Mortality Attributable to Cigarette Smoking in the United States

Richard G. Rogers
Robert A. Hummer
Patrick M. Krueger
Fred C. Pampel

More than 50 years of research and thousands of studies on the relative risks of death for smokers and nonsmokers have demonstrated that cigarette smoking is the single most important preventable cause of premature mortality in the United States (US Department of Health and Human Services [DHHS] 2000). Smoking substantially increases the risks of death from causes that include cancer (especially of the lung, larynx, esophagus, pharynx, mouth, bladder, pancreas, kidney, and cervix), cardiovascular diseases (hypertension, ischemic heart disease, cerebrovascular disease, and atherosclerosis), and respiratory diseases (pneumonia, influenza, bronchitis, emphysema, and chronic airway obstruction) (DHHS 1989, 2001). Given the high mortality rates for these smoking-related diseases, the widespread prevalence of cigarette use has great potential to diminish life expectancy.

This potential persists despite a major decline in the level of smoking since 1964, when the US Surgeon General's report first highlighted the negative consequences of cigarette use. In 1965, 42 percent of US adults aged 20 years and older smoked, 14 percent had formerly smoked, and 44 percent had never smoked (CDC 2002c). By 2000, the corresponding figures had improved to 23 percent current smokers, 23 percent former smokers, and 54 percent never smokers. While encouraging, the trends nonetheless leave a large population vulnerable to the harmful effects of smoking. Moreover, the rate of decline in cigarette use has stalled. The adoption rates by youth increased during the 1990s (Mendez, Warner, and Courant 1998), and slower rates of decline among females relative to males have narrowed the long-standing female advantage in lung cancer mortality and life expectancy (Pampel 2002).

The stubborn resistance of cigarette use to efforts at eradication suggests that smoking will remain a major source of premature mortality in years to come. Public warnings about the harm to health of smoking are so well known that the US public actually overestimates the risks (Viscusi 1992); higher cigarette prices due to taxes and to lawsuits against tobacco companies create a financial disincentive to smoke; prohibitions against smoking in office buildings, public facilities, and even restaurants and bars force smokers into outside streets, alleyways, and quarantined rooms; and nonsmokers feel free to criticize smokers as a public nuisance and shame them for their inability to stop a destructive habit. Still, about 44 million Americans aged 20 and older in the year 2000 were at risk of early death from current cigarette smoking, and about another 44 million were at risk from former cigarette smoking (CDC 2002c).

Attempting to present a concrete figure that summarizes the harm of smoking for health, the 1989 Surgeon General's Report (DHHS 1989) calculated the number of US deaths attributed to cigarette smoking to be about 400,000 a year—a number that has received much publicity. Building on the method used in the report, CDC (2002a) has created a web page that allows users to calculate the same figure for more recent years (and, if desired, for particular states and demographic subgroups). CDC (2002a) calculations estimate 394,507 deaths due to smoking in the year 2001, or about 16.3 percent of all US deaths during the year.

Problems in determining the implications of cigarette smoking for mortality and life expectancy

The figure of almost 395,000 excess deaths, the data on which it is based, and the methods used to calculate it have produced some controversy (Levy and Marimont 1998), as have earlier estimates that have suggested up to 500,000 excess deaths per year in the United States due to tobacco use (Ravenholt 1984, 1990). Several limitations of the procedures used to determine smoking-attributable deaths have been noted in the literature. First, the calculations are often based on relative risks of death for smokers and nonsmokers obtained from a nonrandom sample of the US population (Sterling, Rosenbaum, and Weinkam 1993). For example, the American Cancer Society's (ACS) prospective Cancer Prevention Study II (Garfinkel 1980) of one million Americans aged 30 and older from 1982 to 1992 provides a sample large enough to reliably estimate the mortality of current, former, and never smokers by age, sex, and cause of death. But the sample relies on volunteers, who tend on average to have higher education than the population as a whole. By overrepresenting high-status healthy nonsmokers, the sample tends to overstate the benefits of nonsmoking and exaggerate the risks of smoking.

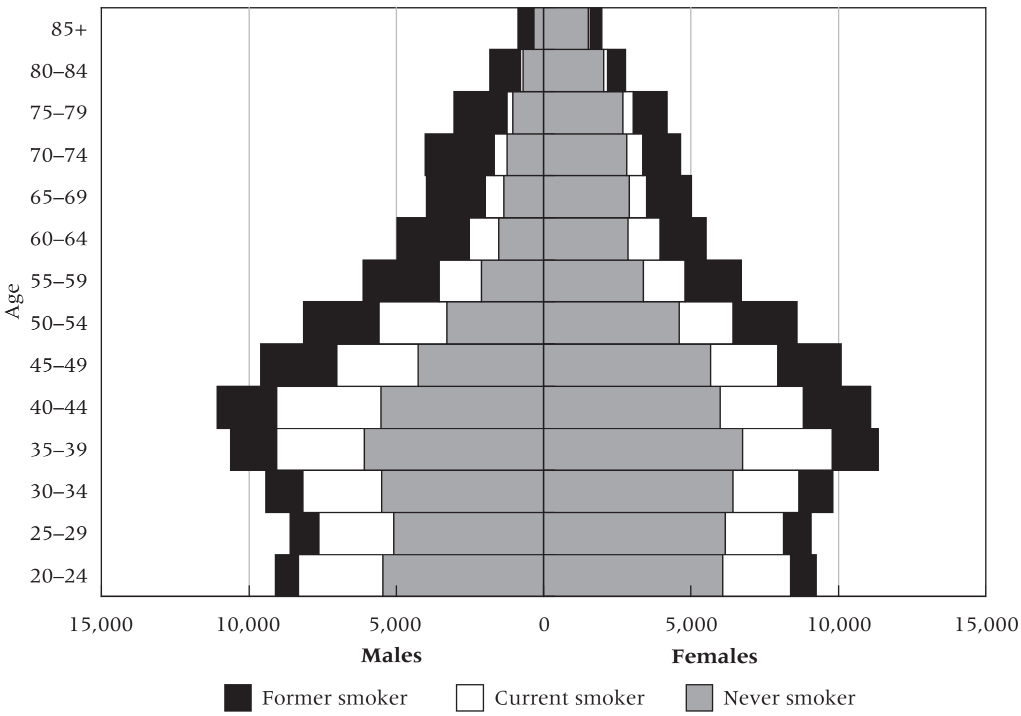
Malarcher et al. (2000) thus finds evidence that the smoking-attributed mortality calculated from relative risk rates in the ACS data is 19 percent higher than would be derived from a representative sample of the US population.

Second, studies typically rely on crude categories of smoking status and age, as well as an incomplete set of causes of death (CDC 2002b). By distinguishing between never, former, and current smokers, but without attending to different numbers of cigarettes smoked by former and current smokers, efforts to identify the harm of smoking may miss critical information. Measuring the amount of smoking is crucial because a dose–response relationship exists between smoking and mortality: for both former and current smokers, the risk of death increases as cigarette consumption increases (DHHS 1989). At exceptionally low levels, smoking has modest effects. More seriously, heavy current and former smokers have significantly higher risks than nonsmokers, and also than light and moderate current and former smokers (Rogers, Hummer, and Nam 2000).

Other measurement problems appear in the treatment of age and cause of death. Calculations sometimes group together persons aged 35–64 years (CDC 2002a), but smoking prevalence and mortality risks vary substantially between those aged 35–40 and those aged 60–64. Such calculations also ignore those under age 35, yet individuals who begin in early adolescence could smoke for 15–17 years before turning 30—time enough to develop heightened smoking-related mortality risks. Similarly, calculations sometimes concentrate on only the four most common smoking-related causes of death (Malarcher et al. 2000), even though individuals are at risk from at least 30 specific causes of death. Studies require both precision when measuring age and breadth when considering causes of death related to smoking (Hummer, Nam, and Rogers 1998).

Third, the calculation of excess or smoking-attributable deaths alone fails to draw out the implications for potential years of life lost and life expectancy (Nam, Rogers, and Hummer 1996). Deaths from smoking have different consequences for life expectancy depending on the age at which they occur. Deaths at younger ages do more to reduce life expectancy than deaths at older ages. Moreover, smoking prevalence varies with age. To illustrate, Figure 1 presents smoking prevalence by age and sex in the United States in 2000 (see also Appendix Table A). The figure displays a curvilinear pattern with age; there are low rates of ever smokers at young adult ages, higher rates of current smokers at middle ages, and low rates of current female smokers and high rates of former male smokers at older ages. These age-specific smoking patterns translate into varied rates of smoking-related deaths across the life course and have diverse consequences for life expectancy. Fully understanding the mortality consequences of smoking thus requires attending to age patterns of smoking and mortality and their implications for life expectancy rather than focusing on the number of deaths

FIGURE 1 US adult population (in thousands) in 2000 by age and sex, according to smoking status



SOURCE: Derived from NCHS 2002.

alone. But such calculations are not commonly made (see Rogers and Powell-Griner 1991, for an exception).

Fourth, calculations that are based on relative risks of mortality for smokers and nonsmokers rarely adjust for confounding factors. Compared to nonsmokers, smokers are more likely to be poor, characterized by fewer years of schooling, be exposed to workplace carcinogens, experience less social integration, and have chronic health conditions, thereby reducing their non–smoking-related chances for survival (Levy and Marimont 1998; Link and Phelan 1995; Mirowsky 1999). Similarly, smokers tend to engage in other risky behaviors that increase their chance of death: excessive drinking, reckless driving, physical inactivity, and nonuse of seatbelts (Gunnarsson and Judge 1997; Paffenbarger et al. 1993; Schoenborn 1986). Further, individuals who experience high stress levels may be more likely to smoke and die early. Efforts to partial out the influence of confounding factors more precisely have produced mixed results: some early evidence suggested that the specification bias was substantial (Peto et al. 1994; Sterling et al. 1993), but the preponderance of other, especially more recent evidence finds only small differences in the relative risks of smoking with and without controls (LaCroix et al. 1991; Thun, Apicella, and Henley 2000; Malarcher et al. 2000). In any case, the potential for bias suggests the need to determine the harm of smoking net of related social and lifestyle factors.

