# A NEW LOOK AT MORTALITY INDEXES WITH EMPHASIS ON SMALL AREA ESTIMATION

Joel C. Kleinman,* National Center for Health Statistics

## INTRODUCTION

One of the oldest and most widely used indicators of health status is the mortality rate. The limitations of the crude mortality rate for comparing specific areas or groups led to the use of various adjustments for factors such as age, race and sex in order to obtain an index which was free from the confounding effects of these factors (Kitagawa, 1966). Currently, the most commonly used adjustments are the direct and indirect methods. However, both these methods are determined to a large extent by death rates in the older age groups which limits their usefulness in health planning and certain epidemiological applications.

In addition, due to the historical use of mortality rates with large populations, relatively little work has been done concerning the standard errors of adjusted rates. However, with increasing need for small-area health status data (as mandated in the National Health Planning and Resource Development Act of 1974) the use of mortality indexes for small populations should become more common and thus there is a need for an assessment of the variability of these indexes.

This study compares four mortality indexes and their standard errors among United States counties using 1969-1971 mortality data.

## DEFINITIONS

### Indexes

For a particular race-sex group in each county, let

$d_i$ = # deaths in age group i

$p_i$ = population in age group i

$m_i = \frac{d_i}{p_i}$ = death rate in age group i

$d = \Sigma d_i$

$p = \Sigma p_i$

Replacing the small letters by capital letters will indicate the corresponding data for a standard population. The age-adjusted rate using the indirect method is usually expressed as the Standard Mortality Ratio (SMR):

$$SMR = \frac{d}{\Sigma M_i p_i} = \frac{\Sigma m_i p_i}{\Sigma M_i p_i} \qquad (1)$$

*The author wishes to thank Timothy Pierce for carrying out the data processing and computations upon which the results are based.

The adjusted rate using the direct method is usually expressed as

$$\Sigma \frac{P_i}{P} m_i$$

It can also be expressed as a ratio similar to the SMR, sometimes called the Comparative Mortality figure (CMF):

$$CMF = \frac{\Sigma \frac{P_i}{P} m_i}{\Sigma \frac{P_i}{P} M_i} = \frac{\Sigma m_i P_i}{\Sigma M_i P_i} \qquad (2)$$

Thus the only difference between the two is that the direct method applies the same standard age distribution to the county's age-specific death rates while the indirect method applies the county's age distribution to a standard set of rates. For this reason, the direct method is usually preferred since two counties with the same set of age-specific rates but different age distributions will have equal CMFs but unequal SMRs. However, in terms of identifying counties with "excess" deaths (an important application in planning) the use of the SMR is more appropriate since it weights the age-specific death rates as they apply to the county's age distribution. Thus, a relatively high death rate is weighted according to the population it actually affects. For this reason, we shall concentrate on indirect adjustment.

Yerushalmy (1951) has pointed out that both the direct and indirect methods of adjustment are greatly influenced by the numbers of deaths and thus death rates in the older age groups are emphasized. He proposed a weighted average of the ratios of each age-specific death rate to a standard age-specific death rate. An indirect method of adjustment which is analogous to Yerushalmy's index is the relative mortality index (RMI):

$$RMI = \frac{1}{p} \Sigma \frac{m_i}{M_i} p_i = \frac{1}{p} \Sigma \frac{d_i}{M_i}$$

This has the advantage of not requiring the county's population by age, an important property for inter-censal estimates. Unlike the two previous indexes, the RMI averages ratios of county age-specific death rates to standard rates and so it is not influenced by numbers of deaths. Indeed it may go too far in this direction. For example, based on United States white males in 1970 doubling of the death rate in the 5-14 age group would result in 8,481 additional deaths while a doubling of the age 35-44 death rate would result in 34,278 additional deaths. Yet the RMI would weight the first increase nearly twice as high as the second (based on the 1970 United States age distribution for white males).

