CHAPTER 6

Measures of Natality and Mortality

Among the statistics of greatest epidemiologic importance are the traditional vital statistics—rates of births, deaths, marriages, and divorces. Because the calculations for marriage and divorce rates are relatively straightforward, and are not usually of epidemiologic interest, this chapter will examine only the rates of births and deaths.

Natality Measures

Natality rates measure additions or probable additions to a population—in other words, live births. Natality is most often measured in terms of period rates that describe the childbearing experience of a population on an annual, or other time period, basis. Natality may also be expressed in terms of cohort rates, which describe the reproductive history of a select group of women up to a specified age.

The term *live birth* would seem to be self-explanatory but the operation of a statistical reporting system requires a relatively precise definition of the events to be counted. A live birth is usually defined as any product of conception that shows any sign of life after complete birth. Such signs of life include heart beat, respiration, crying, pulsation of the umbilical cord, or movement of the voluntary muscles.

The crude birth rate relates live births to the total population (of both sexes and all ages) for a specific interval of time, usually one year.

$$\text{Crude birth rate} = \frac{\text{Number of live births during time interval}}{\text{Total population}} \times 1{,}000$$

A serious methodological problem arises in calculating the crude birth rate or any other rate that is calculated for a period of time rather than cross-sectionally for one point in time. This problem involves the fact that most populations change over time. If the population was changing during the interval for which rate is calculated, what population figure is used as the denominator?

The best answer to this question is to use the average population for the interval. The average population for a year may be calculated easily by summing the population on January 1, the population on January 2, the population on January 3, and so on through December 31, then dividing this sum by 365 (or 366 for a leap year). The problem with this solution is not the simple though lengthy calculation, but the difficulty in obtaining daily population figures. The U.S. Census is taken once every 10 years, not daily. Daily population counts are available for jails, prisons, schools, hospitals, and military institutions, but not for cities, towns, states, or nations.

The solution to this problem found in almost every text is to use the midinterval population. Thus, for an annual crude birth rate, the population on July 1 of that year would be used as the denominator. This solution is offered as though it actually makes sense; as though a census was actually conducted each year on July 1 for the convenience of epidemiologists. In fact, we must settle for the best population statistic available, which more often than not is the last Census figure. This problem, and its lack of a satisfactory solution, applies as well to all of the period rates discussed in this text.

Another problem is that, because age and sex differences are not accounted for in the denominator, the crude birth rate does not represent a true probability of childbearing applicable to any individual member of that population. Because populations vary in their age and sex distributions, comparisons of crude birth rates of different populations are limited. Likewise, changes over time in the annual crude birth rates of a population may be due to changes in the age or sex composition of the population rather than due to changes in the fertility of the population.

A measure that more appropriately relates births to an approximation of the population at risk is the general fertility rate (GFR). The denominator is composed of women aged 15–44. Obviously, only women are "at risk" of childbearing. Although women younger than 15 or older than 44 may give birth, it is within these age bounds that most childbearing occurs.

$$GFR = \frac{\text{Number of live births during interval}}{\text{Average population during interval}} \times 1{,}000$$

The total fertility rate (TFR) is the sum of annual age-specific birth rates for women aged 10–49. Because these statistics are usually kept for 5-year age groups, the rate for each age group is multiplied by five before summing the rates to obtain the TFR. Not only does the TFR have the advantage of a more inclusive "at risk" population (10–49 rather than 15–44), but, because it is made up of age-specific rates, it is not influenced by the age distribution of the women in the population.

Another widely used summary of age-specific rates is the gross reproduction rate (GRR). The GRR is the same as the total fertility rate except that only female births are counted. The GRR can be quickly computed from the TFR by multiplying the TFR by the percentage of births that are female.

The net reproductive rate (NRR) differs from the GRR in that only those female births who will survive until reproductive age at current mortality rates are included in the rate. The calculations of TFR, GRR, and NRR are illustrated in Table 6.1.