Consider in more detail some of the factors that may bias the effect of smoking on mortality. Measures of socioeconomic status—such as income, educational level, and employment status—are negatively associated with smoking and with mortality risk. Lower socioeconomic status is not only associated with smoking, but also increases the risk of death through reduced exercise, increased stress, poorer diets, and less access to health information and medical care (Adler et al. 1994). Education is commonly used as a socioeconomic control in smoking research because it is one of the best sociodemographic predictors of cigarette smoking, and because in adulthood it is relatively stable and unlikely to be affected by poor health (Zhu et al. 1996). More highly educated individuals are more likely to invest in their health and to make better-informed and therefore sounder decisions (Hummer, Rogers, and Eberstein 1998; Sickles and Taubman 1997). For example, compared to individuals aged 25 and older with 16 or more years of education, those with 13 to 15 years of schooling are 2.1 times as likely to smoke, those with 12 years of schooling are 2.8 times as likely to smoke, and those with 9 to 11 years of schooling are 4.2 times as likely to smoke (Zhu et al. 1996). And compared to individuals with lower educational levels, those with higher levels experience lower mortality (Rogers et al. 2000).

Individuals who consume alcohol are also more likely to smoke. For example, 37 percent of men and women who consume four or more drinks per day are also current smokers, whereas just 22 percent of those who consume less than one drink per day are current smokers (Thun et al. 1997). Overall, moderate alcohol consumption confers survival advantages. Compared to abstainers, males and females who consume at least one alcoholic drink a day can expect a 30 to 40 percent lower risk of death due to cardiovascular diseases (Doll et al. 1994; Thun et al. 1997). Nevertheless, heavy drinking can lead to heightened risks of death, especially from cirrhosis of the liver, some cancers, and violent causes (Thun et al. 1997). Although moderate alcohol consumption can slightly reduce the risk of death, smoking doubles the mortality risk (Thun et al. 1997).

Body mass is also associated with both smoking and mortality risk (Garrison et al. 1983). Generally, former smokers have higher body mass than never smokers, who in turn have higher body mass than current smokers. Smoking reduces body fat by reducing caloric intake, increasing metabolic rate, and increasing the level of energy expended (Himes 2000). Additionally, smokers often have poor diets (Levy and Marimont 1998). Because smoking can reduce body mass, quitting smoking may lead to weight gain and higher mortality risk due to greater body mass. Furthermore, smokers who are underweight may experience increased risk of death because being underweight indicates an underlying chronic condition, often associated with wasting, such as cancer, emphysema, or other chronic respiratory diseases (Krueger et al. 2004).

The association between smoking and mortality may also be in part due to the beneficial consequences of social ties among nonsmokers. People who do not smoke are more likely to be married. Marital stability over time, in fact, has been linked to higher rates of nonsmoking. In turn, a number of studies have shown that social ties, including marriage, are associated with better health and lower mortality (Rogers 1992; Rogers et al. 2000). Marriage acts to select healthy individuals, to enhance social integration, and to encourage healthful behavior (Lillard and Waite 1995).

Given the limitations of previous literature, this study offers alternative estimates of the effect of cigarette smoking on US adult mortality and translates the estimates into their influence on life expectancy. To build on existing efforts, we (1) use a representative national sample, (2) measure risks of mortality for detailed categories of smoking and age, and consider all causes of mortality rather than specific causes of death, (3) attend to age and sex differences in smoking-related deaths and their consequences for life expectancy, and (4) control for numerous confounding factors. Such enhancements are possible through the application of life tables with covariates, a relatively new and powerful demographic technique. These efforts inform debates and controversies regarding whether the harm of smoking is overstated or understated by government agencies and common estimation procedures, and in so doing we provide a more nuanced picture of the overlapping factors that influence adult mortality in the United States.

Data and methods

To examine the relationship between smoking and adult mortality in the United States, we use the 1990 National Health Interview Survey Health Promotion and Disease Prevention (NHIS-HPDP) supplement. The NHIS is a nationally representative survey of the noninstitutionalized population of the United States that includes annual information on a core set of questions that remain virtually unchanged from one year to the next, and records such variables as age, sex, marital status, family size, income, education, and employment status. It also adds supplemental questions that vary from year to year. The 1990 NHIS-HPDP includes information on cigarette smoking, along with detailed data on other important health behaviors, for 41,104 sample respondents aged 18 and older (NCHS 1993).

One of the most comprehensive mortality data sources available for the United States comes from matching the NHIS to the Multiple Cause of

Death files (NHIS-MCD) via the National Death Index. The record linkage was accomplished through a probabilistic matching scheme that assigns weights to each of 12 factors: 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 1993, 1996; NCHS 2000). Eliminating records with missing data on key variables and records that are ineligible to be linked to death certificates results in 36,592 individual records of adults aged 20 years and older.[1] Matches to the MCD file through December 1997 yield 3,097 deaths over the seven-year follow-up period (NCHS 1993, 2000). The strengths of the data set include its nationally representative character, large size, breadth and depth of health behaviors including cigarette smoking, relatively small amount of missing data, and high quality of matches between the NHIS and MCD files (Patterson and Bilgrade 1986).

Variables and measurement

We code cigarette smoking status, our key predictor variable, into never smokers, current smokers who consume less than a pack of cigarettes (fewer than 20) per day, current smokers who consume a pack to less than two packs of cigarettes (20 to fewer than 40) per day, current smokers who consume two or more packs of cigarettes (40 or more) per day, former smokers who on average consumed less than a pack (fewer than 20) a day, former smokers who consumed a pack to less than two packs (20 to fewer than 40) per day, and former smokers who consumed two or more packs (40 or more) per day.[2] Following convention, never smokers are defined as those who have consumed 100 or fewer cigarettes in their lifetimes. This coding scheme is more comprehensive than earlier efforts that estimated smoking-related mortality risks and life expectancies (e.g., Rogers and Powell-Griner 1991; Sterling et al. 1993; Thun et al. 2000).

The demographic control variables are age, sex, race, and marital status. Marital status is coded as currently (referent), previously, and never married. We control for race by comparing blacks to others (referent). We code sex categorically, with females as the referent. We code age in five-year groups, from 20–24 through 85 and older, with ages 20–24 as the referent. This coding scheme allows us to calculate five-year smoking-specific mortality rates by sex, providing the necessary input for the calculation of correspondingly detailed life tables.

The socioeconomic variables are family income, employment status, and education. Education is categorized as 11 or fewer years of education, high school completion, and some college or more (referent). Employment status is coded as employed (referent), unemployed, or not in the labor force. We measure family income in 1990 dollars. Except for family income, there are relatively few missing data for the variables. We imputed income data for about 17 percent of the records.[3]

Further, NHIS income categories are not defined for equal intervals. For values under $50,000, we took the midpoint of the interval and divided it by 10,000, to approximate a continuous income value. Because the top category of $50,000 and above is open-ended and lacks a midpoint, we estimated a median value for this category.[4]

We also control for health behaviors and conditions that are associated with cigarette smoking and amenable to change: exercise, body mass, drinking, seatbelt use, and stress. The respondent is asked whether he or she is more active, less active, or about as active as others of the same age (referent). Unlike many objective measures of physical activity (e.g., metabolic equivalent levels), which show great variability by age, this variable, which assesses respondents' perceptions of their activity relative to their peers, provides more consistency by age (see Piani and Schoenborn 1993). We operationalized body mass through the body mass index (BMI), which is calculated by dividing weight in kilograms by height in meters squared and is classified according to the World Health Organization (1997) as normal weight (BMI 18.5–24.9; the referent), underweight (BMI <18.5), overweight (BMI 25.0–29.9), or obese class I (BMI 30.0–34.9), II (BMI 35.0–39.9), or III (BMI 40 or greater). Drinking status is categorized as current drinker (referent), former drinker, infrequent drinker, and abstainer. Although studies have demonstrated higher mortality risk among excessive drinkers, small sample sizes precluded detailed examination of drinkers at very high levels of alcohol consumption. Seatbelt use compares individuals who wear seatbelts at least some of the time to those who never wear seatbelts when driving (referent). The stress variable captures self-reports of whether respondents experience stress a lot or not a lot (referent).

Discrete-time hazard models

We employ discrete-time hazard models to determine the risk of death from cigarette smoking, net of other covariates. With prospective data that follow the records of individuals who were interviewed in 1990 to determine whether they died between the time of the interview and the end of 1997 (NCHS 2000), we have a dichotomous dependent variable and cases based on the combination of persons and number of years survived. Assuming that the deaths are distributed evenly within each year, the pooling of persons and years in the discrete-time hazard models means, for example, that individuals who survive a year contribute one person-year of survival, and individuals who die within the second year contribute one person-year of exposure and one death. Because individuals were interviewed throughout 1990, some were exposed to the risk of death for nearly the entire year (from January through December), while others were exposed for as little as a few days (for example, if they were interviewed in late December);

therefore, we counted 1990 as one-half a person-year of exposure. Thus, individuals interviewed in 1990 could have contributed as many as 7.5 person-years of survival over the full range of the follow-up period.

In the discrete-time hazard models, estimates take the form of logistic regression coefficients (Allison 1984; Powers and Xie 2000). To determine which particular sets of variables contribute most to the confounding of the relationship between smoking and mortality risk, we build our models progressively (see Mirowsky 1999). The first model examines the relationship between cigarette smoking and mortality, controlling only for basic demographic variables. More complex models sequentially include socioeconomic status, health behaviors, and health conditions. Progressive adjustment is a valuable way to first show that an association exists and then show how holding sets of confounding variables constant will reduce, accentuate, or eliminate the association. We corrected all coefficients and standard errors in the models for stratification and clustering in the sample design.[5]

Life tables with covariates

Whereas conventional life tables numerically express the expected number of years of additional life to be lived at specific ages given a set of age-specific mortality rates, life tables with covariates also adjust for factors such as alcohol consumption, exercise, and socioeconomic status that are needed to identify the independent mortality risks associated with smoking status. With the intercept and coefficients from the discrete-time hazard models, we construct smoking-status-specific life tables with covariates by converting the coefficients to age-specific central death rates, or m_x values (Moore and Hayward 1990). In conventional life table analysis, the central death rate is calculated by dividing the deaths for individuals at a specific age during the year by the age-specific midyear population. Using the multivariate model, we calculate m_x values, separately by sex, with the following equation:

$$m_x = \frac{1}{1 + e^{-z}}$$

where x is a specific age group, say, ages 20 to 24, and z is the estimated logit coefficient for the age group and a given set of values for the other variables.

