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THE EFFECT OF OBESITY ON OVERALL, CIRCULATORY DISEASE- AND DIABETES-SPECIFIC MORTALITY

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Summary. This paper explores the relationship between body mass and risk of death among US adults. The National Health Interview Survey–Multiple Cause of Death linked data set is used for the years 1987–1997, and Cox proportional hazard models are employed to estimate the association between obesity, as measured by the body mass index (BMI), and overall, circulatory disease-specific and diabetes-specific mortality. A U-shaped relationship is found between BMI and overall mortality. Compared with normal weight individuals, mortality during the follow-up period is 34% higher among obese class II individuals and 77% higher among obese class III individuals, controlling for age and sex. A J-shaped relationship exists between circulatory disease mortality and obesity, with a slightly higher risk of death for all categories of BMI. The relationship between BMI and diabetes mortality is striking. Compared with normal weight individuals, obese class I individuals are 2·8 times as likely to die, obese class II individuals are 4·7 times as likely to die, and obese class III individuals are 9·0 times as likely to die of diabetes during the follow-up period, controlling for age and sex. These results demonstrate that obesity heightens the risk of overall and circulatory disease mortality, and even more substantially increases the risk of diabetes mortality. These mortality findings, together with the substantial recent increases in obesity, lend urgency to public health programmes aimed at reducing the prevalence and consequences of obesity.

Introduction

This article reveals the relationship between obesity and overall, circulatory disease-specific and diabetes-specific mortality among US adults. Examining the relationship between obesity and mortality is important because obesity is increasing in prevalence

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in the United States. Indeed, the percentage of overweight and obese individuals has continually risen since 1960 (Expert Panel, 1998). Obesity significantly impacts the general health and life chances of individuals, affects national mortality trends and may hamper future mortality improvements. Indeed, total mortality might be reduced by as much as 15% if everyone experienced the low mortality afforded by optimum body mass levels (Waaler, 1983).

High body mass can contribute to higher risks of death to all causes, but especially to increased morbidity and mortality due to circulatory diseases and diabetes. Further, if obesity leads to increased rates of diabetes, the United States could witness increased diabetes-related mortality. Gu and colleagues (Gu, Cowie & Harris, 1999) followed two cohorts from the National Health and Nutrition Examination Survey (NHANES I). The first cohort was aged 35–74 in 1971–1975, and the second cohort was the same age in 1982–1984. Between the two periods, non-diabetic men and women experienced greater declines in heart disease and overall mortality than did diabetics: age-adjusted heart disease mortality declined by 36% among non-diabetic men but declined by just 13% among diabetic men, and it declined by 27% among non-diabetic women but *increased* by 23% among diabetic women (Gu *et al.*, 1999).

Specifically, this paper uses recent nationally representative survey data linked to follow-up mortality data to address the following questions: (1) How has the distribution of body mass changed in the United States during the past decade? (2) What is the relationship between different levels of obesity and overall mortality in the United States? (3) Does this relationship vary by age and sex? (4) What is the strength of the relationship between different levels of obesity and mortality resulting from circulatory diseases and diabetes?

Previous research

Obesity has been measured in a variety of ways, including skin-fold thickness, relative girth, body density and the body mass index (BMI). Some indices, while important, can only be assessed through medical examinations. Some studies have examined the relationship between stature (height) and mortality in the 18th, 19th and early 20th centuries (see Floud, Wachter & Gregory, 1990), but these were assessing the effects of poor nutrition, compromised health and exposure to infectious diseases early in life, and often did not adjust for weight. The body mass index (BMI) is used frequently in mortality studies because it simultaneously includes height and weight, can be assessed through a medical examination, is less prone to measurement error, is reliable and can be determined relatively accurately through self-reports (Stewart, 1982). It is an important measure because of its association with mortality (Dorn *et al.*, 1997; Durazo-Arvizu *et al.*, 1998; Gordon & Doyle, 1988; Lee & Paffanberger, 1992; Lee *et al.*, 1993; Lindsted, Tonstad & Kuzma, 1991; Manson *et al.*, 1995; Sidney, Friedman & Siegelaub, 1987; Vandenbroucke, Mauritz & de Bruin, 1984; Yuan *et al.*, 1998); its application in medical examinations and life insurance underwriting (Society of Actuaries, 1980); and its prominence in establishing and evaluating national health agenda (Expert Panel, 1998).

Most research has identified a classic U- or J-shaped relationship between BMI and mortality. That is, the risk of death is high among people with very low BMIs,

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low among those with mid-range BMIs and high again among those with the highest BMIs. This pattern of relationship between BMI and mortality is relatively consistent across studies, although the relationship does not always emerge for each geographic area, sex, race/ethnic group or cause of death under study (see Durazo-Arvizu *et al.*, 1998; Keys, 1989; Manson *et al.*, 1987).

The U-shaped relationship between BMI and mortality has been frequently identified (see Garrison *et al.*, 1983; Gordon & Doyle, 1988; Sidney *et al.*, 1987; Vandenbroucke *et al.*, 1984; Waaler, 1983). Durazo-Arvizu *et al.* (1998) estimated the relationship between BMI and mortality among 13,242 persons originally interviewed between 1971 and 1975, and followed until 1987. They found a U-shaped relationship between body weight and mortality, even after adjusting for smoking and baseline illnesses. Those persons, with BMIs around the average for their race–sex group, exhibited the lowest mortality rates during the follow-up period. Their analysis of the highest weight quintiles suggested that white women with BMIs above 29·2 exhibited 25% higher mortality risk compared with white women with BMIs in the 23–25 range, whereas white men with BMIs at 29 or above displayed 17% higher mortality compared with white men with BMIs in the 26–29 range. The findings for black men and women differed slightly but were consistent with the findings for white men and women.

Visscher *et al.* (2000) recently examined the relationship between BMI and mortality among 7985 European men from five countries. They defined BMI according to four categories (underweight, normal weight, overweight and obese), based on the World Health Organization guidelines. They found the classic U-shaped relationship between BMI and mortality. For example, among never-smokers and compared with normal weight individuals, those who were underweight were 2·3 times as likely to die during the follow-up, and those who were obese were 40% more likely to die between 1970 and 1985. They obtained similar results for former smokers, and similar but attenuated results for current smokers.

In a unique prospective study of 18,244 Chinese men in Shanghai, China, Yuan *et al.* (1998) uncovered a U-shaped relationship between BMI and mortality among life-long never-smokers: compared with individuals of desirable BMIs (21·0 to less than 23·5), those with low BMIs (less than 18·5) displayed a relative mortality risk of 1·73, and those with high BMIs (greater than or equal to 26) displayed a relative mortality risk of 1·48, net of age, education and alcohol consumption. The increased risk of death for those of high BMI among these never-smokers was primarily due to cardio- and cerebrovascular disease, whereas the increased risk of death for those of low BMI was mainly due to infectious diseases. They found no association between body mass and mortality among current- or ever-smoking men. This study is important because it is one of the first to examine the effects of BMI on mortality in a developing country.