A GRR of 1,000 signifies that if all the women born at the beginning of a generation survive through their reproductive period and as a group continue to give birth at this rate, they will exactly reproduce themselves. However, mortality before reproductive age will prevent complete replacement. An NRR of 1,000 means that each generation of women will just replace itself. A net rate of less than 1,000 indicates a potentially declining population, whereas an NRR greater than 1,000 signifies potential population increase.

Mortality Measures

Mortality describes the frequency of deaths over a period of time. These measures are among the most widely used statistics in epidemiology, partly because they are among the most accurately counted events in all of our health statistics.

The crude death rate represents the risk of dying for a randomly selected individual from the entire population of a designated area.

TABLE 6.1 Total, Gross, and Net Reproduction Rates: United States, 1981

Age Group in Years	Age-Specific Fertility Rates Per 1,000 Women	(x) Proportion of Females at Birth[a]	(=) GRR	(x) Proportion Surviving Females (l_x)[b]	(=) NRR
10–14	1.1	.488	.54	.9757	0.52
15–19	52.7	.488	25.72	.9743	25.05
20–24	111.8	.488	54.56	.9715	53.01
25–29	112.0	.488	54.66	.9680	52.91
30–34	61.4	.488	29.96	.9639	28.88
35–39	20.0	.488	9.76	.9581	9.35
40–44	3.8	.488	1.85	.9492	1.76
45–49	0.2	.488	0.09	.9363	0.08
Σ	363.0	.488	177.14	—	171.56
Σx5[c]	TFR = 1815	—	GRR = 885.7	—	NRR = 857.8

[a] The proportion of females at birth varies only slightly between age groups; the proportion of the total is an adequate figure to use.

[b] This data from current life tables. Use l_x column and compute proportion of females surviving.

[c] TFR, GRR, and NRR: Values summed and multiplied by five (5) because age groups are in 5-year intervals.

Source: Statistical Abstract of the United States, 1985.

Computed from total deaths due to all causes and total population, it measures the decrease in a population due to death.

$$\text{Crude death rate} = \frac{\text{Total number of deaths during interval}}{\text{Total population}} \times 1{,}000$$

Specific death rates for any defined group within the population measure the risk of dying for any member of that group. They are computed from the number of deaths occurring in the defined group and the total number of persons in that group using the formula:

$$\text{Specific death rate} = \frac{\text{Number of deaths in specific group}}{\text{Population of group}} \times 1{,}000$$

The groups for which specific death rates may be calculated may be defined by any characteristic or combination of characteristics provided that the characteristics are found both in the census and on death certificates. For example, a specific death rate might be calculated for white, divorced women between the ages of 40 and 49 if that suits the epidemiologist's purpose.

Perhaps the most epidemiologically important of all mortality rates are those that are specific as to cause of death. These rates represent the risk of death from a specific condition and may be either crude or specific—that is, the denominator may be either the total population or some specific population subgroup.

$$\text{Cause-of-death rate} = \frac{\text{Number of deaths due to a stated cause}}{\text{Population at risk}} \times 100{,}000$$

$$\text{Cause-of-death rate for a specific subgroup} = \frac{\text{Number of deaths among a specified group due to a stated cause}}{\text{Population of group}} \times 100{,}000$$

Infant and Maternal Mortality Measures

The infant mortality rate traditionally has been considered of great importance in public health. It has been widely applied as an index of the general health of a community or nation, either to compare one to another or to study changes over time. As an index it has been found to be highly sensitive to variations in sanitary conditions, food resources, and medical care.

Infant mortality may be subdivided into two separate measures. Deaths during the first 27 days of life are known as *neonatal mortality*. Those occurring to infants less than 1 year of age but no less than 4 weeks old are termed *postneonatal mortality*. The death rate during the first year of life is higher than at any other age until old age. In less developed nations, the postneonatal mortality rate is only slightly less than the neonatal mortality rate. As nations become more developed, postneonatal deaths decline more than do neonatal deaths, widening the gap between the two rates.