A compromise between these extremes is the use of "productive years of life lost" as a way of counting deaths (Haenszel, 1950). The basic idea is to weight each death according to 70 minus the age of the decedent, the assumption being that each individual should be expected to live 70 productive years of life. When the deaths are grouped by age intervals, 70 minus the midpoint is used as the weight. Thus a years of life lost index can be defined as

$$\text{YLL} = \frac{\Sigma\, d_i(70-l_i)}{\Sigma\, M_i p_i (70-l_i)} = \frac{\Sigma m_i p_i (70-l_i)}{\Sigma M_i p_i (70-l_i)}$$

where $l_i$ is the midpoint of the age interval and the sums are evaluated only for positive values of $70-l_i$. Thus, using the standard eleven age groups (under 1, 1-4, 5-14,..., 75-84, 85+), all deaths above age 65 are excluded from the calculation. Using the example from the previous paragraph, doubling the age 5-14 death rate results in an additional 508,860 years of life lost compared to 1,028,340 years of life lost in the 35-44 age group. The YLL index is the one which seems most appropriate for identifying areas with excess mortality in a health planning and resource allocation context.

Each index was computed separately for each color-sex group (white male, white female, other male, other female) using the 1969-1971 age-color-sex-specific rates for the total United States as the standards. For the CMF the total 1970 United States population age distribution was used as the standard. A combined index was formed for each of the "indirect" indexes (SMR, RMI, YLL) by extending the summation in each formula over 44 (= 4 color-sex groups x 11 age groups) categories.

Standard errors

Since these indexes will be based on small area data, it is important to compare their variances. With the exception of Chiang's (1961) work and an unpublished paper by Chiang and Linder (1969) little work has been done in this area. Any of the preceding indexes can be represented as

$$I = \frac{\Sigma w_i m_i}{w}, \quad w = \Sigma w_i$$

where the $w_i$ and $w$ are considered constants not subject to random variation. Thus the standard error of I is

$$s(I) = \sqrt{\frac{\Sigma w_i^2 \sigma_i^2}{w^2}}$$

where $\sigma_i^2 = \text{Var}(m_i)$. Following, Chiang (1961),

$$\sigma_i^2 = \frac{m_i\left[1-a_i n_i m_i\right]}{p_i\left[1+(1-a_i)n_i m_i\right]} \qquad i = 1,\ldots,10$$

where $\sigma_{11}^2 = 0$
$a_i$ = fraction of last year of life
$n_i$ = number of years in age interval

The standard life table values of $a_i$ ($a_1 = .1$, $a_2 = .4$, $a_3 = \ldots = a_{10} = .5$) were used (Chiang, 1968). For comparing the indexes, the coefficient of variation s(I)/I will be used.

In this study average annual death rates using 1969-1971 deaths and 1970 population were computed. That is,

$$m_i = \frac{d_i}{3p_i}$$

where $d_i$ = total deaths for 3 years in age group i

$p_i$ = 1970 county population in age group i

for each race-sex group. In Chiang's formula for $\sigma_i^2$, $p_i$ was replaced by $3p_i$. Also when $d_i = 0$, $m_i$ was set to zero in computing the index but $m_i$ was set to $M_i$ in computing $\sigma_i^2$.

RESULTS

The results are based on the 2,805 counties* with 5,000 or more total population in 1970. Five indexes were considered for each county: white male, white female, other male, other female, and combined. Each index was computed only if the population for the color group was at least 5,000. The combined indexes for the three indirect adjustment methods (SMR, RMI, YLL) were computed for all 2,805 counties. There were 2,701 counties with white population 5,000 or more, 695 with other population 5,000 or more, and 671 with both white and other population 5,000 or more.

There was substantial variation in the age distribution among the 2,805 counties: the percent over 65 varied from below 7 percent in the lowest decile to over 16 percent in the upper decile with a median of 11.4 percent. The crude death rate varied from below 7.4 per 1,000 in the lowest decile to over 14.0 per 1,000 in the highest decile with a median of 10.7 (the United States rate for 1969-1971 was 9.4 per 1,000). Incidentally the need for age adjustment is indicated by the fact that the correlation coefficient between the crude death rate and the percent over 65 was .88. The correlation coefficient between the crude death rate and each of the indexes discussed below was on the order of .3.

* Of the 3,140 United States counties, 13 were not considered due to different coding between FIPS and NCHS. These were the 5 boroughs of New York City, 2 counties in Hawaii, and 6 county-equivalents in Alaska.