Excess deaths from smoking

To determine how many deaths are attributable to smoking, we calculate the number of excess deaths on the basis of age-specific population size, age-specific smoking prevalence, and mortality risk. With 2,349,005 deaths among individuals aged 20 and older in the United States in 2000 (Miniño et al. 2002), the excess number of deaths measures how many of these deaths could have been averted if all current and former smokers were to experience the mortality risk associated with never smokers or with less risky smoking statuses. Building on the general formulas for attributable fractions, or the proportion of deaths that were caused by cigarette smoking (see Lilienfeld and Stolley 1994), we calculate age- and sex-specific deaths for five-year age groups and smoking-specific deaths for six smoking statuses.

First, we determine how many individuals would be in each smoking status by multiplying the age- and sex-specific smoking status prevalence rates (derived from NCHS 2002) by the age- and sex-specific population, based on the age- and sex-specific distribution of the US adult population in the year 2000 (US Census Bureau 2000). Table A of the Appendix lists these numbers. Second, we compute the excess risks of each smoking status relative to never smokers by subtracting the age-specific central death rates for never smokers from the age-specific central death rates for each of the smoking statuses. These death rates come from our analysis of the NHIS-MCD data. Third, we multiply the excess age-specific death rates for each smoking status by the number of persons in each age group and smoking status. This product translates the age-specific excess rates into age-specific excess deaths. Fourth, we sum the excess number of deaths for each age group within each smoking status and then sum the excess number of deaths for all smoking statuses to obtain a total.

For example, the number of excess deaths (*ED*) for current heavy smokers (*c*) compared to never smokers (*n*) comes from the following formula:

$$ED_c = \sum_{x=20-24}^{85+} \left[(Prev_{x,c} * Pop_x) * (m_{x,c} - m_{x,n}) \right]$$

where $Prev_{x,c}$ is the prevalence of current heavy smokers at age x, Pop_x is the age-specific population, $m_{x,c}$ is the central death rate for current heavy smokers at age x, and $m_{x,n}$ is the central death rate for never smokers at age x (for similar calculations, see Doll and Peto 1981a, 1981b). After using the formula to calculate the number of excess deaths for light, moderate, and heavy former and current smokers, we calculate the total number of excess deaths separately by sex. This approach also allows us to estimate the number of excess deaths that would be saved through other, more logically consistent transitions—for example, if all current smokers became former smokers.

Results

Table 1 presents descriptive statistics for each variable by smoking status. Females are more likely than males to be never smokers, as are blacks than

TABLE 1 Percent distribution of demographic, social, and behavioral characteristics by smoking status, US adults, 1990

	Current smoker			Former smoker			Never smoker
	2+ packs	1–<2 packs	<1 pack	2+ packs	1–<2 packs	1 pack	
Age (years)[a]	47.1	44.9	41.8	57.5	54.2	50.2	45.6
Sex							
Female	1.5	10.2	11.6	2.3	6.5	9.8	58.1
Male	3.8	14.0	10.9	7.2	12.2	9.6	42.4
Race							
Non-black	2.8	12.6	10.4	5.0	9.7	9.7	49.8
Black	0.8	7.7	18.2	1.4	5.2	9.2	57.5
Marital status							
Currently married	2.7	12.2	10.1	5.5	11.0	10.8	47.7
Previously married	3.6	14.7	13.0	4.5	8.4	8.5	47.4
Never married	1.2	9.2	14.1	1.4	3.5	6.7	64.0
Family income (in 1990 $10,000s)[a]	3.4	3.2	3.1	3.8	3.8	3.8	3.5
Employment status							
Employed	2.7	12.9	11.6	4.1	8.8	9.5	50.4
Unemployed	4.8	16.6	17.5	3.2	5.9	7.0	45.0
Not in the labor force	2.2	9.7	9.8	5.8	10.5	10.3	51.7
Education							
11 years or less	3.5	15.9	13.8	5.0	9.2	8.6	44.1
High school degree	3.1	14.3	12.7	4.8	9.2	8.9	47.1
Any college	1.7	8.0	8.7	4.3	9.2	11.0	57.2
Drinking status							
Non-drinker	0.7	4.1	5.1	1.1	2.9	3.4	82.7
Infrequent drinker	1.6	8.8	9.5	2.5	6.4	8.3	63.0
Former drinker	3.7	12.4	8.6	9.6	17.8	13.0	34.8
Current drinker	3.1	14.8	13.7	5.2	10.2	11.1	41.9
Seatbelt use							
Never	7.0	22.8	12.5	6.3	8.3	6.5	36.5
At least some of the time	2.2	11.0	11.2	4.4	9.3	10.0	52.0
Stress							
A lot	4.2	14.2	13.0	4.8	8.8	9.3	45.8
Not a lot	2.0	11.2	10.6	4.5	9.4	9.8	52.5
Physical activity							
More active than peers	2.4	10.1	10.7	5.5	10.2	10.9	50.4
About as active	2.4	12.7	11.3	4.1	8.9	9.2	51.4
Less active	3.4	13.6	12.1	4.4	8.3	8.9	49.3
Body mass index							
Obese class III	3.5	9.6	9.0	8.1	7.9	9.0	53.0
Obese class II	2.8	9.7	8.5	5.2	9.0	9.1	55.6
Obese class I	2.9	9.5	10.4	8.2	9.8	9.2	49.9
Overweight	3.0	11.2	10.0	6.3	11.2	10.0	48.3
Normal weight	2.2	13.1	12.1	3.0	8.2	9.7	51.9
Underweight	2.6	13.9	16.8	1.6	5.0	8.6	51.5

[a]Age and family income represent mean values rather than percents.
SOURCE: Derived from NCHS 1993.

nonblacks, never-married individuals than married ones, people not in the labor force than those unemployed, and more highly educated people than less highly educated ones. Similarly, nondrinkers are more likely than drinkers to be never smokers, as are regular seatbelt users than nonusers, people experiencing less stress than those under stress, and physically active people than inactive ones. Individuals who engage in unhealthy behaviors or exhibit less healthy characteristics—for example, those who never wear their seatbelts, who are under a lot of stress, and who are less physically active—are more likely to smoke, and, among smokers, to be moderate or heavy smokers. For example, 23 percent of those who never wear a seatbelt are current moderate smokers; in contrast just 11 percent of those who wear a seatbelt at least some of the time are moderate smokers. Thus, we find correlations between smoking and other covariates of mortality risk. For the multivariate models that simultaneously control for these risk factors in predicting mortality, we turn to Table 2.

Table 2 reveals the relationship between smoking status and mortality risk net of other covariates. We present results for eight models. Model 1 examines the effects of smoking and age on mortality risk. Among all smoking statuses, never smokers (the referent) experience the lowest risk of death over the follow-up period, and former smokers experience lower mortality than current smokers. Former and current smokers display a clear mortality gradient associated with cigarette consumption. Indeed, over the follow-up period, compared to never smokers, current light smokers (less than a package of cigarettes per day) experience a 2.4-fold greater mortality risk (or $e^{0.861}$), current moderate smokers (one to less than two packs per day) experience a 2.5-fold greater mortality risk, and current heavy smokers (two or more packs) experience a 3.6-fold greater mortality risk.

Model 2 additionally controls for sex. Because, compared to females, males experience higher mortality, are more likely to smoke, and have higher levels of cigarette consumption, controlling for sex reduces the mortality differentials by smoking status. In fact, the differential between former light smokers and never smokers is no longer statistically significant. Model 3, which controls for both demographic and socioeconomic factors, further reduces the smoking status differentials compared to Model 2.

Controlling for the beneficial effects of light to moderate drinking in Model 4 actually increases the mortality gap between never smokers and people with other smoking statuses (for similar results, see Thun et al. 2000). There is a J-shaped relationship between drinking and mortality: compared to moderate and infrequent drinkers, nondrinkers and former drinkers experience higher mortality risk. Compared to individuals who have never smoked, individuals who have ever smoked are also more likely to drink (see Table 1; see also Thun et al. 1997). Model 5 adjusts for other health behaviors and health conditions. In combination, other health behaviors further attenuate the relationship between smoking status and mortality; nevertheless, the relationship between cigarette smoking and mortality remains strong after the inclusion of these behavioral and health covariates.

Finally, Model 6 adjusts for all covariates simultaneously. Controlling for demographic, socioeconomic, and most health and behavioral factors dampens the excess mortality attributable to smoking, but controlling for drinking slightly increases the differential.[6] All told, the most inclusive model reveals that current smokers exhibit more than twice the risk of mortality in the seven-year follow-up period compared to never smokers, with the greatest risk for current heavy smokers. In addition, former light, moderate, and heavy smokers all continue to show considerably higher mortality risks in the most complete model, although not as high as any of the current smoking categories. Among the current smoking statuses, controlling for covariates has a greater impact at heavier smoking levels. For example, compared to Model 1, in Model 6 the coefficient for current light smokers is lower by .130, the coefficient for current moderate smokers is lower by .176, and the coefficient for current heavy smokers is lower by .328. Thus, while controlling for confounding effects is clearly important and has a greater impact among individuals with higher levels of cigarette consumption, the smoking–mortality relationship remains extremely strong and graded according to smoking status.

Because both smoking and mortality vary by sex, Models 7 and 8 present sex-specific results for the full models. For each smoking category, relative risks of death are higher for females than for males. For example, compared to male never smokers, male heavy smokers experience a 2.2-fold higher risk of death over the follow-up period; but compared to female never smokers, female heavy smokers suffer a 3.5-fold higher risk of death over the follow-up period. Thus, net of other factors, smoking seems to be more hazardous for females than for males.[7] More than likely, this is due to generally higher mortality among nonsmoking men compared to nonsmoking women, but it could also reflect sex differences both in lifetime smoking patterns and in reporting patterns of cigarette smoking.