Cornoni-Huntley and her research team (Cornoni-Huntley *et al.*, 1991) examined the effects of BMI among 14,407 participants of the Epidemiologic Follow-up Study of the first National Health and Nutrition Examination Survey. Their study identified a clear U-shaped relationship between BMI and mortality and contributed to the literature by providing mortality estimates for individuals at older ages, i.e. those aged 65–74. Moreover, they demonstrated that at ages 55 and above, with increasing age

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there is a consistent decline in weight at specific heights. For example, the 50th percentile in weight for men who are 70 inches tall is 183 pounds at ages 55–59, 178 pounds at ages 70–74, and just 170 pounds at ages 80–84. This study underlines the importance of examining the age-specific effects of BMI on mortality.

Some studies have found that different sub-populations are characterized by either a J- or U-shaped pattern. Lee & Paffenberger (1992) examined the risk of death among Harvard University alumni, in which there was initial screening for cancer and cardiovascular disease. They found that both weight loss and gain significantly increased mortality risk due to all causes and coronary heart disease, but did not affect mortality due to cancer (also see Iribarren *et al.*, 1995). Subsequently, Lee *et al.* (1993) used the same population, adjusting for age, physical activity and cigarette smoking, and screening for cancer, coronary heart disease, and stroke. They found that the relationship between BMI and mortality was J-shaped among the general sample, but U-shaped among current smokers.

The J-shaped relationship between BMI and mortality has also been frequently cited in the literature. For instance, Manson *et al.* (1995) studied 115,195 women aged 30–55 over a 16-year follow-up period who were free of known disease at baseline. Manson and colleagues found that compared with normal weight women, obese women suffered from the greatest risk of mortality, and underweight women suffered from higher mortality, but not as high as obese women.

Several studies have identified a linear relationship between BMI and mortality. For instance, Lindsted *et al.* (1991) discovered a positive relationship between BMI and mortality risk among 8828 Seventh-Day Adventist men in a 26-year follow-up study, but found no increased mortality among very lean men. This provides further insight into the BMI/mortality relationship as these men abstained from drinking and smoking.

Dorn *et al.* (1997) assessed the long-term relationship between BMI and mortality from all causes and from specific causes among individuals aged 20–96 in Buffalo, New York. They used a 29-year follow-up of men and women who were originally interviewed in 1960, and adjusted for age, education and cigarette smoking. They found a significant linear association between BMI and all-cause mortality in men aged 65 or less, but not in women, and observed a quadratic relationship among men aged 65 or older, with the lowest risks appearing in the BMI range of 23–27. Further, BMI was strongly associated with cardiovascular disease and coronary heart disease mortality in women and younger men, but not in older men, and was not related to an increased risk of death from cancer or non-cardiovascular disease in either sex.

It is unclear whether, compared with normal weight individuals, current populations of very lean men and women experience higher or equal mortality risks. Several studies have suggested that smoking and/or preclinical disease account for the higher mortality of men and women at the lowest weights (Manson *et al.*, 1995; Sidney *et al.*, 1987). Other studies claim that smoking does not explain higher mortality in the lowest BMI category (Vandenbroucke *et al.*, 1984). Yuan *et al.* (1998) found that lean male Chinese never-smokers exhibited higher mortality due to infectious diseases; but this finding may be less salient to analyses in more developed countries, where the risk of infectious disease is quite low. Lindsted *et al.* (1991) assert that men who are lean by choice should experience low mortality. But Cornoni-Huntley *et al.* (1991)

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mused that hip fracture among the elderly, especially elderly women, is related to extreme lean body mass, as well as increased risk of death. As the prevalence of smoking declines in the general population, the effect of smoking on BMI should dampen.

In sum, inconsistencies remain in the literature regarding the relationship between BMI and mortality, although most studies point to a higher risk of mortality for those persons in the upper end of the weight distribution. Several studies have been based on select sub-populations, for example, a single sex, a specific region of the country, university alumni or specific religious groups. Furthermore, many studies have not separately presented results for different sexes or ages, and have not provided detailed BMI categories. Here, previous research has been built upon by focusing on six categories of body mass; testing the relationship between BMI and premature mortality for overall, circulatory disease-specific and diabetes-specific causes of death; specifying the relationship separately by age group and sex; and using a very large nationally representative sample of the US population.

Data and methods

Data

The National Health Interview Survey (NHIS) was employed for the years 1987–1994, linked via the National Death Index (NDI) to the Multiple Cause of Death files (MCD) for the years 1987–1997, the largest and most current nationally representative data available to study the relationship between body weight and mortality risk (National Center for Health Statistics [NCHS], 2000). The NHIS annually surveys about 75,000 US resident non-institutionalized individuals aged 18 and above. The NHIS includes a core set of questions that remain virtually unchanged from year to year on a variety of sociodemographic, socioeconomic, geographic and health status items, including height and weight (NCHS, various years). NCHS used the same sampling frame for the period 1987–1994, enabling the pooling of these annual surveys. Because the same sampling frame is used, each record represents a unique individual.

Combining 8 years of the core NHIS yields a sample of 647,015 persons, thus permitting mortality analyses of numerically small groups, such as individuals who are classified by different levels of obesity. The NHIS provides annual cross-sectional data for the non-institutionalized US civilian population which, when linked to the MCD, allows the examination of the risk of death over time. The data provide detailed information for the NHIS subjects who survived subsequent years and for those who died.

Deaths matched to the MCD indicate that 47,271 of the surveyed individuals died of any cause, including 19,929 who died of circulatory diseases, and 1209 who died of diabetes between 1987 and 1997. The NCHS devised a probabilistic matching scheme that assigns weights to each of twelve items: social security number; first and last name; middle initial; race; sex; marital status; day, month, and year of birth; and state of birth and residence (Horm, 1996; NCHS, 2000). Patterson & Bilgrade (1986) have shown that the matching methodology is highly accurate. About 3% of the NHIS records termed ‘ineligible’ contain insufficient information to be matched to

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any death records. The NCHS identifies the ineligible records so that they can be dropped from subsequent analyses. An additional 2·5% of the sample were also excluded due to missing values on height, weight, education or marital status.

Measuring body mass

Body mass index (BMI) is the key variable in this analysis. It is derived using Quetelet's Index by converting self-reported weight and height into metric units and calculating BMI in kg/m^2. Although a few studies have suggested using other powers, including 1·5 (see Cornoni-Huntley *et al.*, 1991), here convention is followed and height is squared. Compared with using height to the 1·5 power, using height squared assumes that as weight increases, body mass increases, but at a slower rate, which appears to be a reasonable assumption.