The CMF and SMR gave nearly identical results. The correlation coefficients between the two were over .97 for each color-sex group. Their coefficients of variation (cv) were also similar although there was a tendency for the SMR to have a slightly smaller cv (it can be proven that SMR has a smaller variance than CMF). Thus, despite the theoretical differences between the two, the actual differences over U.S. counties are unimportant. For this reason, we will concentrate on comparing the three indirect indexes.

The correlation matrices for the indexes are shown in Table 1 based on the 671 counties with all color-sex indexes computed. For each index, the white males have the highest correlation with the combined index. The order of the remaining correlations are white female, other male and other female for SMR and RMI but white females have the lowest correlation with the combined YLL index. The correlations between the sex groups are moderate (.4-.7). The correlations between white males and other males (.39-.49) are higher than those between white females and other females (.20-.30).

Table 2 shows the correlation matrices for each color-sex group again based on the 671 counties. Except for other females, the RMI-YLL correlation is highest (.76-.88) and the SMR-RMI lowest (.45-.66). For other females SMR-YLL has the highest correlation (.77).

Results based on the 2,701 counties with white indexes computed and the 695 counties with other indexes computed are similar to those cited above.

Selected percentiles of the distributions of the indexes are presented in Table 3. The distributions of RMI and YLL have more variation than SMR, due in part to their larger random error component (see below). Thus, the RMI and YLL estimate greater "excess" mortality than does the SMR. For example, based on the combined indexes, the upper quintile of the RMI distribution consists of counties at least 26.4 percent above what would be expected based on U.S. rates while the SMR upper quintile estimates only 9.1 percent excess deaths; YLL is intermediate with its upper quintile at 21.4 percent. The RMI and YLL distributions are both skewed to the right while the SMR distributions are symmetric.

Simultaneous pictures of the counties classified in the extremes of the distributions are given in Table 4 which shows the areas in the highest quintile of each index. The percentage of counties in the highest quintile of at least one index was approximately 35 percent for each color-sex group. Of these fewer than one-fourth within each color-sex group were classified high by all three indexes. As was the case with the correlation coefficients, the RMI and SMR had the least agreement. However, the agreement between RMI and YLL was similar to that for SMR and YLL for white females, other males, and other females. For white males and combined, the RMI-YLL agreement was greater.

Table 5 illustrates the differences between the combined and color-sex specific YLL indexes in terms of counties classified as extreme (in the upper or lower quintile). Except for white males, the combined index identified only 56 percent-64 percent of the counties which had a high color-sex-specific index. These results are consistent with the correlations in Table 1 and point to the need for using race-sex-specific indexes whenever possible.

In terms of coefficients of variation (cv), the ordering of the indexes are as expected based on the age groups each emphasize: SMR has the smallest cv and RMI the largest. Table 6 shows selected percentiles of the cv's. Four-fifths of the counties had SMRs with cv's below 4 percent-9 percent. For YLL less than 40 percent had cv's in this range, and for RMI only 10-20 percent had cv's in this range. Eighty percent of the counties had YLL indexes with cv's below 12 percent-23 percent.

In order to facilitate a quick rule of thumb for anticipating cv's, Table 7 shows the range of cv's observed for selected county population size groups. For the SMR, cv's above 5 percent were virtually nonexistent in counties over 10,000 population. In the 5-10,000 group, however, more than 40 were over 5 percent. The RMI has larger cv's and it is not until the 100,000 + group that the majority of cv's are below 5 percent. Clearly, this index is not very useful for small populations. The YLL index is intermediate between the two. For populations above 25,000, virtually all cv's are below 10 percent and the majority are below 5 percent.

## CONCLUSIONS

The results presented show that substantial differences exist among the indexes studied (except for Standardized Mortality Ratio and Comparative Mortality Figure). In addition, the counties with excess mortality vary for each color-sex group. The implications of these results for two types of applications are presented briefly below.

First, in terms of epidemiological investigations which use regression analysis of age-adjusted rates using counties or other ecological areas as the unit of analysis (e.g., Lave and Seskin, 1973), our results show that the results are influenced heavily by white male death rates in the older age groups. Even when separate color-sex groups are used, the death rates for white males in the three age groups between 55 and 84 account for nearly 80 percent of the variation in the white male SMR. Thus, more thoughtful specification of the model in such studies is called for. If a combined index is necessary and a relative risk model is appropriate, the relative mortality index (or Yerushalmy's amalagous direct method) seems a better alternative than the SMR or CMF. Of course, the ideal approach is to use age-specific rates but for small populations these rates have a large random error component.