Although the relationships in Table 2 impart important information, they cannot be interpreted as intuitively as one would interpret life expectancies. Fortunately, we can convert the regression coefficients into central death rates and, ultimately, into life expectancy estimates. Table 3 displays sex-specific life expectancies at age 20 by smoking status, controlling for various risk factors. For the first set of columns, "Average," we calculate smoking-specific life expectancies by providing sample averages for the other covariates, including race, marital status, and the socioeconomic and behavioral factors. Life expectancy estimates at age 20 are hypothetical and based on the set of age-specific rates calculated for particular smoking statuses. Thus, the estimates for, say, former light smokers are based on a hypothetical set of per-

TABLE 2 Logistic regression coefficients of smoking status and other risk factors on mortality, US adults, 1990–97

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7 (females)	Model 8 (males)
Smoking status[a]								
Current 2+	1.274*	1.117*	1.037*	1.071*	0.912*	0.946*	1.240*	0.803*
Current 1–<2	0.910*	0.812*	0.753*	0.795*	0.695*	0.734*	0.803*	0.656*
Current <1	0.861*	0.811*	0.718*	0.758*	0.695*	0.731*	0.851*	0.609*
Former 2+	0.637*	0.448*	0.471*	0.501*	0.447*	0.473*	0.648*	0.399*
Former 1–<2	0.529*	0.377*	0.379*	0.406*	0.363*	0.388*	0.502*	0.321*
Former <1	0.178*	0.084	0.097	0.127*	0.109	0.137*	0.222*	0.061
Never	ref	ref	ref	ref	ref	ref	ref	ref
Age (years)								
20–24	ref	ref	ref	ref	ref	ref	ref	ref
25–29	–0.494	–0.484	–0.346	–0.341	–0.367	–0.361	–0.405	–0.328
30–34	–0.348	–0.331	–0.072	–0.068	–0.103	–0.097	–0.515	0.047
35–39	–0.243	–0.222	0.087	0.085	0.057	0.059	–0.290	0.180
40–44	0.399	0.424	0.763*	0.755*	0.725*	0.721*	1.257*	0.432
45–49	0.512	0.545*	0.906*	0.891*	0.872*	0.864*	1.179*	0.720*
50–54	1.019*	1.063*	1.405*	1.386*	1.395*	1.383*	1.804*	1.157*
55–59	1.455*	1.501*	1.784*	1.766*	1.789*	1.776*	1.979*	1.692*
60–64	2.098*	2.143*	2.328*	2.306*	2.354*	2.338*	2.774*	2.100*
65–69	2.403*	2.449*	2.476*	2.453*	2.533*	2.515*	2.690*	2.452*
70–74	2.922*	2.974*	2.875*	2.855*	2.982*	2.966*	3.274*	2.825*
75–79	3.328*	3.384*	3.223*	3.206*	3.354*	3.340*	3.771*	3.095*
80–84	3.704*	3.766*	3.540*	3.517*	3.684*	3.664*	4.121*	3.390*
85+	4.398*	4.476*	4.195*	4.166*	4.373*	4.347*	4.745*	4.138*
Sex (male=1)		0.384*	0.508*	0.514*	0.571*	0.576*		
Race (black=1)			0.249*	0.235*	0.217*	0.206*	0.145	0.276*
Marital status								
Currently married			ref	ref	ref	ref	ref	ref
Previously married			0.148*	0.147*	0.134*	0.133*	0.160*	0.054
Never married			0.255*	0.251*	0.237*	0.235*	0.257*	0.189
Family income			–0.058*	–0.052*	–0.049*	–0.044*	–0.027	–0.055*
Employment status								
Employed			ref	ref	ref	ref	ref	ref
Unemployed			0.489*	0.500*	0.467*	0.476*	–0.154	0.655*
Not in the labor force			0.524*	0.515*	0.429*	0.424*	0.460*	0.412*
Education								
11 years or less			0.216*	0.188*	0.168*	0.147*	0.046	0.215*
High school degree			0.055	0.051	0.053	0.050	0.013	0.067
Any college			ref	ref	ref	ref	ref	ref
Drinking status								
Non-drinker				0.208*		0.183*	0.286*	0.088
Infrequent drinker				–0.075		–0.076	–0.066	–0.039
Former drinker				0.192*		0.151*	0.250*	0.094
Current drinker				ref		ref	ref	ref
Seatbelt use (never=1)					0.161*	0.158*	0.231*	0.109
Stress (a lot=1)					0.204*	0.203*	0.224*	0.190*

continued.../

TABLE 2 (continued)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7 (females)	Model 8 (males)
Physical activity								
More active than peers					–0.242*	–0.235*	–0.198*	–0.264*
About as active					ref	ref	ref	ref
Less active					0.307*	0.300*	0.367*	0.231*
Body mass index								
Obese class III					0.369*	0.360*	0.210	0.601
Obese class II					0.183	0.181	0.258	0.038
Obese class I					0.034	0.038	–0.011	0.065
Overweight					–0.039	–0.040	–0.085	–0.010
Normal weight					ref	ref	ref	ref
Underweight					0.371*	0.358*	0.214	0.655*
Intercept	–6.791*	–6.962*	–7.387*	–7.453*	–7.478*	–7.536*	–8.023*	–6.681*
Log likelihood	–14,250	–14,203	–14,064	–14,048	–13,975	–13,963	–6,519	–7,405

[a]Packs of cigarettes per day.
*p < .05.
SOURCES: Derived from NCHS 1993, 2000.

sons who are exposed to the complete set of age-specific rates for former light smokers. (Appendix Tables B and C provide abridged sex-specific smoking-status life tables for the Average column in Table 3.[8])

In the Average case, compared to female never smokers at age 20, female current light smokers can expect to live 14.1 fewer years, female current moderate smokers can expect to live 13.4 fewer years, and female current heavy smokers can expect to live 19.1 fewer years. There is also a graded relationship between never and former smokers depending on quantities smoked. Compared to female never smokers at age 20, female former light smokers can expect to live 4.3 fewer years, female former moderate smokers can expect 9.0 fewer years, and female former heavy smokers can expect 11.2 fewer years of life.[9] In the Average case, the gap between female never smokers and all other smoking categories is appreciably larger than in the comparisons for males.

The best-case scenario, in the second set of columns, assumes that all individuals are married, have high socioeconomic status, and engage in healthy behaviors. This is not a realistic scenario: few people fit it with perfect consistency throughout their lives, and at older ages individuals are likely to become widowed, retire, earn less income, and become less active. Thus, the life expectancy figures at age 20 should be interpreted as purely illustrative. Nevertheless, the best case is instructive: compared to female current heavy smokers, female never smokers can expect to live 29.6 additional years; and compared to male current heavy smokers, male never smokers can expect to live 15.4 additional years. Although these estimates

TABLE 3 Sex-specific life expectancy estimates at age 20, in years, by smoking status, for combinations of health and socioeconomic status, US adults, 1990–97

	Average[a]		Best case[b]		High socioeconomic status/poor health[c]		Low socioeconomic status/good health[d]		Worst case[e]	
Smoking status	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**
Never smoker	72.4	63.4	92.4	75.2	57.8	49.6	73.0	58.8	48.1	37.1
Current smoker										
Two or more packs per day	53.3	51.5	62.8	59.8	42.8	39.2	53.7	47.7	34.0	27.2
One to less than 2 packs per day	59.0	53.5	70.4	62.1	47.9	41.0	59.4	49.6	38.9	29.0
Less than 1 pack per day	58.3	54.1	69.4	62.9	47.3	41.6	58.7	50.3	38.3	29.5
Former smoker										
Two or more packs per day	61.2	57.1	73.6	66.7	49.7	44.3	61.5	53.1	40.6	32.1
One to less than 2 packs per day	63.4	58.3	77.0	68.1	51.5	45.3	63.8	54.2	42.3	33.1
Less than 1 pack per day	68.1	62.4	84.8	73.8	54.9	48.8	68.6	57.9	45.5	36.4

[a]Average case indicates average values for socioeconomic and health status.
[b]Best case assumes that all individuals are married, earn $50,000, are employed, have some college education, currently drink, use a seatbelt, are not under a lot of stress, are more active than peers, and are of normal weight.
[c]High socioeconomic status/poor health assumes that individuals earn $50,000, are employed, have some college education, abstain from drinking, never use a seatbelt, are under a lot of stress, are less active than peers, and are in obese class III.
[d]Low socioeconomic status/good health assumes that individuals earn $15,000, are not in the labor force, have 11 years of education or less, currently drink, use a seatbelt, are not under a lot of stress, are more active than peers, and are of normal weight.
[e]Worst case assumes that individuals have never married, earn $15,000, are not in the labor force, have 11 years of education or less, abstain from drinking, never use a seatbelt, are under a lot of stress, are less active than peers, and are in obese class III.
SOURCES: Derived from Table 2, Models 7 and 8, and from Appendix Tables B and C.

are based on data that exclude persons living in institutional settings, who might be less healthy, these results show the powerful influence of heavy smoking within a population that has statistically been freed of other risk factors.

