Standardized Lifetime Risk

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The authors propose the use of two new standardized measures of risk, the standardized lifetime risk and the standardized number of years of life lost. These measures maintain the advantages of standardized rates but are more readily understood without special training. In this paper, standardizing weights based on 1992 data from England and Wales are provided, and the new measures are illustrated with a variety of examples. The new standardized rates are useful for examining trends over time; for comparing the impact of various diseases on public health; and for comparing rates of a given disease in several different countries. The authors think it is far more informative to say that 41 out of every 1,000 women die of breast cancer than to say that the standardized mortality rate is 51 per 100,000 women per year. *Am J Epidemiol* 1999;149:869–75.

epidemiologic methods; incidence; mortality; risk; risk assessment

Publications often quote death or disease rates per million. For instance, authors often make statements such as: "[Cervical cancer] is the eighth commonest cancer in women, with an annual incidence in the UK of 144 new cases for every million population" (1, p. 6). Even epidemiologists and biostatisticians find the phrase "144 new cases for every million population" hard to comprehend, so what is the lay public to make of it? Additionally, the crude incidence rates should not be used to compare different populations. The above authors meant "144 new cases per million *females* per year." That is, they do not include the whole population (males are excluded), but they do include young girls, in whom the incidence of cervical cancer is less than one per million. Crude rates can be used to compare different diseases in the same population, but they are not useful for comparing rates of the same disease in different populations or over time. To overcome this problem, age-standardized rates are used. That is, one calculates the rate that would have been observed had the age distribution in the population of interest matched that of some standard population.

For most people, it is easier to relate to the lifetime risk of getting a particular disease than to the annual rate of incidence of that disease. One might ask,

"What is the risk of a 20-year-old woman's getting cervical cancer at some stage in her life?" Of course, we can't know the exact answer to such a question, because it depends on what happens to life expectancy and to the incidence of cervical cancer over the next 70 years; and we are not generally interested in the lifetime risk of cervical cancer for women born 90 years ago. The standard method for estimating lifetime risk of a disease assumes that all future incidence and mortality rates will match those of the current year (2). It is a fiction which is reasonable so long as one realizes what is meant by "lifetime risk." The problem is that when we adjust for mortality, the lifetime risk of a disease will be greater in a country with greater life expectancy than in one with lower life expectancy, even if the age-specific incidence rates are identical in the two countries. Similarly, if life expectancy improves over time, the lifetime risk will increase even if the incidence rates do not change.

The cumulative rate (3) provides a partial solution. It is simply the sum of the annual age-specific rates. It has the advantage of dispensing with the selection of a standard population, and it is straightforward to convert from cumulative rates to cumulative risks by means of the formula $P = 1 - \exp(-\Lambda)$, in which Λ is the cumulative rate and P is the cumulative risk or probability. When Λ is small (e.g., <0.05), $P \approx \Lambda$, so the cumulative rate can roughly be thought of as the cumulative probability. Thus, for instance, the cumulative rate from birth to age 74 years can be used to calculate the cumulative risk over that period, which can roughly be thought of as the lifetime risk when the cumulative rate is small.

METHODS

What we propose here is a measure that would be called a "standardized lifetime risk" but is, more formally, a "standardized cumulative risk." Let S_i be the proportion of the standard sex-specific population who survive until age i, and let R_i be the age-specific rate of the disease of interest in a given population and a particular calendar year. Then the standardized lifetime risk for that population and calendar year is defined to be the weighted sum of age-specific rates:

$$\sum_{i=0}^{99} S_i \times R_i. \tag{1}$$

(Here we assume that the contribution from people living to >100 years is negligible. Note also that if one is using 5-year age groups, the formula would be

$$\sum_{j=1}^{20} 5 \times S_j \times R_j, \tag{2}$$

where the subscript j indexes the different age groups.)