For Health Planning applications, the use of the SMR or CMF is inappropriate since death rates among the elderly are probably least amenable to health planning intervention. Similarly the RMI seems to place too much emphasis on very small death rates in the young age groups. Thus, the years of life lost index seems a reasonable compromise. We have also shown that the SMR combined index which is the only one possible when published sources of county mortality data are used (e.g., National Center for Health Statistics, 1975), is a poor substitute for the color-sex specific YLL indexes. Thus, health planning agencies should attempt to go beyond the published data to obtain age-race-sex-specific death rates in order to be able to compute the YLL indexes.

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Table 1. Correlation coefficients between color-sex groups for three mortality indexes: United States counties, 1969-1971[a]

| Index | | White Male (WM) | White Female (FM) | Other Male (OM) | Other Female (OF) | Combined (C) |
|---|---|---|---|---|---|---|
| | WM | 1.0000 | | | | |
| | WF | .6173 | 1.0000 | | | |
| SMR | OM | .4407 | .2731 | 1.0000 | | |
| | OF | .4227 | .2987 | .7266 | 1.0000 | |
| | C | .8708 | .7699 | .6330 | .6041 | 1.0000 |
| | WM | 1.0000 | | | | |
| | WF | .4346 | 1.0000 | | | |
| RMI | OM | .3892 | .2214 | 1.0000 | | |
| | OF | .2795 | .2038 | .4152 | 1.0000 | |
| | C | .8182 | .6894 | .5915 | .5505 | 1.0000 |
| | WM | 1.0000 | | | | |
| | WF | .4925 | 1.0000 | | | |
| YLL | OM | .4938 | .2615 | 1.0000 | | |
| | OF | .3859 | .2621 | .6266 | 1.0000 | |
| | C | .8336 | .6017 | .7438 | .6633 | 1.0000 |

[a]Based on 671 counties with White and Other population 5,000 or more

SMR = Standardized Mortality Ratio
RMI = Relative Mortality Index
YLL = Years of Life Lost Index

Table 2. Correlation coefficients between indexes for each color-sex group: United States counties, 1969-1971[a]

| Color-Sex | | SMR | RMI | YLL |
|---|---|---|---|---|
| | SMR | 1.0000 | | |
| WM | RMI | .6408 | 1.0000 | |
| | YLL | .7297 | .8841 | 1.0000 |
| | SMR | 1.0000 | | |
| WF | RMI | .4484 | 1.0000 | |
| | YLL | .5100 | .7603 | 1.0000 |
| | SMR | 1.0000 | | |
| OM | RMI | .6576 | 1.0000 | |
| | YLL | .7574 | .7942 | 1.0000 |
| | SMR | 1.0000 | | |
| OF | RMI | .5416 | 1.0000 | |
| | YLL | .7667 | .7023 | 1.0000 |
| | SMR | 1.0000 | | |
| C | RMI | .6444 | 1.0000 | |
| | YLL | .7336 | .8777 | 1.0000 |

[a]Based on 671 counties with White and Other population 5,000 or more

Table 3. Selected percentiles of mortality indexes: United States counties 1969-1971

| Index | Color-Sex | Number of Counties[a] | 10 | 20 | Percentile 40 | 60 | 80 | 90 |
|---|---|---|---|---|---|---|---|---|
| SMR | WM | 2701 | .867 | .913 | .978 | 1.035 | 1.106 | 1.164 |
| | WF | 2701 | .845 | .892 | .960 | 1.018 | 1.087 | 1.141 |
| | OM | 695 | .771 | .880 | .995 | 1.078 | 1.172 | 1.248 |
| | OF | 695 | .792 | .891 | 1.008 | 1.089 | 1.171 | 1.220 |
| | C | 2805 | .871 | .916 | .978 | 1.029 | 1.090 | 1.139 |
| RMI | WM | 2701 | .819 | .901 | 1.036 | 1.159 | 1.347 | 1.505 |
| | WF | 2701 | .735 | .835 | .964 | 1.081 | 1.245 | 1.404 |
| | OM | 695 | .670 | .799 | .961 | 1.108 | 1.272 | 1.443 |
| | OF | 695 | .689 | .800 | .984 | 1.100 | 1.293 | 1.471 |
| | C | 2805 | .834 | .913 | 1.019 | 1.122 | 1.264 | 1.375 |
| YLL | WM | 2701 | .832 | .917 | 1.024 | 1.127 | 1.271 | 1.404 |
| | WF | 2701 | .766 | .853 | .967 | 1.066 | 1.191 | 1.313 |
| | OM | 695 | .729 | .848 | .991 | 1.100 | 1.248 | 1.356 |
| | OF | 695 | .749 | .858 | .994 | 1.119 | 1.255 | 1.376 |
| | C | 2805 | .847 | .919 | 1.015 | 1.098 | 1.215 | 1.316 |