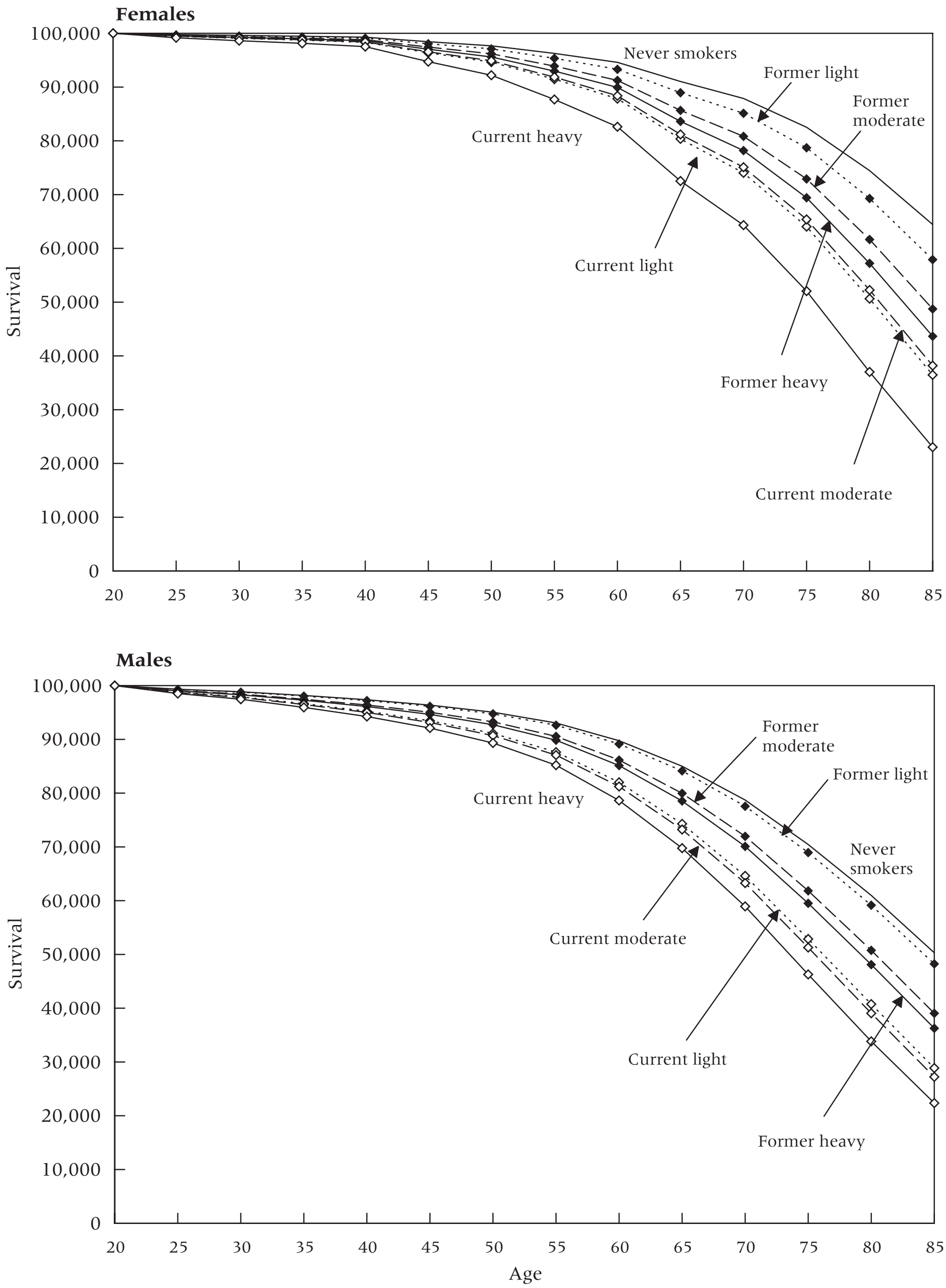
Although both the socioeconomic status and health dimensions are clearly important, the third and fourth columns show that individuals can expect to live longer with good health but low socioeconomic status than with the reverse. At the same time, smoking status continues to strongly differentiate individuals within each of these hypothetical groups and in comparison to hypothetical individuals in the other columns. Looking at the first, third, and fourth sets of columns in Table 3, an Average never smoker can expect to live longer than any current or former smoker who has either poor health or low socioeconomic status. Indeed, only former smokers in the best-case scenario (second set of columns)—who have high socioeconomic status and good health, an infrequent set of circumstances—have higher life expectancies than Average never smokers.

When looking at the worst-case scenario in the fifth set of columns, female never smokers still have an advantage of 9 to 14 years of additional life expectancy at age 20 compared to current smokers, and male never smokers show an advantage that ranges from 7 to 10 years, even with the strong risk factors for mortality specified here. Thus, within an extremely high-risk mortality group, smoking remains a very important predictor of premature adult mortality in the United States.

Figure 2 presents survival curves by smoking status and sex, based on the "Average" scenario described in Table 3. The y-axis sets all smoking status groups to 100,000 persons at age 20 and plots their survival through old age, based on the smoking-status mortality rates calculated within five-year age groups. Not surprisingly, never smokers have the highest survival. For instance, almost 65 percent of all female never smokers at age 20 can expect to live past age 85. Survival curves in this figure for both sexes are quite similar for current light and current moderate smokers. Survival is lower among current and former smokers and with increasing cigarette consumption. Less than one-quarter of female current heavy smokers can expect to live to age 85. The survival curves begin with the same number of never smokers and current heavy smokers. But 37 percent more female never smokers survive to age 70, 2.0 times as many female never smokers survive to age 80, and 2.8 times as many female never smokers survive to age 85. Thus, the smaller numbers of heavy smokers, coupled with the low survival of heavy smokers, translate into a much smaller number of heavy smokers at the oldest ages.

From the sex- and age-specific mortality rates, smoking-status prevalence rates, and US population distributions, we can estimate the number of smoking-attributable deaths for different scenarios (see Table 4). For ex-

FIGURE 2 Survival curves by smoking status for US females and males with "Average" values for socioeconomic and health status, US adults, 1990–97



SOURCES: Derived from Appendix Tables B and C.

TABLE 4 Estimated number of deaths from smoking that would have been averted in the year 2000, under various scenarios, by sex

	Females	Males	Total
All current and former smokers experience the mortality of never smokers	137,648	200,173	337,821
All current smokers experience the mortality of former smokers	55,778	72,849	128,627
Current smokers experience the mortality of those consuming one pack of cigarettes less per day, and current light smokers experience the mortality of former light smokers	35,668	40,076	75,744
Current light smokers experience the mortality of former light smokers	34,434	30,237	64,671

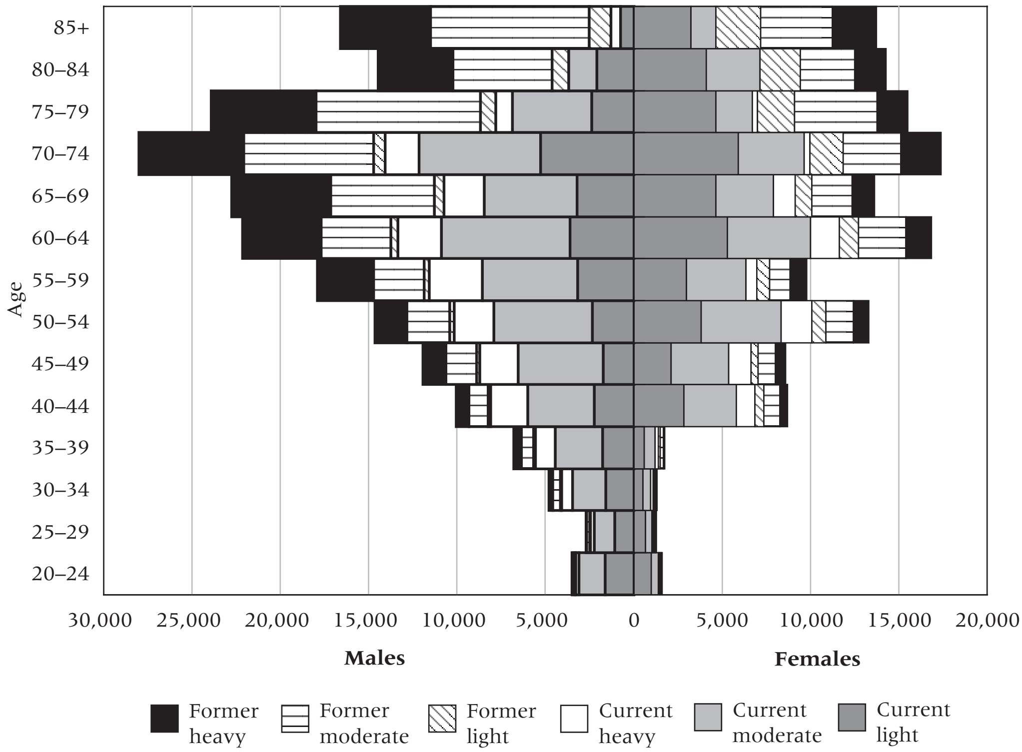
SOURCES: Derived from Table 2 and Appendix Tables B, C, and D.

ample, if current *and* former smokers had the same mortality rates as never smokers, we would expect to see 337,821 fewer deaths in the United States in 2000. This is the upper bound of our estimates—the largest number of deaths that can be attributed to smoking within that particular year. But current smokers cannot become never smokers; the best mortality rates they can achieve are those for former smokers. If all current light, moderate, and heavy smokers were assigned their appropriate former smoker categories, 128,628 deaths would be averted. Or if each current smoker moved down one smoking status—if heavy smokers experienced the mortality of moderate smokers, moderate smokers that of light smokers, and current light smokers the mortality of former light smokers—75,744 deaths would be averted. Because of the large number of current light smokers, much of this change—64,672 deaths—is due solely to current light smokers becoming former light smokers.

The estimated number of deaths averted by reducing cigarette consumption varies by sex. Compared to females, males are generally more likely to be smokers, especially heavy smokers, and former smokers. Thus, in most scenarios, males can avert more deaths than females by reducing smoking consumption. For a striking example, in 2000, if all current and former smokers could have experienced the mortality of never smokers, 137,648 female deaths, but over 200,000 male deaths would have been averted. Because females are disproportionately more likely than males to be current light smokers, converting light smokers to former light smokers has a differential advantage for females relative to males.