The Expert Panel (1998) is followed and BMI categorized into six groups: underweight (BMIs of less than 18·5), normal weight (the reference category: BMI 18·5–24·9), overweight (BMI 25–29·9), obesity classification I (BMI 30–34·9), obesity classification II (BMI 35·0–39·9) and obesity classification III (BMI 40 or greater). This expands Visscher *et al.*'s (2000) four BMI categories with one obesity class into six categories with three obesity classes. It is asserted that increasing obesity further increases the risk of mortality, and more detailed obese classes will accurately capture this mortality differential.

The prospective design of the data set minimizes the recall bias in reporting of height and weight. Furthermore, Stewart (1982) has demonstrated that, compared with actual measurements, self-reported height and weight are relatively accurate, even among those who are overweight. Nonetheless, it is possible that respondents misreport their height and/or weight. To investigate the degree of possible heaping or exaggeration, a series of Whipple's Indices on the height and weight distributions were calculated (for the calculation of the Whipple Index, see Stockwell, 1976); results not shown.

There appears to be a greater predisposition for males who are anywhere from 1 to 3 inches shy of 6 feet to respond that they are 6 feet tall, both because of a greater status attached to taller males, and because more males are near 6 feet, a prime point for over-reporting height measurements. Males consistently demonstrated a preference for reporting heights at one-foot intervals, and a visual inspection of the distribution indicates that the 6-foot mark deviates substantially from the normal distribution. Because fewer females are close to 6 feet tall, and because there is less prestige associated with females attaining such a height, there is less height over-reporting among females.

Both sexes demonstrate marked heaping for body weight, although the distributions as a whole approximate normality, indicating that most people are simply rounding to the nearest five or ten pound increment. Between the sexes, it is more likely that females under-report their weight. Tendencies to report heights and weights closer to ideal BMIs – by over-reporting of height among males, especially at 6 feet, and the possible under-reporting of weight among females – may dampen the mortality risks associated with under- and overweightedness. If some individuals currently classified as normal weight are actually overweight, then the use of this

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group as a reference will underestimate the mortality differential between normal and overweight individuals, and could lead to conservatively biased estimates (Berry & Feldman, 1985).

Independent variables and measurement

Both BMI and the risk of death vary by socioeconomic, geographic and sociodemographic variables. Sociodemographic variables include age, sex and marital status. Age is measured continuously, ranging from 18 to 99 years and over. The risk of mortality by BMI is also separately analysed for four different age groups of adults: 18–24, 25–44, 45–64 and 65 and over. Sex is coded as a simple categorical variable, with females as the reference. Marital status is coded as currently (the reference), previously and never married.

Socioeconomic variables include income equivalence, educational status and employment status. Family income is measured on a continuous income equivalence scale, which takes into account the family income and family size of the respondent (e.g. Rogers, 1995). Income equivalence (W) is equal to family income (I) divided by family size (S) raised to an equivalence elasticity (e): $W = I/S^e$. Van der Gaag & Smolensky is followed (1982) and an equivalence elasticity of 0·38 is used to adjust for differences in consumption across different sized families. This income equivalence scale adjusts family income by family size, adjusts for patterns of consumption, and is generally more strongly associated with mortality than such income measures as income in dollars or logged dollars. Education is coded into three categories: 0–11 years, high school graduate and some college education (reference). Employment status is coded as employed (reference), unemployed and not in the labour force.

The geographic variables include metropolitan status and region. Metropolitan status is coded as residence in a central city, non-central city, farm or non-farm (reference). The region variable includes the four main census regions: North-east, West, South, and Mid-west (reference). Smoking, past diagnosis of cancer, or history of heart disease are not available on the core version of the NHIS, and thus could not be included in this analysis. Thus, this analysis focuses on the overall population, rather than a healthy subset of the population, but with further controls for demographic factors, along with marital, socioeconomic and geographical status.

Survival

The dependent variable is survival status, measured dichotomously as survived or died over the course of the follow-up period. Information is also presented on circulatory disease- and diabetes-specific mortality, based on the three-digit codes in the 9th revision of the International Classification of Diseases (ICD-9; US Department of Health and Human Services, 1990). The ICD-9 codes for circulatory diseases are 390–459 and that for diabetes is 250. These causes are coded on an underlying cause basis.

Statistical modelling

Because people were interviewed throughout the calendar year, and because the deaths for individuals surveyed between January 1987 and December 1997 could have

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taken place in as many as 132 follow-up months, a Cox proportional hazards model is used to estimate the gross and net associations of obesity with the risk of mortality (Shah *et al*., 1997). A duration variable was created to allow for variability in the exposure of death in months (for confidentiality, the data set does not include detail on day of interview or of death). The mean duration of the follow-up period is 82 months, with a range of 0–132 months.

In the analyses of overall mortality, the association between BMI and the risk of overall mortality during the follow-up period is estimated, while controlling for different sets of factors. In the analyses of circulatory disease- and diabetes-specific mortality, death from a specific cause is contrasted with survivors, with data on persons who died from other causes during the follow-up interval censored at the time of their death. All coefficients are reported in the form of hazard ratios. All analyses are weighted to approximate the US non-institutionalized population of adults. Because the NHIS uses a complex, weighted, clustered and stratified sampling design, Stata 7 software is used (StataCorp, 2001) to correctly estimate the coefficients and the standard errors.

Results

Figure 1 displays changes in the BMI distribution between 1987 and 1994, and their univariate statistics are given in Table 1. The vertical lines demarcate underweight, normal weight, overweight and obese classes I, II and III. Although the distributions each include a long tail at the heaviest BMIs, indicating extreme obesity for a select few people, the graph has been truncated at 57, because there are proportionately very few people at the heaviest extremes. Further, a few of the very highest BMIs appeared to be illogical, or misreports. Between 1987 and 1994, the BMI distribution shifted to the right, indicating a heavier population on average. Over this time period, the mean BMI increased from 24·9 to 25·6. Moreover, the apex of the distribution declined and shifted to a heavier weight. In 1987, the greatest percentage of the population had a BMI of 23·0, although by 1994 the modal category had a BMI of 24·0. Compared with 1987, the 1994 distribution was wider as well, as noted by the larger standard deviation, which increased from 4·7 to 5·1. Because of the shift in the population towards heavier weights and higher levels of obesity, it is important to fully understand its relationship with mortality.