As a general rule, the lower the infant mortality of a society is, the lower the proportion of those deaths that occur postneonatally. The higher the infant mortality rate, the higher the proportion of postneonatal deaths. The lower the infant mortality rate, the higher the ratio of neonatal to postneonatal deaths. This relatively consistent relationship suggests that postneonatal mortality is more related to the sort of causal variables associated with economic development, such as improvements in sanitation, nutrition, and medical care. Neonatal mortality, on the other hand, appears to be less affected by such variables and may be more often due to genetic causes or complications of the birth process.

$$\text{Infant mortality rate} = \frac{\text{Number of deaths under 1 year of age during year}}{\text{Number of live births during year}} \times 1{,}000$$

$$\text{Neonatal mortality rate} = \frac{\text{Number of deaths under 28 days of age during year}}{\text{Number of live births during year}} \times 1{,}000$$

$$\text{Postneonatal mortality rate} = \frac{\text{Number of deaths occurring from 28 days, up to but not over 1 year of age during year}}{\text{Number of live births during year}} \times 1{,}000$$

The infant mortality rate should be the sum of the neonatal and postneonatal mortality rates. However, in calculating the postneonatal mortality rate according to the formula given above, some degree of error is introduced, which decreases the precision of any such summing process. The degree of error is usually negligible and for most practical purposes can be discounted. Nevertheless, it is true that those infants who died during the neonatal period (the first 4 weeks after birth) were not, of course, "at risk" of dying again during the postneonatal period. Therefore, a more precise calculation of the postneonatal death rate would require that the number of neonatal deaths be subtracted from the denominator of the rate. This seldom-used but more precise formula is:

$$\text{Postneonatal death rate} = \frac{\begin{array}{c}\text{Number of deaths of infants}\\ \text{more than 28 days old}\\ \text{but less than 1 year old}\end{array}}{\begin{array}{c}\text{Number of live births that year}\\ \text{minus number of neonatal deaths}\end{array}} \times 1{,}000$$

There is another source of error in all of the infant mortality rates. In fact, they are not truly rates at all; they are only ratios. One of the essential elements of a rate is that all of the persons represented in the numerator must also be represented in the denominator. All of the infant mortality measures violate this principle. The problem is simply that an infant may be born during one calendar year and die during the next while still less than 1 year old. For instance, if an infant born on December 31, 1987 dies on January 1, 1988, it is included in the numerator but not the denominator for the 1988 infant and neonatal mortality rates. Likewise, that infant is included in the denominator for the 1987 postneonatal death rate, although it was not actually at risk for postneonatal death in 1987.

A fetal death (or stillbirth) is one in which an infant is delivered dead. If the infant shows any sign of life after the delivery—such as pulsation of the umbilical cord or movement of the voluntary muscles—then it is considered a live birth followed by a neonatal death.

The fetal mortality rate is intended as a measure of the risk of fetal death among all pregnancies carried beyond a specified period of gestation (usually 20 weeks). An alternate statistic, the fetal death ratio, relates fetal deaths to live births. Due to incomplete reporting and variations in reporting requirements, neither of these statistics is generally a good measure of the true risk of fetal death. Any

conclusions based on these statistics should be approached with the greatest of caution.

$$\text{Fetal mortality rate} = \frac{\begin{array}{c}\text{Number of fetal deaths}\\ \text{of specified period of gestation}\end{array}}{\begin{array}{c}\text{Number of live births}\\ \text{plus number of fetal deaths}\\ \text{of specified period of gestation}\end{array}} \times 1{,}000$$

$$\text{Fetal death ratio} = \frac{\begin{array}{c}\text{Number of fetal deaths}\\ \text{of specified period of gestation}\end{array}}{\text{Number of live births}} \times 1{,}000$$

Perinatal mortality is a concept that combines fetal deaths with loss of life in early infancy. A majority of neonatal deaths arise from conditions established before delivery or from complications of the birth process itself. Similar causes are likely to be responsible for the loss of viable fetuses. Thus, combining the two into a single rate seems logical. It also eliminates discrepancies that may arise from the recording of live births as fetal deaths or vice versa.