The estimated number of deaths that could have been averted by assuming different composition by smoking status also varies by age. Figure 3 shows the number of deaths that could have been averted by age group and sex if everyone experienced the mortality risks of never smokers. Three-

FIGURE 3 Estimated smoking-attributable deaths among current and former smokers, by age and sex, US adults, 2000



quarters of these averted deaths fall between ages 40 and 79 years; only 7 percent fall between 20 and 39 years. As age increases, the number of deaths averted increases disproportionately with increasing cigarette consumption, first among current smokers and later among former smokers. For instance, at ages 30–54, almost 40 percent of all deaths averted would be among current moderate smokers. Among individuals aged 45–49, 17 percent of all deaths averted would be among current heavy smokers. At ages 60 and older, nearly 30 percent of all deaths averted would be among former moderate smokers, and half of all deaths averted would be among all former smokers. And at ages 75 and older, almost 60 percent of all deaths averted would be among former moderate and heavy smokers. Compared to females, males have smoked more cigarettes for longer periods, a fact that contributes to more potential deaths averted at every age.

Discussion

Using data from a nationally representative sample of noninstitutionalized US adults, detailed measures of smoking status and age, and mortality information from all causes of death, we have estimated smoking-attributable deaths after controlling for factors that confound the relationship between smoking and mortality. Because cigarette smoking is associated with other risky behaviors and conditions—including heavy drinking, lack of exercise, and lower socioeconomic status—we cannot summarily attribute all of smokers' excess mortality directly to smoking. However, we find that the influence of other factors on the relationship between smoking and mortality is modest (see also CDC 2002a; Thun et al. 2000), and differentially affects estimates among individuals with the highest levels of cigarette consumption.

Although adjusting for confounding effects is clearly instructive, particularly among individuals with higher levels of cigarette consumption, the net smoking–mortality relationship remains extremely strong and graded after the inclusion of a range of major risk factors for adult mortality in the United States. Indeed, in our most complete multivariate models, compared to never smokers, current smokers exhibit up to 2.6 times the risk of mortality in the follow-up period, whereas former smokers who used to smoke at least one pack of cigarettes per day exhibit 1.6 times the risk of death over the follow-up period.

Using the multivariate models, we also show how age- and sex-specific smoking-status differences in mortality risks translate into life expectancies. The life table figures have the benefits of adjusting for confounding factors, converting coefficients into more meaningful and easily interpretable statistics, summarizing large amounts of information, depicting results visually in the form of survival curves, and presenting various life expectancy scenarios. Indeed, we were able to present life expectancy estimates for the "average" person as well as for individuals in good or poor health and with high or low socioeconomic status. We found that smoking status negates other factors conducive to high life expectancies: an adult of a given age with only average characteristics on all other factors who is a never smoker can expect to live longer than even an adult of that age with high socioeconomic status and other healthy behaviors who is a current smoker.

Our estimate of smoking-attributable adult mortality is similar to the results of Malarcher et al. (2000), but smaller than the estimates of Peto and colleagues (1994), Thun and coauthors (2000), and CDC (2002a). In the hypothetical absence of prior smoking, we estimate that 337,821 deaths in the United States in the year 2000 could have been averted, which is 14.4 percent smaller than the estimate of 394,507 provided by CDC for the year 2001 (2002a). Our lower figure results from differences in methodologies, time periods, subpopulations, and assumptions. In contrast to many of the previous studies, we categorize smokers into seven smoking-status groups rather than three, use sex-specific estimates, base the excess deaths on the year 2000 population rather than on earlier years, and estimate the risk of death due to smoking with controls for confounding factors, including socioeconomic status and health behaviors.

The upper-bound estimate of excess deaths from smoking assumes that individuals in all smoking statuses could experience the low mortality risk of never smokers. Although this provides a sense of the numbers of excess deaths that result from smoking, not all such deaths could reasonably be averted through smoking reductions. For example, if all current smokers quit and assumed the mortality of former smokers rather than never smokers, we estimate that around 128,628 deaths could have been averted in a single year. Or, if current light smokers became former light smokers—a more reasonable goal—64,672 deaths could have been averted in a year. Even though light smokers have much lower mortality risks than heavy smokers, light smokers are more numerous and they contribute a large portion of the preventable deaths.

Of course, a lag exists between smoking behavior and mortality from lung and other cancers, chronic lower respiratory disease, and coronary heart disease. Conversely, the benefits of reduced smoking for mortality may take some time to emerge: once a person stops smoking, the body may take several months or even as long as 15 years to fully recover (DHHS 1990). Indeed, some current and former smokers will die from smoking-related chronic illnesses that they have already contracted (Nam, Hummer, and Rogers 1994). Still, our estimates illustrate the potential to avert deaths and extend life expectancy through reduced smoking. Although the United States has made significant inroads in reducing tobacco consumption over the past 40 years, much room for improvement remains.

Deaths averted vary not only by smoking status, but also by sex. Compared to females, males are generally more likely to be smokers, especially heavy smokers, and former smokers, and are less likely to be light smokers. Reductions in smoking among those who smoke at the highest levels differentially benefit males, whereas reductions in light smoking differentially benefit females. Effective social policies and intervention programs must be sensitive to sex differences in smoking patterns.

Deaths averted also vary by age: at older ages, the number of deaths averted increases disproportionately with increasing cigarette consumption, first among current smokers and later among former smokers. But the added years of life would be small given the risks older persons face from diseases unrelated to smoking. A larger proportion of deaths are averted among middle-aged adults. Unlike many health conditions—such as some cancers and Alzheimer's disease, which have high prevalence rates and high associations with mortality at older ages—cigarette smoking has its highest prevalence and—because the addiction tends to be cumulative—its greatest effect on mortality in the middle years. At younger ages, a substantial majority of all deaths averted would be among current light smokers. Relatively fewer deaths would be averted at the youngest ages both because of the lag effect of smoking on mortality and because relatively few young people smoke heavily, but the consequences for life expectancy would be large. This fact emphasizes the importance of preventing the adoption of smoking at young ages.

Our results are subject to limitations. Like most studies in this area, our baseline data are cross-sectional in nature and, thus, smoking status reports may not completely capture lifetime smoking patterns for individuals in the United States. Second, although NHIS data linked to the National Death Index provide a key resource for estimates such as ours, the number of deaths in the follow-up used here, when split into different age, sex, and smoking-status groups, results in estimates that are subject to some error, particularly among younger adults, among whom there are relatively few deaths on which to base our estimates. Our data set also did not allow us to take into account other types of tobacco use, such as cigars or smokeless tobacco, as well as the effects of passive smoke. And finally, the survey interviewed only noninstitutionalized adults, which increases our life expectancy estimates relative to the total US population.

In sum, we have used demographic methods to provide new estimates of smoking-related mortality in the United States. Our results strongly suggest that (1) taking confounding factors into account results in only modestly reduced effects of smoking on mortality, and (2) smoking continues to be a major public health threat in the United States, one that resulted in as many as 340,000 deaths in the year 2000 and vastly reduced life expectancies among smokers compared to nonsmokers. Thus, policies and programs that continue to reduce smoking in the United States could pay off in substantially longer lives for individuals and much lower death rates for the population at large, especially among males.

APPENDIX TABLE A Numbers of adults by smoking status, by five-year age groups, United States, 2000

Age group	Never smoker	Former smoker	Current smoker
Males			
20–24	5,446,442	775,845	2,868,917
25–29	5,090,359	961,233	2,542,370
30–34	5,504,563	1,257,522	2,668,305
35–39	6,085,336	1,560,359	2,972,469
40–44	5,515,371	2,020,089	3,548,516
45–49	4,252,691	2,570,867	2,770,872
50–54	3,275,480	2,572,810	2,305,834
55–59	2,098,995	2,577,261	1,445,863
60–64	1,522,088	2,452,819	999,632
65–69	1,353,131	1,988,245	633,335
70–74	1,249,426	2,339,315	424,359
75–79	1,033,982	1,804,087	199,838
80–84	702,329	1,057,225	72,425
85+	333,216	511,278	33,167
Total	43,463,409	24,448,955	23,485,902
Females			
20–24	6,068,339	870,170	2,302,382
25–29	6,166,232	918,657	1,980,658
30–34	6,432,296	1,141,185	2,236,505
35–39	6,763,162	1,562,154	3,027,185
40–44	6,002,186	2,272,723	2,818,381
45–49	5,661,436	2,144,431	2,281,746
50–54	4,599,306	2,177,713	1,822,612
55–59	3,388,559	1,927,704	1,400,915
60–64	2,858,578	1,551,803	1,102,563
65–69	2,912,347	1,504,108	588,103
70–74	2,812,481	1,285,772	557,821
75–79	2,692,432	1,151,274	348,128
80–84	2,047,607	599,362	127,239
85+	1,525,201	383,223	69,275
Total	59,930,162	19,490,279	20,663,513

SOURCE: Derived from NCHS 2002.

APPENDIX TABLE B Abridged life tables, by smoking status, for "Average" US females, i.e., those with average values for socioeconomic and health status, 1990–97