Table 2 examines the distribution of each of the variables in the analysis by BMI. Less than 4% of the adult population is considered underweight. In 1987, over one-half of the population was of normal weight, but by 1994 a minority of the adult population was of normal weight. Compared with 1987, there were also proportionally more people in all overweight categories: overweight, obese class I, obese class II and obese class III. Together, the 1994 figures suggest that 48·6% of the adult population fell into the overweight or obese categories. Further, adult obesity increased from 11·8% to 15·6% over this relatively short time period: more than a 30% increase. Thus, the increase in BMI between 1987 and 1994 is due to proportionally fewer adults who are under- or normal weight, and proportionally more individuals who are overweight and obese.

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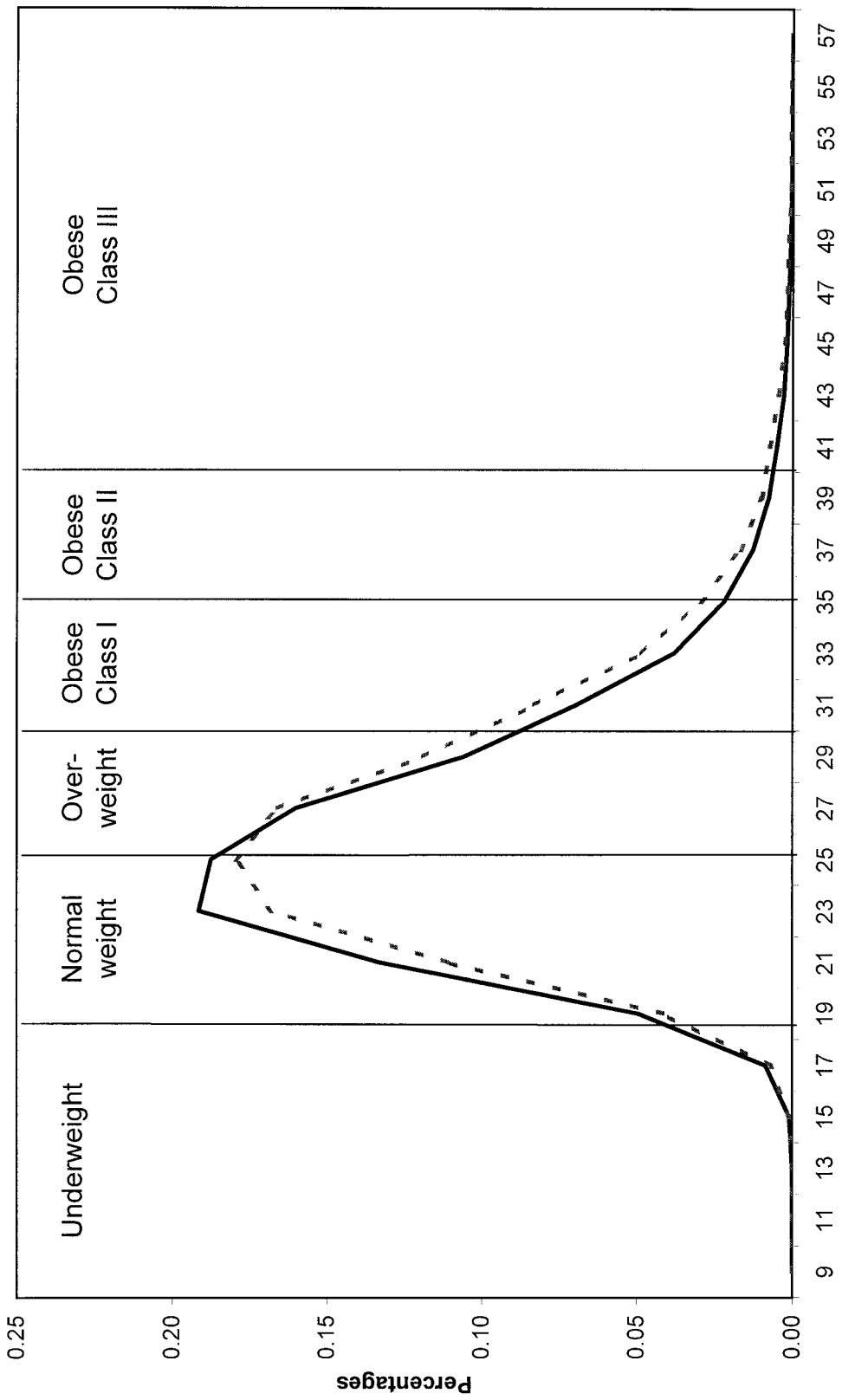


Fig. 1. Frequency distribution of body mass index, comparing 1987 (solid line) and 1994 (dashed line), US adults.

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Table 1. Univariate statistics of the body mass index, US adults, 1987 and 1994

				1987		1994	
	All years	1987	1994	Females	Males	Females	Males
Mean	25·1	24·9	25·6	24·4	25·5	25·0	26·2
Mode	26·0	23·0	24·0	22·0	26·0	22·0	26·0
SD	4·8	4·7	5·1	5·2	4·0	5·6	4·3

Table 2 also provides the percentage BMI distribution for the sociodemographic, socioeconomic and geographic factors. Extreme obesity, as marked by obese classes II and III, is more prevalent among females than males, previously rather than currently or never-married individuals, those with lower rather than higher incomes, those with less than a high school degree rather than those with a more advanced education, those not in the labour force rather than those employed or unemployed, those in central city and non-farm areas rather than those in non-central city and farm areas, and those in the South and Mid-west rather than the North-east and West. A closer look at the BMI variation by sex indicates that females are more highly represented in the tails of the distribution and in the normal weight category, while males are much more highly concentrated within the overweight and obese class I categories.

Table 3 shows an overall U-shaped relationship between BMI and mortality risk with substantially increasing mortality as obesity increases. Indeed, Model 1 shows a mortality gradient with obesity compared with normal weight individuals after controlling for age and sex; those in obesity class II are 34% more likely to die and those in class III are 77% more likely to die over the follow-up period. However, compared with normal weight individuals, those who are overweight (BMI 25–30) are 13% less likely to die over the follow-up period. The lower mortality of overweight individuals may be due to unmeasured factors, such as lower rates of smoking, but is consistent with the findings of other studies (Durazo-Arvizu *et al.*, 1998; Gordon & Doyle, 1988), which suggest that the lowest mortality is found at BMIs of 24–27. The increased risk of death for underweight people suggests that they may already be ill or more susceptible to illness (see Calle *et al.*, 1999).