Additionally, one might calculate a standardized "number of years of life lost" due to death from a particular disease as follows:

$$\sum_{i=0}^{99} S_i \times R_i \times A_i, \tag{3}$$

where A_i is the standard life expectancy at age i and is calculated as

$$A_i = \sum_{j=i}^{99} (j - i) \times (S_j - S_{j+1})/S_i = \sum_{j=i}^{99} S_j/S_i. \tag{4}$$

The ratio of the standardized number of years of life lost to the standardized lifetime risk gives the standardized mean number of years lost by an individual who dies from that specific cause:

$$\frac{\sum_{i=0}^{99} S_i \times R_i \times A_i}{\sum_{i=0}^{99} S_i \times R_i}. \tag{5}$$

It is simply a weighted average of the standard life expectancies at each age with weights equal to the standardized probability of dying from the disease at a given age.

A slightly different formula should be used when the data are considered in 5-year age groups. In that case, define A_i recursively starting with the oldest age group: $A_{20} = s_{20}/(1 - s_{20})$, where s_j is the probability of surviv-

ing for 1 year given that one is in the jth age group (i.e., s_j equals 1 minus the all-cause mortality rate, d_j). For $j = 19, 18, ..., 1$,

$$A_j = s_j + s_j^2 + s_j^3 + s_j^4 + (1 + A_{j+1}) \times s_j^5$$

$$= (s_j - s_j^6)/(1 - s_j) + A_{j+1} \times s_j^5$$

$$\approx 5 - 15d_j + A_{j+1} \times s_j^5. \tag{6}$$

Our proposal is a weighted cumulative rate with weights that are independent of the cause of death. Thus, our definition of lifetime risk does not adjust the standardizing weights (which are derived from all-cause mortality) for the numbers of people dying from the specific cause. One could argue, for instance, that the lifetime risk of cardiovascular disease death should be much larger than is estimated by our method, since, if people did not die from cardiovascular disease in their 40s and 50s, more would live into their 60s and 70s and the numbers dying from cardiovascular disease at those ages would be greater. We do not use that reasoning in this paper. Similarly, the number of years of life lost due to death from a particular disease will be underestimated by the method proposed here. Not only are the S_j's not adjusted upwards but the residual life expectancies are also unchanged and so do not reflect the greater life expectancy that would result from removing a cause of death. Thus, for instance, one could argue that the number of years of life lost due to all-cause mortality is infinite, for if one removed all causes of death, people would live forever. The effect of these adjustments (i.e., of replacing s_j by $s_j + R_j$) on breast cancer mortality is to increase the standardized lifetime risk from 40.9 per 1,000 female births to 42.0 per 1,000 and the standardized years of life lost from 769 per 1,000 women to 792 per 1,000. Similarly, the standardized lifetime risk of death due to ischemic heart disease in men increases from 25.0 percent to 32.9 percent and the years of life lost increase from 3,037 per 1,000 male births to 4,169 per 1,000 when adjusting the weights for the component of all-cause mortality that is due to ischemic heart disease. The effect on less common causes of death is minimal.

A method for estimating the standard error of the new measures is described in the Appendix.

In this paper, we prefer to estimate the all-cause mortality rate as a smooth function of age in order to estimate S_i and A_i for each year from birth to age 100. Table 1 provides standard survival curves and the corresponding residual life expectancies for men and women, based on 1992 mortality data from England and Wales (4). These standards are used throughout this paper.

TABLE 1. Standard survival and mean residual life expectancy in men and women, based on 1992 mortality data from England and Wales*

Age (years)	Males		Females	
	Survival†	Residual life‡	Survival†	Residual life‡
0	1,000	78.2	1,000	83.2
2	993	75.7	994	80.7
7	991	70.7	993	75.7
12	990	65.8	992	70.7
17	988	60.9	991	65.8
22	984	56.0	990	60.8
27	980	51.1	988	55.9
32	976	46.2	986	51.0
37	970	41.4	982	46.1
42	962	36.6	977	41.2
47	949	31.9	969	36.4
52	929	27.3	955	31.7
57	893	22.9	933	27.2
62	835	18.8	897	22.8
67	741	15.2	839	18.7
72	610	11.9	751	14.9
77	446	9.0	628	11.5
82	270	6.7	463	8.5
87	124	4.8	278	6.0
92	37	3.3	119	4.1
97	6	2.0	30	2.5

* These "weights" are used throughout this paper.
† Number of individuals surviving from an initial birth cohort of 1,000.
‡ Expected number of years of life left.

