin-fold measurements predicted mortality similarly to BMI.

Continued

Table 5. Continued

Study Author, Year	Population	Effect of Obesity on Mortality	Study Design	Definition of Obesity	Length of Follow-Up	Size of Older Cohort (Mean Age)	Smoking	Fitness/Exercise	Strengths	Weaknesses	Comments
Harris et al. (1988) <sup>38</sup>	Framingham Heart Study	RR = 1.4 (CI 0.9–2.2) for men; RR = 1.6 (CI 1.1–2.3) for women	Prospective cohort	BMI ≥ 70% (28.5 for men; 28.7 for women)	1–19 years after age 65; mean N/A	N = 1,723 All > 65 yo	Current and exsmokers excluded.	N/A	Weight and height measured directly	Variable follow-up; limited generalizability due to some old data and collection in 1 community	Lowest BMI associated with higher mortality despite excluding smokers
Tayback et al. (1990) <sup>31</sup>	NHANES-I	RR = 1.1 (CI 1.0–1.2) for men 65–74 yo RR = 1.0 (CI 1.0–1.1)	Prospective cohort	Upper 10% (BMI > 30)	Mean 8.7 yrs	N = 4,710 55–74 yo; unclear how many > 65 yrs	Included as covariate	N/A	Extensive sensitivity analyses	Whites only; relatively young cohort; old data	Poverty associated with death in low BMI group Obesity may increase hospitalization(women)

BMI = body mass index (kg/m<sup>2</sup>); Ca = cancer; CI = 95% confidence interval; CV = cardiovascular; DM = diabetes mellitus; dz = disease; HR = hazard ratio; NHEFS = National Health and Nutrition Examination Survey Epidemiological Follow-Up Study; NHANES = National Health and Nutrition Examination Survey; pt = patients; RR = relative risk; SDA = Seven Day Adventist; SMR = standardized mortality rates; yo = years old.

ity, including relative strengths and weaknesses and some details of study design.

In addition to smoking, it may also be important to separate the effects of obesity from physical inactivity and low fitness status. This is infrequently done, although the two conditions frequently coexist. However, even in obese younger men (mean age 43.8 years), low cardiorespiratory fitness is associated with increased mortality.<sup>35</sup> Both increased BMI and physical inactivity are independently related to short-term healthcare changes in adults with more than 40 years in a healthcare plan.<sup>36</sup> However, we were not able to examine the effects of exercise or aerobic capacity in this dataset. Nevertheless, we do note that, in our analyses, functional limitations were independently associated with increased mortality. In general, these studies demonstrate that thin older people have higher mortality, although not consistently demonstrating increased mortality for older obese people, especially for the oldest cohorts.

There are other limitations to our results. We used self-reported heights and weights to compute BMI. Some studies have documented that self-reports are very accurate, whereas others have suggested systematic biases (overestimation of height in men and underestimation of weight in women).<sup>37,38</sup> Other investigators have suggested that BMI may not accurately reflect health risks from obesity, and that measures of central obesity, such as waist-hip ratio (WHR), may better predict complications of obesity.<sup>39,40</sup> Additionally, many studies have used different definitions for obese and thin; some have been based upon absolute levels of BMI, and others, like ours, are referenced to the population studied. In addition, we did not include community-level resources, which may be important determinants of health utilization (and subsequent mortality); the LSOA provides no means by which to directly assess community-level resources available to the family (especially across the life course). Although we recognized that adjusting for nursing home residence would be an important covariate, the decreased mortality of patients who had ever been in a skilled nursing facility surprised us. We hypothesized that use of such facilities may reflect higher socioeconomic status; poor patients with functional limitations may be cared for more often by relatives in the community than in institutions. Recent work has suggested that nursing home beds may be a scarce resource that is less available to poor older people, but we found that those who had used skilled nursing facilities in this survey had lower income than those who had not.<sup>41</sup> As a final limitation, the data used in this study are observational in nature; experimental data do not currently exist (and most likely never will) to address the research questions analyzed within this paper.

Do our results suggest that older obese people should not be encouraged to lose weight? Weight loss can reduce hyperinsulinemia, blood pressure, and pain due to osteoarthritis and potentially reduce functional limitations.<sup>42,43</sup> Older obese community residents surveyed by telephone report frequent efforts at weight loss, although fewer than younger adults.<sup>44</sup> In particular, those age 70 and older were less likely to report using exercise in hopes of losing weight. Additionally, those age 70 and older were no more likely than others to be encouraged by healthcare professionals to lose weight.<sup>45</sup> Weight cycling

(loss and then gain of 10% of body weight) may or may not<sup>46</sup> be associated with higher mortality than maintenance of the same level of obesity.<sup>47</sup> Therefore, one can postulate that any attempt at weight loss should be sustained and gradual if it is to be associated with decreased mortality. Our study only included baseline weights and heights; conclusions about the effects of weight cycling cannot be drawn from this dataset. Interestingly, in the oldest old (age 85 and older), thinness is less of a risk factor for death than in the entire cohort. This may represent age selection among thin older people or sampling bias, or it may reflect gradual weight loss during the older years.

Other examples of risk factors for mortality that have been identified in younger populations that do not uniformly apply to older populations include higher cholesterol levels<sup>48</sup> and African-American race.<sup>49</sup> Indeed, when we applied our models to this data set, African Americans consistently had lower hazard ratios for mortality, despite the fact that African Americans in the general population have much lower life expectancies than do Americans of European descent.<sup>50</sup> In some cases, it has been suggested that those who have survived to be older, despite the presence of risk factors, may represent "hardier stock" than other older persons.

Our results, obtained in a large, diverse population of community-dwelling older people, disprove our hypothesis that elevated BMI is associated with increased mortality at advanced ages. A variety of alternative models and sensitivity analyses confirm these results to be robust. We believe that our results add to those of others (see Table 5) that suggest weight goals appropriate in younger age groups may be inappropriate for older individuals.

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