A single definition of perinatal mortality has not yet been agreed on. There are two commonly used formulae, usually referred to by the designations *PMR* I and *PMR* II. There are arguments for the choice of each formula. The critical consideration is that the method used must always be specified. Any comparisons should only be made where the figures are all calculated by the same formula.

$$PMR\ \text{I} = \frac{\begin{array}{c}\text{Infant deaths under 7 days of age}\\ \text{plus fetal deaths of 28-weeks gestation}\end{array}}{\begin{array}{c}\text{Number of live births}\\ \text{plus fetal deaths of 28-weeks gestation}\end{array}} \times 1{,}000$$

$$PMR\ \text{II} = \frac{\begin{array}{c}\text{Infant deaths under 28 days of age}\\ \text{plus fetal deaths of 20-weeks gestation}\end{array}}{\begin{array}{c}\text{Number of live births}\\ \text{plus fetal deaths of 20-weeks gestation}\end{array}} \times 1{,}000$$

The maternal mortality rate reflects not only the quality of obstetrical care but also the general level of environmental and social health in the community. This statistic relates the number of childbirth-associated (puerperal) deaths to the number of live births during the same interval (usually 1 year). Technically this is a ratio, not a rate, because the numerator (mothers) is not included in the denominator (infants).

Live births are used in calculating this statistic because that is the way the data are recorded—a birth certificate for each infant rather than for each mother or each pregnancy. Live births, of course, do not represent all pregnancies at risk for maternal death. To arrive at such a denominator we would have to include fetal deaths as well. Given the unreliability of fetal death registrations, it has become customary not to bother.

$$\text{Maternal mortality rate} = \frac{\text{Number of deaths due to puerperal causes}}{\text{Number of live births}} \times 1{,}000$$

Adjusted Rates

If we were to conduct a study of mortality rates in relation to hair color, we might find that people with gray or white hair showed significantly higher mortality rates than persons with any other color hair. It would be unwise, however, to conclude that gray or white hair is causally related to high mortality. The problem, obviously, is that gray or white hair is often associated with old age and that the elderly have a higher annual death rate than the young.

This problem is known as *confounding*. The above example is a confounder because it is causally associated with both age and mortality. This makes it difficult to assess any possible effect of hair color on mortality. One way to do so would be to only compare persons of the same age—is hair color associated with mortality rates among 20-year-olds, for instance. The other way is to statistically adjust the data so as to eliminate the influence of age differences between the different hair color groups.

We experience exactly this same problem in many epidemiologic comparisons between groups or communities. It would not be surprising to learn that the crude death rate in St. Petersburg, Florida, with its large number of retirees, is greater than that in Gainesville, Florida, with its large number of University of Florida students. An older population is likely to have a higher death rate and (as will be discussed in Chapter 8) different morbidity rates than a younger population. In fact, age is almost always a confounding factor whenever two communities are compared. For this reason, such comparisons should always be made using age-adjusted rates.

Age-adjusted (standardized) rates are rates that have been statistically transformed into the rates that would exist in the communities under comparison if both communities had the same age distribution. Adjusted rates may be calculated for natality and morbidity, as well as for mortality. Rates may be adjusted, or standardized, not only for age but also for other person factors, such as race and sex. The most frequently used adjusted rates, however, are age-adjusted mortality rates. We will use such rates to illustrate the adjustment process.

For our example, we will take two hypothetical counties—Snow County and Frost County. In 1960, the crude death rate in Snow County was 15.3 per 1,000 population. The crude death rate in Frost County in 1960 was 6.7 per 1,000. The age distributions of the two populations are found in Table 6.2. An examination of the table shows the age distributions of the two counties to be quite different. The population of

TABLE 6.2 Age Distribution of the Population of Two Hypothetical Counties

Age Group in Years	Snow County		Frost County	
	Population	Distribution (Percent)	Population	Distribution (Percent)
<1	5,674	1.52%	4,597	2.90%
1–4	22,167	5.92	17,128	10.80
5–9	26,713	7.13	17,877	11.27
10–14	25,219	6.73	14,575	9.19
15–19	18,710	4.99	12,481	7.87
20–24	13,855	3.70	14,906	9.40
25–29	15,401	4.11	12,966	8.17
30–34	18,476	4.93	12,393	7.81
35–39	20,966	5.60	11,113	7.00
40–44	20,667	5.52	9,663	6.09
45–49	20,582	5.49	8,111	5.11
50–54	21,088	5.63	6,474	4.08
55–59	23,238	6.20	5,118	3.23
60–64	28,747	7.67	3,735	2.35
65–69	36,610	9.77	3,152	1.99
70–74	29,173	7.79	2,048	1.29
75–79	16,415	4.38	1,341	0.85
80–84	7,243	1.93	588	0.37
85+	3,721	0.99	357	0.23
Totals	374,665	100.00%	158,623	100.00%