RESULTS

We first illustrate these methods using cervical cancer data. Table 2 gives age-specific incidence rates and mortality rates for cervical cancer in England and Wales from 1980 and 1994, respectively (5, 6). We have provided these data to enable interested readers to verify our calculations. Use of the above formulae with the survival and life expectancy for each 5-year age group taken to be that of the middle year (e.g., age 57 years for the group aged 55–59) gives a standardized lifetime risk of cervical cancer of 12.9 per 1,000 female births and a standardized lifetime risk of dying from cervical cancer of 4.3 per 1,000. The standardized number of years of life lost due to cervical cancer is 96.0 per 1,000 female births. All of these quantities were calculated using the standard survival curve from 1992 (table 1).

Next we consider the use of the proposed measures to describe trends in cervical cancer mortality in England and Wales. Figures 1 and 2 plot the standardized lifetime risk of dying from cervical cancer (figure 1) and the standardized years of life lost due to cervical cancer mortality (figure 2) against each year between 1950 and 1994. The age-standardized mortality rate is graphed in figure 3 for comparison. Note

TABLE 2. Cervical cancer rates in England and Wales, 1980 and 1994

Age (years)	Incidence per 100,000 women per year (1980)	Mortality per 100,000 women per year (1994)
0–4	0	0
5–9	0.06	0
10–14	0	0
15–19	0	0
20–24	2.46	0.23
25–29	10.76	1.08
30–34	16.93	2.37
35–39	20.90	4.42
40–44	20.78	5.93
45–49	19.58	5.60
50–54	23.91	6.42
55–59	35.04	6.47
60–64	34.92	8.19
65–69	30.01	9.81
70–74	26.75	16.30
75–79	24.81	16.50
80–84	22.39	18.95
85–89	22.58*	16.50
90–94	22.58*	16.15
≥95	22.58*	10.38

* Rate for women aged ≥85 years.

how the recent fall in the standardized years of life lost is even more impressive than the fall in standardized lifetime risk. The curve in figure 3 gives the same qualitative impression of falling mortality as does figure 1, but the numeric values of the standardized lifetime risk are much easier to relate to than those of the age-standardized risk. For instance, between 1960 and 1980, the standardized lifetime risk fell by 2.9 per 1,000 female births. Over the same period, the age-standardized rate changed by 4.4 per 100,000 women.

Until recently, mortality and cancer incidence data were not subdivided by age beyond 85 years. The effect of using a single rate for cervical cancer for ages ≥85 years rather than separate rates for ages 85–89, 90–94, and ≥95 years was to change the standardized measures by less than 0.1 percent of their values.