Additional controls in Table 3 reveal more completely the relationship between BMI and overall mortality. The addition of income equivalence in Model 3 significantly reduces the effect of BMI on mortality, especially among the most obese and the underweight. This suggests that part of the higher mortality experienced among the most obese individuals is due to their lower incomes. Most likely, very overweight individuals are penalized in the job market, and their income levels reflect this discrimination. This mortality gap between obese and normal weight individuals further closes after sequentially including marital status, education, employment status and geographic variables. With each block of variables there is a slight decrease in the relationship between BMI and overall mortality. Nevertheless, the effects of

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Table 2. Percentage distribution of body mass index by year and sociodemographic, socioeconomic, health and regional variables, US adults, 1987–1994

	Under weight	Normal weight	Over weight	Obese class I	Obese class II	Obese class III
Year						
1987	3·8	54·0	30·4	8·6	2·2	1·0
1994	3·3	48·2	33·2	11·0	3·0	1·4
1987–1994	3·5	51·3	31·9	9·7	2·5	1·1
Sociodemographic status						
Age[a]	40·9	41·9	46·3	46·7	45·7	44·3
Sex						
Female	5·4	57·7	23·3	9·2	3·1	2·9
Male	1·4	44·3	41·2	10·3	2·1	0·7
Marital status						
Currently married	2·8	49·0	34·6	10·2	2·5	1·0
Previously married	4·2	49·6	30·6	10·8	3·2	1·6
Never married	5·4	60·6	23·6	7·0	2·1	1·2
Socioeconomic status						
Income equivalence						
<$7500	5·2	51·0	26·6	10·9	3·9	2·4
$7500–12,499	4·3	47·4	31·1	11·7	3·6	1·8
$12,500–17,499	3·6	49·4	32·1	10·8	2·9	1·2
$17,500–22,499	3·4	50·7	32·4	9·9	2·6	1·1
$22,500–27,499	3·3	51·3	32·4	9·7	2·4	1·0
$27,500–32,499	3·2	52·1	32·8	9·0	2·1	0·8
$32,500–37,499	3·1	54·2	32·0	8·2	1·8	0·6
$37,500–42,499	2·9	53·9	32·6	8·2	1·8	0·6
$42,500+	2·5	55·0	32·9	7·4	1·6	0·5
Education						
<12 years	3·8	44·0	34·3	12·7	3·6	1·7
High school graduate	3·4	50·4	32·2	10·2	2·7	1·2
Some college	3·4	56·0	30·3	7·7	1·9	0·8
Employment status						
Employed	2·9	51·8	32·7	9·3	2·3	0·9
Unemployed	3·8	52·1	29·6	10·3	2·9	1·4
Not in labour force	4·6	50·2	30·5	10·4	3·0	1·5
Geographical status						
Metropolitan statistical area						
Central city	3·7	52·0	30·8	9·6	2·7	1·3
Non-central city	3·4	52·2	32·1	9·2	2·2	0·9
Farm	2·4	45·3	37·5	11·6	2·6	0·7
Non-farm	3·5	48·5	32·6	11·1	3·1	1·3
Region						
Mid-west	3·2	50·0	32·6	10·3	2·8	1·2
North-east	3·3	51·5	32·6	9·5	2·3	1·0
West	3·6	54·9	30·2	8·3	2·1	0·9
South	3·8	49·9	31·8	10·3	2·8	1·3

Source: derived from NCHS (various years).
[a]Age presents the mean age by BMI.

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Table 3. Hazards ratios of the effects of the body mass index on overall mortality, US adults, 1987–1997

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Body mass index						
Obese, class III (BMI 40·0 or greater)	1·77*	1·73*	1·60*	1·57*	1·53*	1·52*
Obese, class II (BMI 35·0 to less than 40·0)	1·34*	1·34*	1·27*	1·25*	1·23*	1·23*
Obese, class I (BMI 30·0 to less than 35·0)	1·01	1·02	0·99	0·98	0·98	0·98
Overweight (BMI 25·0 to less than 30·0)	0·87*	0·88*	0·87*	0·86*	0·87*	0·87*
Normal (BMI 18·5 to less than 25·0)	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Underweight (BMI less than 18·5)	1·91*	1·85*	1·82*	1·82*	1·81*	1·81*
Sociodemographic status						
Age (single years)	1·08*	1·08*	1·08*	1·08*	1·07*	1·07*
Male sex (female is reference)	1·83*	1·97*	2·03*	2·02*	2·13*	2·13*
Marital status						
Currently married		Ref.	Ref.	Ref.	Ref.	Ref.
Previously married		1·31*	1·22*	1·22*	1·26*	1·25*
Never married		1·59*	1·46*	1·48*	1·43*	1·43*
Socioeconomic status						
Income equivalence			0·83*	0·85*	0·89*	0·90*
Education						
<12 years				1·23*	1·20*	1·20*
High school graduate				1·13*	1·12*	1·12*
Some college				Ref.	Ref.	Ref.
Employment status						
Employed					Ref.	Ref.
Unemployed					1·39*	1·39*
Not in labour force					1·78*	1·77*
Geographical status						
Metropolitan statistical area						
Central city						1·09
Non-central city						1·05
Farm						0·92
Non-farm						Ref.
Region						
Mid-west						Ref.
North-east						1·01
West						1·00
South						1·03
Log likelihood	− 357,821	− 357,319	− 356,506	− 356,395	− 355,555	− 355,546

†$p \leq 0{\cdot}05$; *$p \leq 0{\cdot}01$.
Interviewed $n = 647{,}015$; deaths over follow-up $n = 47{,}271$.
Source: derived from NCHS (various years).

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obesity on mortality, particularly for those persons who are class II or III obese, remain clear and strong in even the most inclusive model.

Tables 4 and 5 examine the relationship between BMI and the risk of mortality within age and sex groups, respectively. By age, the effects of obesity are most pronounced during the middle ages. For example, among individuals aged 25–44 and 45–64, compared with normal weight individuals, those who are in obese class III are 1·8 and 1·6 times as likely to die, respectively, even after controlling for other social, economic and geographic factors (see Table 4, Models 6 and 9). Obese elderly persons exhibit higher risks of death, but of smaller relative magnitude than found at younger ages. Obesity is much less prevalent among the elderly (see Table 2), most likely due to higher mortality among the obese at younger ages, as well as weight loss associated with illness. Moreover, even the most obese individuals aged 18–24 have no statistically significant increase in mortality compared with their normal weight counterparts, indicating that the lower risks of mortality at these ages may counteract the increased risks due to higher BMIs. But this relationship may change in the future, because adolescents are the fastest growing group of obese individuals in the country.

Table 5 indicates that both sexes exhibit a strong graded U-shaped relationship between BMI and mortality. For both males and females, the effects are strong for the two highest categories of obesity. Indeed, even in the most complete model for each sex, obese class III individuals exhibit 49% (females) to 69% (males) higher mortality over the follow-up period compared with normal weight persons. Furthermore, compared with ideal weights, underweight individuals exhibit 76% (females) and 96% (males) higher mortality over the follow-up period.