Source: Ferrara, C. P. (1980). *Vital and health statistics.* Atlanta, GA: Centers for Disease Control.

Snow County had a median age of 44 years, with 24.9 percent of the population over age 65. Frost County's population had a median age of 24 and only 4.7 percent of them were over age 65. Obviously, these age differences are likely to be responsible for much of the difference in the two counties' death rates.

Two traditional methods exist for the adjustment of rates. These are the *direct method* and the *indirect method.* More recently, a number of procedures have been developed using multiple linear regression, multiple logistic functions, or discriminant function analysis to adjust rates. These procedures are beyond the scope of this text. The interested reader is referred to Kahn (1983) for a detailed discussion of these methods.

Direct Adjustment

In the direct method of age-adjusting rates, the age-specific rates from the study populations are applied to a standard population to obtain the number of "expected deaths" for each age group. The expected deaths are those that would be expected to occur if the age distribution of the study population were the same as that of the standard population. Any population distribution can be used as a standard population. Among the most commonly chosen standard populations are the population of the United States, the population of the state in which both communities are located, or a hypothetical pooled population created by adding the two community populations together. For the purpose of this example, we will use the 1980 Census population of the U.S. as our standard population.

A necessary step for direct adjustment is the calculation of age-specific death rates for the two counties under study. The results of these calculations, using the general formula for specific death rates, are shown in Table 6.3.

Table 6.4 shows the calculations for direct adjustment of the rates. For each age group (first column), the standard population (second column) is multiplied by the age-specific death rate for each county (third and fourth columns). The result is entered into the fifth or sixth column, respectively. For example, the calculation for the expected number of infant deaths in Snow County is:

$$\text{Expected deaths} = \frac{22.8}{1{,}000} \times 3{,}612{,}000 = 82{,}353$$

TABLE 6.3 Population, Resident Deaths, and Death Rates by Age in Two Hypothetical Counties

Age Group in Years	Snow County Population in 1960	Snow County Deaths in 1960	Snow County Rate (per 1,000 Pop.)	Frost County Population in 1960	Frost County Deaths in 1960	Frost County Rate (per 1,000 Pop.)
<1	5,674	160	28.2	4,597	105	22.8
1–4	22,167	30	1.4	17,128	23	
5–14	51,932	30	0.6	32,452	21	0.6
15–24	32,565	26	0.8	27,387	39	1.4
25–34	33,877	47	1.4	25,359	48	
35–44	41,633	124	3.0	20,776	83	4.0
45–54	41,670	320	7.7	14,585	137	9.4
55–64	51,985	829	15.9	8,853	182	
65–74	65,783	1,901	28.9	5,200	204	39.2
75+	27,379	2,259	82.5	2,286	223	97.6
Totals	374,665	5,726	15.3	158,623	1,065	6.7

Source: Ferrara, C. P. (1980). *Vital and health statistics.* Atlanta, GA: Centers for Disease Control.

TABLE 6.4 Direct Method of Adjustment Mortality in Two Hypothetical Counties Using the 1980 U.S. Enumerated Population as Standard

Age Group in Years	Enumerated Standard Population (U.S. 1980) (in thousands)	(x) Age-Specific Death Rates (per 1,000 Population)		(=) Expected Deaths in 1960 U.S. Population Using County Age-Specific Rates	
		Snow County	Frost County	Snow County	Frost County
< 1	3,612	28.2	22.8	101,858	82,354
1–4	12,736	1.4	1.3	17,830	16,557
5–14	34,942	0.6	0.6	20,965	20,965
15–24	42,487	0.8	1.4	33,990	59,482
25–34	37,082	1.4	1.9	51,915	70,456
35–44	25,634	3.0	4.0	76,902	102,536
45–54	22,800	7.7	9.4	175,560	214,320
55–64	21,703	15.9	20.6	345,078	447,082
65–74	15,581	28.9	39.3	450,291	612,333
75+	9,969	82.5	97.6	822,443	972,974
Totals	226,546	15.3	6.7	2,096,831	2,599,059
Adjusted rates	—	—	—	9.3	11.5

Adapted from: Ferrara, C. P. (1980). *Vital and health statistics.* Atlanta, GA: Centers for Disease Control.