Another use of standardized rates is to compare the public health impacts of various diseases. Table 3 gives the standardized lifetime risk of dying from each of the main causes of death and the standardized number of years of life lost based on disease-specific mortality rates in England and Wales from 1994 (6) and the standardized survival rates from 1992 (table 1). We also present the standardized mean number of years lost by an individual who dies from each of the different causes of death. Notice how this is less than 10 years for prostate cancer and pneumonia, which are normally fatal only in old age, but over 20 years (in women) and over 30 years (in men) for deaths due to injury and poisoning. Once again, although the age-standardized rates (not shown)
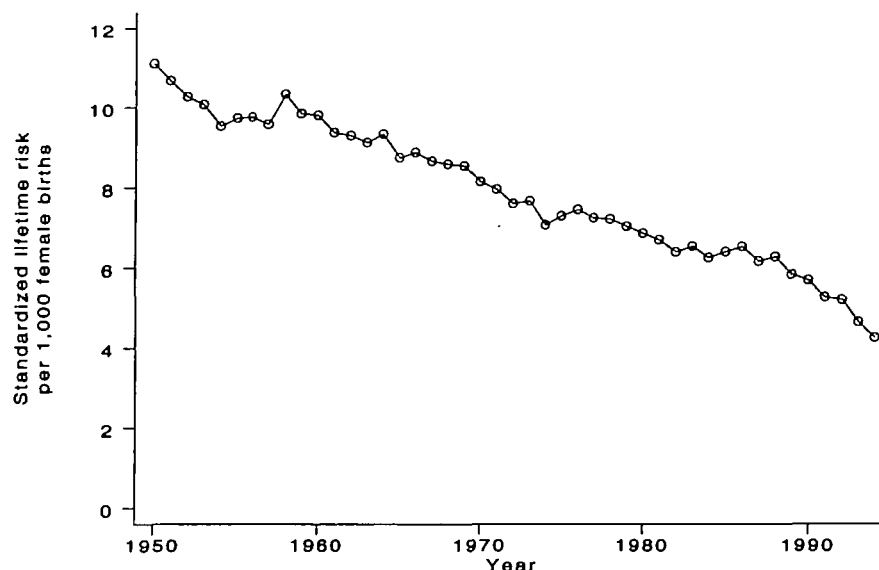
FIGURE 1. Standardized lifetime risk of dying from cervical cancer (per 1,000 female births) in England and Wales between 1950 and 1994. Data were standardized using 1992 mortality rates from England and Wales.

FIGURE 2. Standardized numbers of years of life lost due to cervical cancer (per 1,000 female births) in England and Wales between 1950 and 1994. Data were standardized using 1992 mortality rates from England and Wales.
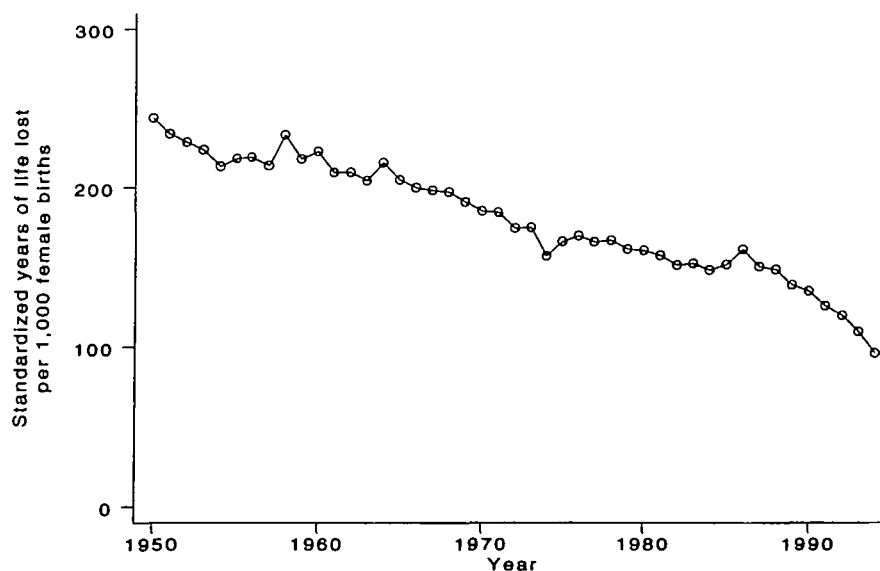
would have permitted some comparison between different causes of death similar to those comparisons using the standardized lifetime risk, the absolute value of the latter is more informative. Furthermore, the additional use of the standardized mean number of years lost enables one to distinguish between mortality in the young, the middle-aged, and the old.