Obesity increases the risk of death for overall mortality through specific causes, including circulatory diseases and especially diabetes. Table 6 presents the risk of mortality due to circulatory diseases as the underlying cause, which is often exacerbated by diabetes and high BMIs. In fact, the risk of death due to circulatory diseases increases as BMI increases above the normal range, and the overall magnitude of the effect is much higher than the risks of overall mortality due to BMI. Those in obese class III are 2·4 times as likely as those of normal weight to die of circulatory diseases over the follow-up period (Model 1). Here, the J-shaped relationship between BMI and circulatory disease mortality is manifest: those who are underweight experience a 57% increase in risk compared with those who are normal weight.

Each subsequent model decreases the relationship between BMI and circulatory disease mortality. Model 3 indicates that by controlling for income, the risk of death in people of obesity class III declines from 2·4 times that of normal weight people, to 2·1 that of normal weight people. Accounting for employment status in Model 5 further attenuates the relationship between BMI and circulatory disease mortality, and most significantly for the most obese people.

Table 7 shows that BMI is an even stronger predictor of mortality when diabetes is the underlying cause of death. As Model 1 indicates, compared with normal weight individuals, being overweight or obese substantially increases the risk of diabetes mortality. Those in the obese class III category are 9·0 times as likely to die, those in obese class II are 4·7 times as likely to die, and those in obese class I are 2·8 times

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Table 4. Hazards ratios of the effects of the body mass index on overall mortality by age, US adults, 1987–1997

	Ages 18–24			Ages 25–44			Ages 45–64			Ages 65 and over		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
Body mass index												
Obese, class III (BMI 40·0 or greater)	1·91*	1·50	1·50	2·56*	1·77*	1·77*	2·20*	1·61*	1·61*	1·32*	1·21*	1·21*
Obese, class II (BMI 35·0 to less than 40·0)	0·97	0·87	0·86	1·86*	1·53*	1·53*	1·48*	1·23*	1·23*	1·21*	1·13*	1·13*
Obese, class I (BMI 30·0 to less than 35·0)	0·82	0·78†	0·78†	1·08	1·00	1·00	1·11*	1·02†	1·02†	0·98	0·94	0·94*
Overweight (BMI 25·0 to less than 30·0)	0·96	0·96	0·96	0·88	0·89	0·89	0·86*	0·85*	0·85*	0·87*	0·86†	0·86*
Normal (BMI 18·5 to less than 25·0)	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Underweight (BMI less than 18·5)	1·20	1·15	1·15	1·94*	1·73*	1·73*	2·73*	2·24*	2·24*	1·80*	1·78*	1·78*
Sociodemographic status												
Age (single years)	0·98	1·09*	1·09*	1·06*	1·08*	1·08*	1·09*	1·06*	1·06*	1·08*	1·07*	1·07*
Male sex (female is reference)	2·82*	2·61*	2·61*	2·08*	2·51*	2·51*	1·78*	2·23*	2·23*	1·81*	1·98*	1·98*
Marital status												
Currently married		Ref.	Ref.		Ref.	Ref.		Ref.	Ref.		Ref.	Ref.
Previously married		1·63*	1·62*		1·74*	1·71*		1·41*	1·40*		1·15*	1·15*
Never married		2·16*	2·14*		2·32*	2·26*		1·39*	1·38*		1·09*	1·09*
Socioeconomic status												
Income equivalence		0·92*	0·94*		0·86*	0·87*		0·85*	0·85*		0·92*	0·92*
Education												
<12 years		2·20*	2·22*		1·62*	1·62*		1·24*	1·24*		1·11*	1·11*
High school graduate		1·64*	1·66*		1·24*	1·24*		1·08*	1·08*		1·07	1·07
Some college		Ref.	Ref.		Ref.	Ref.		Ref.	Ref.		Ref.	Ref.
Employment status												
Employed		Ref.	Ref.		Ref.	Ref.		Ref.	Ref.		Ref.	Ref.
Unemployed		1·38*	1·38*		1·50*	1·50*		1·19*	1·19*		1·30*	1·30*
Not in labour force		1·48*	1·46*		2·13*	2·12*		1·94*	1·94*		1·45*	1·45*
Geographical status												
Metropolitan statistical area												
Central city			1·06			1·07			1·18			1·04
Non-central city			0·85			0·88			1·08			1·06
Farm			1·26			1·01			0·90			0·89†
Non-farm			Ref.			Ref.			Ref.			Ref.
Region												
Mid-west			Ref.			Ref.			Ref.			Ref.
North-east			0·25*			2·48			0·77*			1·08
West			1·00			1·00			1·00			1·00
South			0·62			1·76			0·98			0·96
Log likelihood	− 5576	− 5500	− 5495	− 29,653	− 28,953	− 28,939	− 82,150	− 80,921	− 80,911	− 208,757	− 208,313	− 208,308

†$p \leq 0{\cdot}05$; *$p \leq 0{\cdot}01$.
Ages 18–24: interviewed $n = 84{,}793$; deaths over follow-up $n = 849$. Ages 25–44 interviewed $n = 281{,}716$; deaths over follow-up $n = 3911$. Ages 45–64: interviewed $n = 171{,}550$; deaths over follow-up $n = 11{,}523$. Ages 65 and over: interviewed $n = 108{,}956$; deaths over follow-up $n = 30{,}988$.
Source: derived from NCHS (various years).

Table 5. Hazards ratios of the effects of the body mass index on overall mortality by sex, US adults, 1987–1997

	Female			Male		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Body mass index						
Obese, class III (BMI 40·0 or greater)	1·76*	1·49*	1·49*	1·86*	1·69*	1·69*
Obese, class II (BMI 35·0 to less than 40·0)	1·40*	1·25*	1·25*	1·28*	1·23*	1·24*
Obese, class I (BMI 30·0 to less than 35·0)	1·10*	1·01	1·01	0·94*	0·95*	0·95*
Overweight (BMI 25·0 to less than 30·0)	0·96*	0·92*	0·92*	0·80*	0·84*	0·84*
Normal (BMI 18·5 to less than 25·0)	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Underweight (BMI less than 18·5)	1·81*	1·76*	1·76*	2·26*	1·96*	1·96*
Sociodemographic status						
Age (single years)	1·09*	1·07*	1·07*	1·08*	1·07*	1·07*
Marital status						
Currently married		Ref.	Ref.		Ref.	Ref.
Previously married		1·24*	1·24*		1·25*	1·24*
Never married		1·34*	1·34*		1·46*	1·45*
Socioeconomic status						
Income equivalence		0·91*	0·91*		0·89*	0·89*
Education						
<12 years		1·16*	1·16*		1·23*	1·23*
High school graduate		1·09*	1·10*		1·13*	1·13*
Some college		Ref.	Ref.		Ref.	Ref.
Employment status						
Employed		Ref.	Ref.		Ref.	Ref.
Unemployed		1·28*	1·28*		1·43*	1·43*
Not in labour force		1·74*	1·74*		1·80*	1·80*
Geographical status						
Metropolitan statistical area						
Central city			1·16*			1·04
Non-central city			1·12*			0·99
Farm			0·82*			0·99
Non-farm			Ref.			Ref.
Region						
Mid-west			Ref.			Ref.
North-east			1·34			0·84
West			1·00			1·00
South			1·20			0·95
Log likelihood	− 154,637	− 153,914	− 153,905	− 170,814	− 169,327	− 169,322

†$p \leq 0{\cdot}05$; *$p \leq 0{\cdot}01$.
Females: interviewed $n = 346{,}233$, deaths over follow-up $n = 22{,}253$. Males: interviewed $n = 300{,}782$, deaths over follow-up $n = 25{,}018$.
Source: derived from NCHS (various years).