Age	$_5m_x$	$_5q_x$	l_x	$_5d_x$	$_5L_x$	T_x	$\dot{e}_x$
A. Never smokers							
20	0.000482	0.00241	100000	241	499398	7242339	72.4
25	0.000322	0.00161	99759	160	498395	6742941	67.6
30	0.000288	0.00144	99599	143	497636	6244546	62.7
35	0.000361	0.00180	99455	179	496829	5746910	57.8
40	0.001693	0.00843	99276	837	494289	5250081	52.9
45	0.001566	0.00780	98439	768	490277	4755792	48.3
50	0.002921	0.01450	97671	1416	484817	4265515	43.7
55	0.003477	0.01724	96255	1659	477130	3780697	39.3
60	0.007669	0.03762	94596	3559	464085	3303568	34.9
65	0.007059	0.03468	91037	3157	447294	2839483	31.2
70	0.012576	0.06097	87880	5358	426007	2392189	27.2
75	0.020519	0.09759	82522	8053	392480	1966183	23.8
80	0.028862	0.13460	74469	10023	347289	1573703	21.1
85	0.052548	1.00000	64446	64446	1226414	1226414	19.0
B. Current smokers who smoke two or more packs per day							
20	0.001665	0.00829	100000	829	497928	5333792	53.3
25	0.001111	0.00554	99171	550	494482	4835864	48.8
30	0.000996	0.00497	98622	490	491884	4341382	44.0
35	0.001246	0.00621	98132	609	489136	3849499	39.2
40	0.005827	0.02872	97523	2800	480611	3360363	34.5
45	0.005394	0.02661	94722	2521	467309	2879751	30.4
50	0.010024	0.04890	92201	4508	449737	2412442	26.2
55	0.011917	0.05786	87693	5074	425781	1962706	22.4
60	0.026018	0.12214	82619	10091	387868	1536924	18.6
65	0.023983	0.11313	72528	8205	342127	1149056	15.8
70	0.042169	0.19074	64323	12269	290942	806930	12.5
75	0.067520	0.28884	52054	15036	222682	515988	9.9
80	0.093157	0.37780	37019	13986	150129	293306	7.9
85	0.160871	1.00000	23033	23033	143177	143177	6.2
C. Current smokers who smoke one to less than two packs per day							
20	0.001075	0.00536	100000	536	498660	5899044	59.0
25	0.000718	0.00358	99464	356	496429	5400384	54.3
30	0.000643	0.00321	99108	318	494743	4903955	49.5
35	0.000804	0.00401	98790	397	492956	4409212	44.6
40	0.003769	0.01867	98393	1837	487373	3916256	39.8
45	0.003488	0.01729	96556	1670	478607	3428883	35.5
50	0.006493	0.03195	94887	3031	466855	2950276	31.1
55	0.007725	0.03789	91855	3480	450575	2483421	27.0
60	0.016950	0.08130	88375	7185	423910	2032846	23.0
65	0.015613	0.07513	81189	6100	390697	1608936	19.8
70	0.027632	0.12923	75090	9704	351188	1218238	16.2
75	0.044651	0.20084	65386	13132	294098	867051	13.3
80	0.062184	0.26909	52254	14061	226116	572953	11.0
85	0.110118	1.00000	38193	38193	346836	346836	9.1
D. Current smokers who smoke less than one pack per day							
20	0.001128	0.00563	100000	563	498594	5833338	58.3
25	0.000753	0.00376	99437	374	496253	5334745	53.6
30	0.000675	0.00337	99064	334	494484	4838492	48.8
35	0.000844	0.00421	98730	416	492611	4344007	44.0
40	0.003955	0.01958	98314	1925	486758	3851397	39.2
45	0.003660	0.01814	96389	1748	477575	3364639	34.9

/continued…

APPENDIX TABLE B (continued)

Age	$_5m_x$	$_5q_x$	l_x	$_5d_x$	$_5L_x$	T_x	$\dot{e}_x$
50	0.006813	0.03349	94641	3170	465280	2887063	30.5
55	0.008104	0.03972	91471	3633	448274	2421783	26.5
60	0.017775	0.08509	87838	7474	420506	1973509	22.5
65	0.016374	0.07865	80364	6321	386018	1553004	19.3
70	0.028961	0.13503	74043	9998	345222	1166985	15.8
75	0.046760	0.20933	64045	13407	286711	821763	12.8
80	0.065064	0.27981	50639	14169	217772	535052	10.6
85	0.114945	1.00000	36470	36470	317280	317280	8.7
E. Former smokers who smoked two or more packs per day							
20	0.000922	0.00460	100000	460	498851	6116206	61.2
25	0.000615	0.00307	99540	306	496937	5617356	56.4
30	0.000551	0.00275	99234	273	495490	5120419	51.6
35	0.000690	0.00344	98961	341	493955	4624930	46.7
40	0.003233	0.01603	98621	1581	489151	4130975	41.9
45	0.002992	0.01485	97040	1441	481596	3641824	37.5
50	0.005571	0.02747	95599	2627	471427	3160228	33.1
55	0.006629	0.03260	92972	3031	457283	2688801	28.9
60	0.014565	0.07027	89941	6320	433905	2231518	24.8
65	0.013414	0.06489	83621	5426	404539	1797613	21.5
70	0.023780	0.11223	78195	8776	369034	1393074	17.8
75	0.038522	0.17569	69419	12196	316604	1024041	14.8
80	0.053783	0.23704	57223	13564	252203	707437	12.4
85	0.095903	1.00000	43658	43658	455234	455234	10.4
F. Former smokers who smoked one to less than two packs per day							
20	0.000796	0.00397	100000	397	499006	6335782	63.4
25	0.000532	0.00265	99603	264	497352	5836775	58.6
30	0.000476	0.00238	99338	236	496100	5339423	53.7
35	0.000596	0.00297	99102	295	494773	4843323	48.9
40	0.002794	0.01387	98807	1371	490609	4348550	44.0
45	0.002586	0.01285	97436	1252	484053	3857941	39.6
50	0.004817	0.02380	96185	2289	475201	3373889	35.1
55	0.005732	0.02826	93896	2653	462846	2898687	30.9
60	0.012609	0.06112	91243	5576	442272	2435842	26.7
65	0.011610	0.05641	85666	4833	416250	1993570	23.3
70	0.020612	0.09801	80834	7922	384362	1577320	19.5
75	0.033456	0.15437	72911	11255	336418	1192958	16.4
80	0.046808	0.20952	61656	12918	275985	856539	13.9
85	0.083950	1.00000	48738	48738	580555	580555	11.9
G. Former smokers who smoked less than one pack per day							
20	0.000602	0.00300	100000	300	499249	6806811	68.1
25	0.000402	0.00201	99700	200	497998	6307562	63.3
30	0.000360	0.00180	99500	179	497051	5809564	58.4
35	0.000450	0.00225	99321	223	496046	5312513	53.5
40	0.002112	0.01050	99097	1041	492885	4816467	48.6
45	0.001954	0.00972	98057	954	487899	4323582	44.1
50	0.003643	0.01805	97103	1753	481133	3835684	39.5
55	0.004336	0.02145	95350	2045	471638	3354551	35.2
60	0.009554	0.04665	93305	4353	455643	2882913	30.9
65	0.008795	0.04303	88952	3827	435191	2427270	27.3
70	0.015649	0.07530	85125	6410	409598	1992079	23.4
75	0.025481	0.11977	78715	9428	370004	1582481	20.1
80	0.035768	0.16416	69287	11374	317999	1212477	17.5
85	0.064745	1.00000	57913	57913	894478	894478	15.4

SOURCES: Based on coefficients in Table 2, Model 7, and proportions from Appendix Table D.

APPENDIX TABLE C Abridged life tables, by smoking status, for "Average" US males, i.e., those with average values for socioeconomic and health status, 1990–97

Age	${}_5m_x$	${}_5q_x$	l_x	${}_5d_x$	${}_5L_x$	T_x	$\dot{e}_x$
A. Never smokers							
20	0.001342	0.00669	100000	669	498328	6339283	63.4
25	0.000967	0.00482	99331	479	495460	5840955	58.8
30	0.001406	0.00701	98852	692	492531	5345495	54.1
35	0.001605	0.00799	98160	785	488838	4852964	49.4
40	0.002065	0.01027	97375	1000	484376	4364126	44.8
45	0.002753	0.01367	96375	1317	478582	3879750	40.3
50	0.004255	0.02105	95058	2001	470286	3401168	35.8
55	0.007246	0.03559	93057	3312	457004	2930882	31.5
60	0.010857	0.05285	89745	4743	436868	2473879	27.6
65	0.015362	0.07397	85002	6287	409292	2037011	24.0
70	0.022146	0.10492	78715	8259	372926	1627719	20.7
75	0.028828	0.13445	70456	9473	328597	1254793	17.8
80	0.038347	0.17496	60983	10670	278241	926196	15.2
85	0.077650	1.00000	50313	50313	647955	647955	12.9
B. Current smokers who smoke two or more packs per day							
20	0.002990	0.01484	100000	1484	496291	5148571	51.5
25	0.002155	0.01072	98516	1056	489942	4652280	47.2
30	0.003133	0.01554	97461	1515	483516	4162338	42.7
35	0.003576	0.01772	95946	1700	475479	3678822	38.3
40	0.004597	0.02272	94246	2142	465874	3203343	34.0
45	0.006123	0.03015	92104	2777	453577	2737469	29.7
50	0.009448	0.04615	89327	4122	436328	2283892	25.6
55	0.016030	0.07706	85205	6566	409607	1847563	21.7
60	0.023911	0.11281	78638	8871	371014	1437956	18.3
65	0.033649	0.15519	69767	10827	321767	1066942	15.3
70	0.048116	0.21475	58940	12657	263057	745175	12.6
75	0.062135	0.26890	46283	12446	200300	482118	10.4
80	0.081726	0.33931	33837	11481	140483	281818	8.3
85	0.158177	1.00000	22356	22356	141336	141336	6.3
C. Current smokers who smoke one to less than two packs per day							
20	0.002584	0.01283	100000	1283	496791	5348121	53.5
25	0.001862	0.00927	98717	915	491296	4851329	49.1
30	0.002707	0.01344	97802	1315	485722	4360034	44.6
35	0.003090	0.01533	96487	1479	478736	3874312	40.2
40	0.003973	0.01967	95007	1869	470365	3395576	35.7
45	0.005294	0.02612	93139	2433	459610	2925211	31.4
50	0.008171	0.04004	90706	3632	444448	2465601	27.2
55	0.013877	0.06706	87074	5839	420771	2021153	23.2
60	0.020722	0.09851	81235	8002	386167	1600382	19.7
65	0.029200	0.13607	73232	9965	341250	1214215	16.6
70	0.041837	0.18938	63268	11981	286385	872964	13.8
75	0.054131	0.23839	51286	12226	225866	586579	11.4
80	0.071390	0.30289	39060	11831	165722	360713	9.2
85	0.139643	1.00000	27229	27229	194991	194991	7.2
D. Current smokers who smoke less than one pack per day							
20	0.002463	0.01224	100000	1224	496939	5414187	54.1
25	0.001775	0.00884	98776	873	491697	4917248	49.8
30	0.002581	0.01282	97903	1256	486376	4425551	45.2
35	0.002947	0.01463	96647	1414	479703	3939176	40.8
40	0.003789	0.01877	95234	1787	471701	3459473	36.3
45	0.005048	0.02493	93447	2329	461409	2987772	32.0