On the basis of incidence data obtained from the International Agency for Research on Cancer (7), table 4 gives the standardized lifetime risk of cervical cancer

per 1,000 female births in various geographic areas and among ethnic groups within geographic areas. Notice, in particular, the difference in the standardized numbers of years lost due to cervical cancer (per 1,000 female births) between white women in the United States and women in Shanghai, People's Republic of China, despite the similar standardized lifetime risks. The reason for the much lower number of years of life lost in China is that the disease in Shanghai is extremely rare among women under the age of 55 years. Figure 4 com-
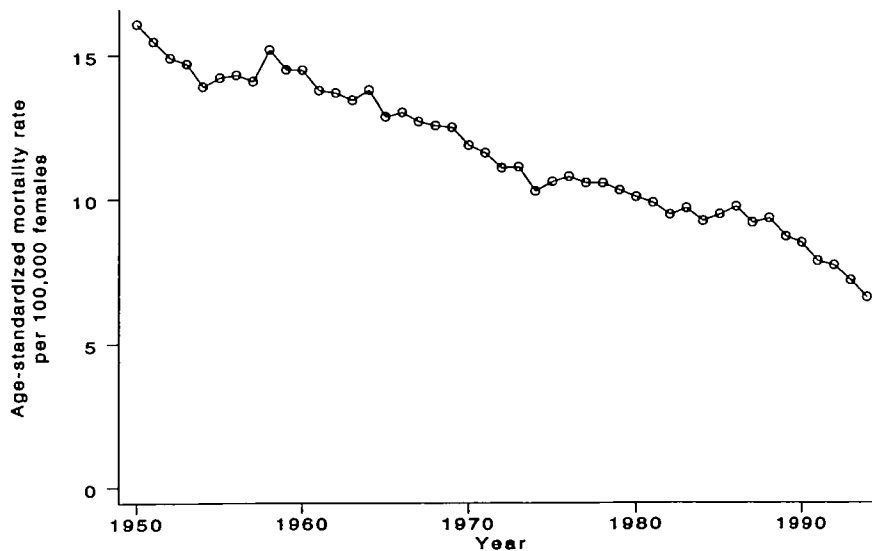
FIGURE 3. Age-standardized rates of mortality from cervical cancer (per 100,000 females) in England and Wales between 1950 and 1994. Data were standardized using 1992 midyear population estimates from England and Wales.

pares the age-specific incidence rates of cervical cancer in Shanghai women with those in US white women.

Note that consideration of traditional measures such as the age-standardized rate and the cumulative rate up to age 74 years does not flag the difference between US white women and Shanghai women nearly so clearly. In all populations in table 4, the cumulative rate is (very) approximately 10 percent of the age-standardized rate. Thus, the two measures are in no sense complementary in this example.

DISCUSSION

The proposed new measures are easy to calculate and are straightforward to interpret. They are also easy for the public to understand. They have an advantage over other measures of lifetime risk, in that they are not dependent on changing or differing rates of mortality from other causes. Thus, they are suitable for comparing 1) different diseases in the same population, 2) the same disease in different populations, and 3) trends in the

TABLE 3. Standardized lifetime risk of death and number of years of life lost for various causes of death in England and Wales, 1994*

Cause of death	ICD-9† code(s)	Males			Females		
		Risk‡	Years lost§	Mean¶	Risk‡	Years lost§	Mean¶
All cancers	140–208	245.8	3,278	13.3	213.8	3,484	16.3
Stomach	151	15.7	197	12.5	9.4	123	13.1
Rectum and colon	153–154	26.9	348	12.9	25.5	349	13.7
Lung	162–163	72.6	959	13.2	35.7	584	16.4
Breast	174				40.9	769	18.8
Prostate	185	30.0	282	9.4			
Ischemic heart disease	410–414	250.5	3,037	12.1	196.2	2,113	10.8
Other heart disease	415–449	34.5	384	11.1	49.7	491	9.9
Cerebrovascular disease	430–438	56.8	675	10.0	116.8	1,125	9.6
Other circulatory disease	440–459	30.6	326	10.7	26.6	269	10.1
Pneumonia	480–486	66.7	560	8.4	94.2	738	7.8
Injury and poisoning	800–999	30.2	974	32.3	18.0	424	23.6

* Standardized by the survival functions given in table 1.
† ICD-9, *International Classification of Diseases*, Ninth Revision (9).
‡ Standard number of persons dying from each specific cause in a cohort of 1,000 live births.
§ Standard number of years of life lost per 1,000 individuals.
¶ Average number of years of life lost by someone who dies from the given cause.