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Table 6. Hazards ratios of death by underlying cause of circulatory diseases, US adults, 1987–1997

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Body mass index						
Obese, class III (BMI 40·0 or greater)	2·37*	2·31*	2·14*	2·11*	2·04*	2·04*
Obese, class II (BMI 35·0 to less than 40·0)	1·78*	1·77*	1·67*	1·64*	1·61*	1·61*
Obese, class I (BMI 30·0 to less than 35·0)	1·27*	1·26*	1·22*	1·20*	1·20*	1·20*
Overweight (BMI 25·0 to less than 30·0)	0·99	1·00	0·98	0·98	0·98	0·98
Normal (BMI 18·5 to less than 25·0)	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Underweight (BMI less than 18·5)	1·57*	1·55*	1·53*	1·53*	1·53*	1·53*
Sociodemographic status						
Age (single years)	1·11*	1·11*	1·10*	1·10*	1·09*	1·09*
Male sex (female is reference)	1·84*	1·99*	2·04*	2·03*	2·11*	2·11*
Marital status						
Currently married		Ref.	Ref.	Ref.	Ref.	Ref.
Previously married		1·27*	1·20*	1·20*	1·23*	1·23*
Never married		1·33*	1·24*	1·25*	1·24*	1·24*
Socioeconomic status						
Income equivalence			0·84*	0·86*	0·89*	0·89*
Education						
<12 years				1·21*	1·19*	1·19*
High school graduate				1·11†	1·09†	1·09†
Some college				Ref.	Ref.	Ref.
Employment status						
Employed					Ref.	Ref.
Unemployed					1·58*	1·57*
Not in labour force					1·68*	1·68*
Geographical status						
Metropolitan statistical area						
Central city						1·07
Non-central city						1·04
Farm						0·88
Non-farm						Ref.
Region						
Mid-west						Ref.
North-east						0·85
West						1·00
South						0·88
Log likelihood	− 143,535	− 143,420	− 143,123	− 143,073	− 142,816	− 142,813

†$p \leq 0{\cdot}05$; *$p \leq 0{\cdot}01$.
Interviewed $n = 647{,}015$, deaths due to circulatory diseases over follow-up $n = 19{,}929$.
Source: derived from NCHS (various years).

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Table 7. Hazards ratios of death by underlying cause of diabetes, US adults, 1987–1997

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Body mass index						
Obese, class III (BMI 40·0 or greater)	8·97*	8·75*	7·75*	7·71*	7·31*	7·32*
Obese, class II (BMI 35·0 to less than 40·0)	4·70*	4·66*	4·28*	4·25*	4·16*	4·15*
Obese, class I (BMI 30·0 to less than 35·0)	2·82*	2·81*	2·65*	2·63*	2·64*	2·64*
Overweight (BMI 25·0 to less than 30·0)	1·65*	1·66*	1·63*	1·62*	1·62*	1·63*
Normal (BMI 18·5 to less than 25·0)	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Underweight (BMI less than 18·5)	1·02	1·00	0·98	0·98	0·98	0·98
Sociodemographic status						
Age (single years)	1·08*	1·08*	1·08*	1·08*	1·06*	1·06*
Male sex (female is reference)	1·27*	1·38*	1·45*	1·46*	1·62*	1·62*
Marital status						
Currently married		Ref.	Ref.	Ref.	Ref.	Ref.
Previously married		1·32*	1·20	1·20	1·28†	1·28†
Never married		1·26†	1·11	1·12	1·08	1·08
Socioeconomic status						
Income equivalence			0·76*	0·77*	0·83*	0·83*
Education						
<12 years				1·14*	1·09*	1·08*
High school graduate				1·17*	1·14†	1·13†
Some college				Ref.	Ref.	Ref.
Employment status						
Employed					Ref.	Ref.
Unemployed					1·33	1·34
Not in labour force					2·68*	2·69*
Geographical status						
Metropolitan statistical area						
Central city						0·79†
Non-central city						0·79
Farm						1·47
Non-farm						Ref.
Region						
Mid-west						Ref.
North-east						0·32
West						1·00
South						0·52
Log likelihood	− 8896	− 8887	− 8846	− 8844	− 8784	− 8781

†$p \leq 0{\cdot}05$; *$p \leq 0{\cdot}01$.
Interviewed $n = 647{,}015$, deaths due to diabetes over follow-up $n = 1209$.
Source: derived from NCHS (various years).

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as likely to die due to diabetes during the follow-up period, compared with normal weight individuals. As with overall mortality, the risk of death from diabetes as an underlying cause increases as BMI increases, and as with circulatory disease mortality even overweight individuals have a higher risk of mortality than the normal weight population. However, compared with normal weight individuals, underweight individuals exhibit the same risk of diabetes mortality over the follow-up period.

Each subsequent model decreases the relationship between BMI and diabetes mortality. Model 2 demonstrates that controlling for marital status decreases the risk of death for those in obesity class III from 9·0 times (Model 1) as likely as normal weight people to 8·8 times as likely. Obesity may prevent unmarried individuals from marrying and may contribute to marital dissolution among those who are married. Compared with married individuals, unmarried individuals may lack social support, access to health resources, and assistance in following medical protocols (Rogers, 1995; Waite & Gallagher, 2000).

Model 3 shows that controlling for income decreases the risk of death in people of obesity class III from 8·8 times (Model 2) as likely as normal weight people to 7·8 times as likely. As more variables are included, the very obese receive the greatest decreases in risk. The addition of employment status in Model 5 causes another quite substantive decrease in the effect of obesity class III on diabetes mortality. The hazard ratios indicate that by accounting for employment status, the risk of dying for very obese people decreases from 7·7 times that of normal weight people (Model 4) to 7·3 times that of normal weight individuals (Model 5). This suggests that one reason obese class III individuals die from diabetes is, compared with others, that they are less likely to be employed. Those who are not in the labour force do not have as ready access to health insurance, medical care or work-supported health promotion and disease prevention programmes (Rogers, Hummer & Nam, 2000).