/continued…

APPENDIX TABLE C (continued)

Age	$_5m_x$	$_5q_x$	l_x	$_5d_x$	$_5L_x$	T_x	$\dot{e}_x$
50	0.007794	0.03822	91117	3483	446879	2526362	27.7
55	0.013239	0.06408	87634	5615	424134	2079483	23.7
60	0.019776	0.09422	82019	7728	390775	1655350	20.2
65	0.027878	0.13031	74291	9681	347254	1264574	17.0
70	0.039966	0.18168	64610	11738	293706	917321	14.2
75	0.051740	0.22907	52872	12111	234082	623614	11.8
80	0.068292	0.29166	40761	11888	174083	389532	9.6
85	0.134010	1.00000	28872	28872	215449	215449	7.5
E. Former smokers who smoked two or more packs per day							
20	0.001999	0.00995	100000	995	497514	5712443	57.1
25	0.001440	0.00718	99005	710	493251	5214929	52.7
30	0.002095	0.01042	98295	1024	488915	4721678	48.0
35	0.002391	0.01189	97271	1156	483464	4232763	43.5
40	0.003075	0.01526	96115	1467	476908	3749299	39.0
45	0.004098	0.02028	94648	1920	468441	3272391	34.6
50	0.006330	0.03116	92728	2889	456418	2803950	30.2
55	0.010765	0.05241	89839	4709	437423	2347531	26.1
60	0.016100	0.07738	85130	6588	409182	1910108	22.4
65	0.022730	0.10754	78543	8446	371597	1500926	19.1
70	0.032661	0.15098	70096	10583	324023	1129329	16.1
75	0.042378	0.19159	59513	11402	269060	805306	13.5
80	0.056113	0.24605	48111	11838	210961	536245	11.1
85	0.111512	1.00000	36273	36273	325285	325285	9.0
F. Former smokers who smoked one to less than two packs per day							
20	0.001849	0.00920	100000	920	497699	5827675	58.3
25	0.001333	0.00664	99080	658	493753	5329976	53.8
30	0.001938	0.00964	98422	949	489735	4836223	49.1
35	0.002212	0.01100	97472	1072	484682	4346488	44.6
40	0.002845	0.01413	96400	1362	478596	3861806	40.1
45	0.003792	0.01878	95038	1785	470729	3383210	35.6
50	0.005859	0.02887	93253	2692	459535	2912481	31.2
55	0.009966	0.04862	90561	4403	441797	2452946	27.1
60	0.014911	0.07188	86158	6193	415307	2011150	23.3
65	0.021063	0.10004	79965	8000	379825	1595842	20.0
70	0.030288	0.14078	71965	10131	334497	1216017	16.9
75	0.039327	0.17903	61834	11070	281494	881519	14.3
80	0.052127	0.23058	50764	11705	224555	600025	11.8
85	0.104025	1.00000	39058	39058	375471	375471	9.6
G. Former smokers who smoked less than one pack per day							
20	0.001425	0.00710	100000	710	498225	6237492	62.4
25	0.001027	0.00512	99290	508	495178	5739267	57.8
30	0.001494	0.00744	98781	735	492069	5244089	53.1
35	0.001705	0.00849	98046	832	488151	4752020	48.5
40	0.002194	0.01091	97214	1060	483419	4263869	43.9
45	0.002924	0.01451	96154	1396	477279	3780450	39.3
50	0.004520	0.02235	94758	2117	468496	3303172	34.9
55	0.007695	0.03775	92640	3497	454459	2834676	30.6
60	0.011527	0.05602	89143	4994	433232	2380217	26.7
65	0.016305	0.07833	84149	6592	404268	1946985	23.1
70	0.023497	0.11096	77558	8606	366274	1542717	19.9
75	0.030573	0.14201	68952	9792	320278	1176443	17.1
80	0.040644	0.18448	59160	10914	268515	856165	14.5
85	0.082100	1.00000	48246	48246	587650	587650	12.2

SOURCES: Based on coefficients in Table 2, Model 8, and proportions from Appendix Table D.

APPENDIX TABLE D Proportions of individuals in categories of the covariates, by sex, US adults, 1990–97

	Females	Males
Smoking status[a]		
Current 2+	0.015	0.038
Current 1–<2	0.103	0.141
Current < 1	0.115	0.109
Former 2+	0.023	0.071
Former 1–<2	0.065	0.122
Former <1	0.097	0.096
Never	0.581	0.424
Race		
Non-black	0.884	0.897
Black	0.116	0.103
Marital status		
Currently married	0.623	0.689
Previously married	0.221	0.099
Never married	0.156	0.212
Family income (in 1990 $10,000s)[b]	3.285	3.649
Employment status		
Employed	0.578	0.764
Unemployed	0.028	0.034
Not in the labor force	0.394	0.202
Education		
11 years or less	0.205	0.199
High school degree	0.411	0.362
Any college	0.384	0.439
Drinking status		
Non-drinker	0.231	0.092
Infrequent drinker	0.181	0.069
Former drinker	0.076	0.113
Current drinker	0.513	0.726
Seatbelt use		
Never	0.068	0.111
At least some of the time	0.932	0.889
Stress		
A lot	0.320	0.236
Not a lot	0.680	0.764
Physical activity		
More active than peers	0.281	0.380
About as active	0.486	0.459
Less active	0.234	0.161
Body mass index		
Obese class III	0.014	0.006
Obese class II	0.028	0.020
Obese class II	0.090	0.102
Overweight	0.238	0.414
Normal weight	0.581	0.447
Underweight	0.050	0.012

[a]Packs of cigarettes per day.
[b]Family income represents mean value rather than proportion.
SOURCES: NCHS 1990, 2000.

Notes

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1 About 1.9 percent of the NHIS-HPDP records, termed "ineligible," contain insufficient information to be matched to death records. NCHS identifies these records so that they may be dropped from the analysis (NCHS 2000). We dropped about 7.9 percent of the remaining individuals because of missing values for education, marital status, body mass index, smoking status, exercise, stress, physical activity, seatbelt use, drinking status, or income.

2 Our analysis assumes smoking statuses persist throughout the follow-up period or until death. Although some individuals change their smoking status over time, and thereby modify their risk of death, many individuals experience return transitions, for example, quitting but later resuming smoking (Mamun et al. 2002). Smoking status at the time of the interview may not fully capture cumulative tobacco exposure. Alternative measures, which often require detailed smoking histories, examine total years smoked, lifetime cigarette consumption, or smoking intensity. Additional data collection efforts and research are warranted to fully capture smoking status transitions, cumulative tobacco exposure, and subsequent mortality risk.

3 We use ordinary least squares regression to estimate income separately for those with family incomes below \$20,000 and for those with incomes equal to or above that amount—a question in the survey with a much higher response rate than more detailed family income categories. We use age, age-squared, marital status, employment status, education, and race to predict income, and use the coefficients to impute values for those missing family income on the more detailed income variable.

4 We find that an estimated median value is more reasonable than an estimated mean, and use the Pareto curve to estimate the median. Parker and Fenwick (1983) note that the double log form of the Pareto curve is linear at the upper tail of the income distribution, so that as the level of income in a category increases, the number of people in that category decreases. This allows them to estimate this slope, v, as:

$$v = \frac{\log(n_t - n_{t-1}) - \log(n_t)}{\log(x_t) - \log(x_{t-1})}$$

where n_t is the number of people in the open-ended category, n_{t-1} is the number of people in the income category immediately preceding the open-ended category, x_t is the lower limit of the open-ended category, and x_{t-1} is the lower limit of the penultimate category. They then use this value to estimate a median value (*MD*) for the category, as specified in Wright (1976: 163):

$$MD = 10^{(.301/v)}(x_t)$$

Thus, for our analyses, we use the estimated median value of \$68,645 for those individuals with a family income of \$50,000 or more.

5 We used Stata 8.2 software (StataCorp 2003) for the correction. The discrete-time hazard models using logistic regression produce results quite similar to those obtained from continuous-time hazard models. In addition, extending the discrete-time hazard model to include dummy variables for each follow-up year does little to change the results. Although the model with the duration effects fits our data slightly better, the estimated effects of the substantive factors on mortality were identical with those in Table 2, Model 6 in terms of direction, magnitude, and levels of significance.

6 We tested but did not find interactions between smoking and income, education, employment status, and seatbelt use. Because we employ age and sex as controls to include in life table analysis, we did not examine the potential for interactions between these two variables and smoking.

7 There is very little difference in relative risks for current light and moderate smokers, and indeed, female light smokers display slightly higher risk than female moderate smokers. This is most likely due to some misreporting of smoking status, as well as some potential changes in smoking status over time (i.e., light smokers increasing their consump-

tion levels and vice versa). Nevertheless, this difference is not statistically significant.

8 For example, the m_x value for female never smokers aged 20–24 is calculated by $m_{20\text{–}24} = 1 / (1 + e^{-z})$. To calculate z for never smokers for this age group, we multiply the proportions of females in each sex-specific category of race, marital status, employment status, education, drinking status, seatbelt use, stress, physical activity, and body mass index, as well as mean income, by the coefficient for each category, using the proportions in Appendix Table D and the coefficients from Table 2, Model 7. We add this value to the intercept and to the value of the age coefficient for the group of interest and the smoking status of interest, which is 0.0 for never smokers aged 20–24 as they are the referent categories, for a value of –7.6368. Thus, calculating m_x for female never smokers aged 20–24 as follows:

$$m_{20-24} = \frac{1}{1 + e^{(-7.6368)}} = 0.000482$$

produces the first entry for females in Appendix Table B.

To retain the age pattern of mortality, the logistic regression used dummy codes for the five-year age groups. To reduce complexity, we did not add interactions between smoking status and age. This approach will produce relatively small differences in age-specific smoking status mortality rates, even though previous studies have shown that relative differences in age-specific mortality are generally greatest in the middle years and smaller at the age extremes.

9 Recall, though, that the difference between female light smokers and female moderate smokers was not statistically significant in the regression model. Thus, the 1.0-year difference in life expectancy between these two groups may reflect randomness and should be cautiously interpreted.

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