TABLE 4.   Standardized lifetime risk of cervical cancer and standardized number of years of life lost due to cervical cancer per 1,000 female births from various cancer registries*

Location of cancer registry	Lifetime risk per 1,000 births	Years of life lost per 1,000 births	Age-standardized risk per 1,000 births (world)	Cumulative rate (ages birth to 74 years)
Goiânia, Brazil	71.4	1,529	48.9	4.99
Cali, Columbia	49.1	1,221	42.2	4.68
Trujillo, Peru	76.7	1,704	54.6	5.84
Canada	11.0	333	10.2	1.00
United States (SEER† Program)				
Whites	7.9	239	7.3	0.73
Blacks	15.1	368	11.7	1.23
Shanghai, China	7.3	125	4.3	0.56
Israel				
All Jews	4.8	133	4.2	0.43
Non-Jews	2.7	82	2.6	0.26
Singapore				
Chinese	20.5	545	17.5	1.89
Malays	10.4	275	8.8	0.91
Indians	19.4	445	12.7	1.49
Denmark	17.4	513	15.9	1.63
Finland	6.2	135	4.4	0.49
England and Wales	12.7	389	11.9	1.21
New Zealand				
Maori	33.7	951	29.9	3.12
Non-Maori	12.7	386	11.8	1.16

* Standardized by the survival functions given in table 1. Data were obtained from the International Agency for Research on Cancer (7). Dates cover the years 1982–1989 and are not the same for all registries.
† SEER, Surveillance, Epidemiology, and End Results.

rates of a given disease over time. The estimate of years of life lost is useful for comparing pairs of diseases such as prostate cancer and breast cancer. Prostate cancer is almost exclusively a disease of old age (1993 mortality rates in England and Wales were 7,664 per million among men aged ≥85 years, compared with 218 per mil-

lion among those aged 55–64 years). By contrast, although the rates of female breast cancer mortality increase rapidly with age, there is a considerable number of deaths in younger women (rates of 908 per million women per year for women aged 55–64 years and 2,944 per million per year for women aged ≥85 years).
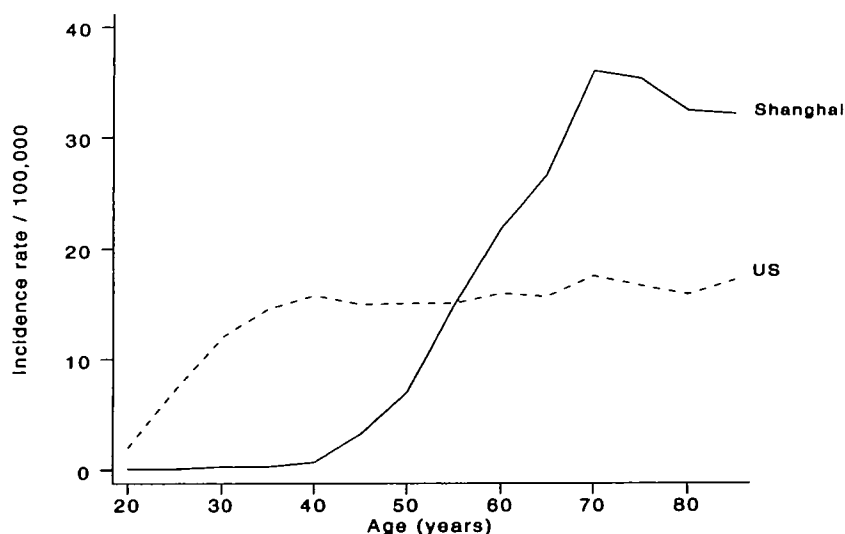
FIGURE 4.   Age-specific incidence of cervical cancer among women in Shanghai, People's Republic of China, and US white women, 1983–1987.