Conclusion

It is important to examine the effects of BMI measures on the risk of mortality because of changes in the distribution of BMI over time. The data presented here show that obesity in the United States increased by over 30% between 1987 and 1994. As greater percentages of individuals become obese, the association between obesity and other risk factors probably changes, leading to different effects on mortality (Expert Panel, 1998). For example, obesity is associated with lower incomes and lower levels of education. But as a greater proportion of the population becomes obese, it is likely that more individuals with higher income and education levels will also be obese (Himes & Reynolds, 2002). Thus, it is crucial to periodically assess the impact on mortality for risk factors that change over time.

Obesity significantly contributes to increased mortality for overall, circulatory disease-specific and especially diabetes-specific mortality, even after accounting for sociodemographic, socioeconomic and geographic variables (Dorn *et al.*, 1997). In fact, accounting for a variety of factors significantly attenuated the risk of death for the most obese people, yet had marginal utility in understanding mortality for those who were overweight or obese class I. This pattern was consistent for overall and circulatory disease mortality, and was most striking for diabetes-specific mortality.

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Persons who are obese class III suffer from a highly elevated risk of death, even after including appropriate statistical controls (Garrison *et al.*, 1983; Manson *et al.*, 1987). But the reductions in mortality risk for people in that category in the most complete statistical models indicate that a variety of social factors are associated with both obesity class III and mortality. Yet the relationship between all classes of obesity and mortality persisted despite the inclusion of a wide range of control variables. Further, the larger number of people who are overweight (31·9%) and obese class I (9·7%) compared with those in obese class II (2·5%) and class III (1·1%) suggests that the greatest reductions in premature mortality – particularly for circulatory diseases and diabetes – might be made through weight reductions among overweight or obese class I individuals. Whereas an extremely high BMI comes with tremendous mortality risks, the prevalence of people in this category is, comparatively speaking, quite low.

Compared with normal weight individuals, individuals in the overweight class (BMI 25·0–29·9) were less likely to die of overall mortality during the follow-up period (Durazo-Arvizu *et al.*, 1998). Nevertheless, they were slightly more likely to die of circulatory diseases and 63% more likely to die of diabetes. Thus, although overweight individuals may not significantly increase their risks of death due to all causes, they have a substantially increased risk of specific causes of death, especially diabetes. Alternatively, compared with normal weight individuals, those who are underweight exhibited 81% higher mortality, a finding that contradicts Lindsted *et al.* (1991). This higher mortality among underweight individuals may be real or could be an artifact of past or current cigarette smoking, or of underlying chronic conditions. That is, some individuals with hip fractures, cancer, or heart, respiratory or infectious diseases may lose weight, and it is the underlying chronic condition, not the low weight *per se*, that affects mortality. Most likely, chronic conditions and cigarette smoking contribute to, but do not fully attenuate, the adverse relationship between lean body mass and mortality (e.g. Cornoni-Huntley *et al.*, 1991; Visscher *et al.*, 2000).

Controlling for socioeconomic status substantially changes the relation between BMI and mortality. For example, compared with normal weight individuals, those who are in obese class III exhibit a 73% higher likelihood of death with controls for age, sex and marital status, but just a 53% higher risk when also controlling for socioeconomic status (compare Models 2 and 5 in Table 3). These relations suggest that education can provide information about healthy diets and ways to maintain ideal body weight, and income can provide the means by which to purchase healthy foods. Further, these relations suggest ways to intervene to reduce obesity: through increased education and health promotion programmes centred in businesses and schools.

For the last several decades, US life expectancies have consistently increased, due in part to reductions in cigarette smoking, better overall standards of living, and increased automobile safety (safer roads and cars, including lap and shoulder belts, front and side air bags, and cars that are built to safely withstand crashes). But increasing rates of obesity may hamper further gains in life expectancy. Obese individuals are more likely to be diabetic, and compared with non-diabetics, diabetics have witnessed smaller declines in mortality over time. Gu *et al.* (1999) assert that the increasing prevalence of diabetes, coupled with the smaller decline in mortality for

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diabetics, may become an increasingly important factor for heart disease mortality in the United States.

Although this paper focuses on mortality, the results suggest morbidity patterns as well. Individuals who die of circulatory diseases and, especially, diabetes, will experience health effects well before death. Many obese individuals will have dealt with treatment and maintenance of diabetes before their eventual demise. Thus, diabetes deaths impart more information than the events surrounding death; they also suggest chronic health conditions in the last several years of life (see Nathan, 1997).

The risk of death due to circulatory diseases and to diabetes was examined through an underlying cause-of-death model. Manton & Stallard (1984) assert that researchers also examine mortality from a multiple-cause-of-death model that allows for the possibility that any death may have more than a single cause and that diseases may interact to produce death. Indeed, combinations of conditions or diseases can be more lethal than single conditions or diseases, affect the timing of death, and influence the mortality differentials between sub-populations (Wrigley & Nam, 1987). These data indicate that diabetes was listed as an underlying or contributing cause over three times as often as it was listed as the underlying cause alone. Any mention of diabetes demonstrated a similar trend in mortality risks as underlying cause of mortality due to diabetes, although the magnitude of the relationship between BMI and mortality risk was lower (results not shown). This is due to the fact that although other causes such as circulatory diseases may be listed as the underlying cause of death, diabetes may greatly increase the number of morbid conditions, and may increase the risk of complications yet diminish the ability to recover from health problems.

The detailed analyses of circulatory disease- and diabetes-specific mortality were possible because of the innovative linkage of the NHIS–MCD files, which permits researchers to pool multiple years of data to examine a large number of deaths. Although this paper focuses on circulatory diseases and diabetes, it is possible to examine other causes in similar detail. Certainly, this unique data set has the potential to help uncover new associations with health behaviours and overall and cause-specific mortality.

BMI has been examined rather than ideal weights, percentage body fat or weights relative to health conditions. Some individuals may have BMIs indicating that they are slightly under- or overweight, but may live long lives if they have a low percentage of body fat and a high percentage of muscle mass. Although BMIs are measured, there is no assessment of diets, the type of foods consumed, or the amount of exercise the person engages in. Clearly, exercise is a central factor associated with health and longevity, and one of the reasons that obesity is hazardous to a person's health is because obesity is a marker for inactivity (see Rogers, Hummer & Nam, 2000). Future research could further examine the interactions among obesity, exercise and mortality.

If the prevalence of obesity continues to increase, the overall risk of mortality, other factors being equal, could also increase. The prevalence of obesity in the US population foreshadows impending health risks and higher mortality. In turn, other things being equal, an increased proportion of deaths can be expected in the United States due to circulatory diseases, and especially due to diabetes-related mortality. Overall, the use of current estimates of a nationally representative population has

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contributed to a greater understanding of the contemporary relationship between obesity and mortality in the United States.

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