Once all of the number of expected deaths has been calculated for each age group in each county, the column of figures can be summed to arrive at the total number of expected deaths for each county. An adjusted death rate can then be calculated by dividing the number of expected deaths by the population of the county and multiplying the quotient by 1,000. Although time consuming, this is a mathematically simple procedure. The use of computers, of course, eliminates the time-consuming aspect.

Indirect Adjustment

For direct adjustment it is necessary to know both the number of persons and the number of deaths in each age group for both counties. In some cases, however, the mortality by age group may not be available and therefore the direct method cannot be used. In other instances, some of the age group populations may be so small that a difference of only a few deaths would cause large fluctuations in age-specific rates, thus rendering direct adjustment misleading. These problems are avoided by use of the indirect method.

In the indirect method the age-specific death rates from a standard population are applied to the age distribution in the study populations—exactly the opposite of the direct method. In our example, we use the 1981 age-specific death rates for the U.S. population. The method is presented in Table 6.5.

Expected deaths are calculated as in the direct method. An index death rate is then calculated by summing the number of expected deaths for each county and dividing by the county's population, then multiplying by 1,000. Then for each county, calculate an adjusting factor by dividing the crude death rate for the standard population by that county's index death rate. Finally, multiply the crude death rate for each county by the adjusting factor for that county in order to arrive at an adjusted death rate. Although this process may seem complex on first examination, it is actually quite simple to perform. The only problem, again, is that it is a lengthy process, but this is solved by the use of a computer.

Whichever method of adjustment is used, the results are essentially the same. Once the influence of differing age distributions is eliminated, the adjusted death rate in Frost County turns out to be higher than in Snow County. Hopefully, this serves to illustrate the value as well as the methods of age adjustment. Further examples of rate adjustment can be found in Ferrara (1980)—illustrations of adjustment of natality and mortality rates, and adjustment for race, sex, and age.

TABLE 6.5 Indirect Method of Adjustment Mortality in Two Hypothetical Counties Using 1980 U.S. Age-Specific Death Rates as Standard

Age Group in Years	Death Rates (per 1,000 Pop.) (U.S. 1981)	Population		Expected Deaths in County Using U.S. Specific Rates	
		Snow County	Frost County	Snow County	Frost County
<1	11.4	5,674	4,597	65	52
1–4	0.6	22,167	17,128	13	10
5–14	0.2	51,932	32,452	10	6
15–24	0.6	32,565	27,387	20	16
25–34	0.8	33,877	25,359	27	20
35–44	1.6	41,633	20,776	67	33
45–54	4.1	41,670	14,585	171	60
55–64	9.3	51,985	8,853	483	82
65–74	21.4	65,783	5,200	1,408	111
75+	54.4	27,379	2,286	1,489	124
Totals	9.5	374,665	158,623	3,753	514
Index death rates	Expected deaths ÷ population × 1,000			10.02	3.24
Adjusting factors	Standard death rate ÷ index death rate			0.948	2.93
Crude rate				15.3	6.7
Adjusted rate	Adjusting factor × crude rate			14.5	19.6

Adapted from: Ferrara, C. P. (1980). *Vital and health statistics.* Atlanta, GA: Centers for Disease Control.

Recommended Reading

Ferrara, C. P. (1980). *Vital and health statistics: Techniques of community health analysis.* Atlanta, GA: Centers for Disease Control.

Kahn, H. A. (1983). *An introduction to epidemiologic methods.* New York: Oxford University Press. (Chapters 5 and 6.)

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