The decreasing weights given to older people make the standardized lifetime risk more stable than the cumulative risk, which gives as much weight to older age groups as to younger ones, even though it is often very difficult to obtain accurate data on diseases and causes of death in persons over the age of 85 years.

In this paper, we have used 1992 all-cause mortality rates from England and Wales to calculate the new standardized measures. Although the survival curve produced from these data is reasonable for calculating lifetime risk in most developed countries, one would probably wish to use a different standard when considering mortality in developing countries. If these measures were to become widely used, we would expect there to be standard survival curves based on world mortality, North American mortality, African mortality, etc., which could be used by researchers to produce standardized lifetime risks and standardized numbers of years of life lost. In most applications, the choice of "standard" would be clear. Occasionally, such as when comparing rates of a given disease around the world, one might wish to use two standards—e.g., those for North America and Africa—so that the standardized rates could be used both for comparisons between regions and for a realistic description of the lifetime risk within each region.

In conclusion, we believe that the measures introduced here combine the advantages of standardized rates, favored by epidemiologists, with the interpretability of "lifetime risk" required by the general public. They are simple to calculate, and we hope to see them widely adopted by descriptive epidemiologists and by journalists writing for a general audience.

REFERENCES

1. Cervical Screening Programme, UK National Health Service. Cervical screening: a pocket guide. London, England: HMSO, 1996.
2. Zdeb MS. The probability of developing cancer. Am J Epidemiol 1977;106:6–16.
3. Day NE. A new measure of age-standardized incidence, the cumulative rate. In: Waterhouse JA, Muir CS, Correa P, et al, eds. Cancer incidence in five continents, vol 3. (IARC Scientific Publication no. 15). Lyon, France: International Agency for Research on Cancer, 1976:443–52.
4. Office of Population Censuses and Surveys. Mortality statistics: cause 1992, series DH2, no. 19. London, England: HMSO, 1993.
5. Office of Population Censuses and Surveys. Cancer statistics registrations 1980, series MB1, no. 12. London, England: HMSO, 1983.
6. Office of Population Censuses and Surveys. Mortality statistics: cause 1993 (revised) and 1994, series DH2, no. 21. London, England: HMSO, 1996.
7. World Health Organization. Age-specific and standardized incidence rates. In: Parkin DM, Muir CS, Whelan SL, et al, eds. Cancer incidence in five continents, vol 6. (IARC Scientific Publication no. 120). Lyon, France: International Agency for Research on Cancer, 1992.
8. Breslow NE, Day NE. Rates and rate standardization. In: Statistical methods in cancer research. Vol 2. The design and analysis of cohort studies. (IARC Scientific Publication no. 82). Lyon, France: International Agency for Research on Cancer, 1987:59.
9. World Health Organization. International classification of diseases. The international statistical classification of diseases, injuries, and causes of death. Ninth Revision. Geneva, Switzerland: World Health Organization, 1977.

APPENDIX

Standard Error

When disease rates are computed from national statistics covering large populations, the variation due to sampling is generally of secondary importance compared with the difficulties in estimating the population denominator and in the classification and coding of disease. However, it is useful to have an estimate of the standard error for use with district data or when rates are based on a study cohort. In order to estimate the standard error, we assume a Poisson model. Let R_j be the rate of disease, d_j the number of events, and n_j the person-years denominator in the jth age group. Then we assume that $\text{var}(d_j) = n_j R_j$ and that the n_j may be regarded as fixed constants. The rate R_j is estimated by $\hat{R}_j = d_j/n_j$ with variance estimated by d_j/n_j^2. Since we take the standard survival probabilities and mean residual life expectancies to be fixed, both the standardized lifetime risk and the standardized number of years of life lost can be viewed as a weighted sum of the $\hat{R}_j$'s. Assuming independence between observations in different age groups, one has (8, p. 59)

$$\text{var}\left(\sum_j w_j \hat{R}_j\right) = \sum_j w_j^2 d_j/n_j^2. \tag{7}$$

For the lifetime risk, the weights are $5S_j$, and for the years of life lost, they are $5S_j A_j$, assuming 5-year age groups.