[a]Indexes computed only when county population in the color group was 5,000 or more

Table 4. Percent of counties in highest quintile of each index by color and sex: United States counties 1969-1971

| Color-Sex | All | SMR and RMI | SMR and YLL | RMI and YLL | SMR only | RMI only | YLL only | None | Total % | N |
|---|---|---|---|---|---|---|---|---|---|---|
| | Indexes for which county classified in highest quintile[a] | | | | | | | | | |
| White male | 7.8 | 1.8 | 2.9 | 6.0 | 7.6 | 5.4 | 3.0 | 65.5 | 100.0 | 2701 |
| White female | 5.8 | 2.0 | 2.9 | 6.1 | 9.2 | 6.0 | 5.3 | 62.8 | 100.0 | 2701 |
| Other male | 8.1 | 1.4 | 4.0 | 4.0 | 6.0 | 6.5 | 3.7 | 66.2 | 99.9 | 695 |
| Other female | 5.2 | 1.9 | 5.2 | 5.2 | 7.9 | 7.5 | 4.2 | 63.0 | 100.1 | 695 |
| Combined | 7.1 | 1.6 | 3.3 | 6.1 | 7.7 | 5.2 | 3.5 | 65.5 | 100.0 | 2805 |

[a]Numbers of counties in highest quintile of each index vary slightly due to ties and interpolation

Table 5. Relationship between counties classified by combined YLL and color-sex specific YLL indexes: United States counties 1969-1971

| Color-Sex | | Combined YLL Index: Highest 20% (H) | Middle 60% (M) | Lowest 20% (L) | Total % | N[a] |
|---|---|---|---|---|---|---|
| WM | H | 72.2 | 27.6 | 0.2 | 100.0 | 547 |
| | M | 8.1 | 84.7 | 7.2 | 100.0 | 1621 |
| | L | 0.9 | 19.4 | 79.7 | 100.0 | 533 |
| | Total | 20.5 | 60.2 | 19.3 | 100.0 | 2701 |
| WF | H | 57.7 | 41.6 | 0.7 | 100.0 | 542 |
| | M | 11.6 | 74.6 | 13.8 | 100.0 | 1618 |
| | L | 4.1 | 38.0 | 57.9 | 100.0 | 541 |
| | Total | 20.5 | 60.2 | 19.3 | 100.0 | 2701 |
| OM | H | 63.8 | 36.2 | --- | 100.0 | 140 |
| | M | 8.4 | 80.8 | 10.8 | 100.0 | 417 |
| | L | 0.7 | 40.7 | 58.6 | 100.0 | 138 |
| | Total | 18.3 | 63.9 | 17.8 | 100.0 | 695 |
| OF | H | 56.2 | 43.1 | 0.7 | 100.0 | 139 |
| | M | 12.2 | 77.1 | 10.7 | 100.0 | 419 |
| | L | 1.4 | 44.6 | 54.0 | 100.0 | 137 |
| | Total | 18.3 | 63.9 | 17.8 | 100.0 | 695 |

[a]Indexes computed only when county population in the color group was 5,000 or more

Table 6. Selected Percentiles of coefficients of variation for each mortality index: United States counties 1969-1971

| Index | Color-Sex | Number of Counties[a] | Percentile 10 | 20 | 40 | 60 | 80 | 90 |
|---|---|---|---|---|---|---|---|---|
| | WM | 2701 | .018 | .025 | .034 | .043 | .053 | .063 |
| | WF | 2701 | .020 | .028 | .039 | .050 | .064 | .078 |
| SMR | OM | 695 | .030 | .038 | .052 | .063 | .075 | .084 |
| | OF | 695 | .034 | .044 | .060 | .072 | .087 | .099 |
| | C | 2805 | .013 | .018 | .025 | .032 | .040 | .047 |
| | WM | 2701 | .066 | .091 | .130 | .167 | .220 | .258 |
| | WF | 2701 | .082 | .119 | .175 | .236 | .320 | .398 |
| RMI | OM | 695 | .083 | .120 | .163 | .201 | .249 | .290 |
| | OF | 695 | .097 | .143 | .198 | .251 | .314 | .386 |
| | C | 2805 | .052 | .073 | .105 | .138 | .185 | .222 |
| | WM | 2701 | .045 | .064 | .092 | .119 | .151 | .176 |
| | WF | 2701 | .062 | .090 | .133 | .175 | .231 | .280 |
| YLL | OM | 695 | .051 | .073 | .101 | .126 | .147 | .164 |
| | OF | 695 | .062 | .092 | .126 | .154 | .176 | .198 |
| | C | 2805 | .035 | .047 | .071 | .089 | .122 | .143 |

[a]Indexes computed only when population in the color group was 5,000 or more

Table 7. Coefficients of variation for combined mortality indexes by county population: United States counties, 1969-1971

| Index | Population | Coefficient of Variation <1% | 1%- | 5%- | 10%- | ≥15% | Total % | N[a] |
|---|---|---|---|---|---|---|---|---|
| SMR | 5,000 | --- | 59.6 | 39.5 | 0.7 | 0.2 | 100.0 | 554 |
| | 10,000 | --- | 98.0 | 1.9 | --- | 0.1 | 100.0 | 1008 |
| | 25,000 | --- | 99.6 | 0.2 | 0.2 | --- | 100.0 | 570 |
| | 50,000 | --- | 100.0 | --- | --- | --- | 100.0 | 332 |
| | 100,000 | 27.8 | 71.9 | 0.4 | --- | --- | 100.1 | 270 |
| | 500,000 | 100.0 | --- | --- | --- | --- | 100.0 | 52 |
| | 1,000,000 | 100.0 | --- | --- | --- | --- | 100.0 | 19 |
| | Total | 5.2 | 86.0 | 8.6 | 0.2 | 0.1 | 100.0 | 2805 |
| RMI | 5,000 | --- | --- | --- | 0.7 | 99.3 | 100.0 | 554 |
| | 10,000 | --- | --- | 0.5 | 60.6 | 38.9 | 100.0 | 1008 |
| | 25,000 | --- | --- | 61.9 | 37.4 | 0.7 | 100.0 | 570 |
| | 50,000 | --- | 0.6 | 97.9 | 1.5 | --- | 100.0 | 332 |
| | 100,000 | --- | 68.1 | 31.5 | --- | 0.4 | 100.0 | 270 |
| | 500,000 | --- | 100.0 | --- | --- | --- | 100.0 | 52 |
| | 1,000,000 | 10.5 | 89.5 | --- | --- | --- | 100.0 | 19 |
| | Total | 0.1 | 9.1 | 27.4 | 29.7 | 33.8 | 100.1 | 2805 |
| YLL | 5,000 | --- | --- | 1.3 | 59.2 | 39.5 | 100.0 | 554 |
| | 10,000 | --- | --- | 60.0 | 39.0 | 1.0 | 100.0 | 1008 |
| | 25,000 | --- | 4.4 | 95.3 | 0.2 | 0.2 | 100.1 | 570 |
| | 50,000 | --- | 63.0 | 37.0 | --- | --- | 100.0 | 332 |
| | 100,000 | --- | 99.6 | --- | 0.4 | --- | 100.0 | 270 |
| | 500,000 | --- | 100.0 | --- | --- | --- | 100.0 | 52 |
| | 1,000,000 | 36.8 | 63.2 | --- | --- | --- | 100.0 | 19 |
| | Total | 0.2 | 20.2 | 45.6 | 25.8 | 8.2 | 100.0 | 2805 |

[a]Based on counties with population 5,000 or more