THE LOWER LIMIT OF THE INFANT MORTALITY RATE IN THE UNITED STATES

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IT HAS often been asserted that the infant mortality rate is a sensitive index of social conditions.[1] If this is true, one would certainly infer that conditions improved tremendously in the United States during the period 1915–1956 (Figure 1).[2] The total rate dropped from 99.9 in 1915 to 26.0 in 1956. In 1956 a rate of 23.2 was reported for the white population and one of 42.1 for the nonwhite population. Among the states, Iowa had the lowest rate with 20.6, but the rural areas of the metropolitan counties of South Dakota reported a rate of 14.6. Assuming that these reported rates are essentially accurate, one may begin to speculate upon the limit to which the infant mortality rate might eventually decline.

A general consensus that the infant mortality rate can be reduced further may be inferred from literally hundreds of statements to this effect throughout the literature. Seldom, however, does one chance upon a numerical estimate of the "irreducible minimum." As an example of the type of assertions to be found, one textbook indicates that infant loss still can be reduced considerably but probably not dramatically.[3] A

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[1] Some writers have indicated that the mean birth weight of a country's babies was also a useful measure of a nation's health. *See* Salber, Eva J.: The Significance of Birth Weight. *Journal of Tropical Pediatrics,* June, 1955, 1, p. 54.

[2] Linder, Forrest E., and Grove, Robert D.: VITAL STATISTICS RATES IN THE UNITED STATES: 1900–1940. Washington: Government Printing Office, 1947, pp. 572–573; annual volumes, VITAL STATISTICS OF THE UNITED STATES, Part II, 1941 thru 1944. Washington: Government Printing Office, 1943–1946; and "Infant Mortality," *Vital Statistics—Special Reports, National Summaries,* September 29, 1958, 48, No. 12, pp. 339–340, and 353. Throughout this paper, the limitations arising from incompleteness of registration of both births and deaths have been ignored.

[3] Eastman, Nicholson J.: WILLIAMS OBSTETRICS (eleventh edition). New York:

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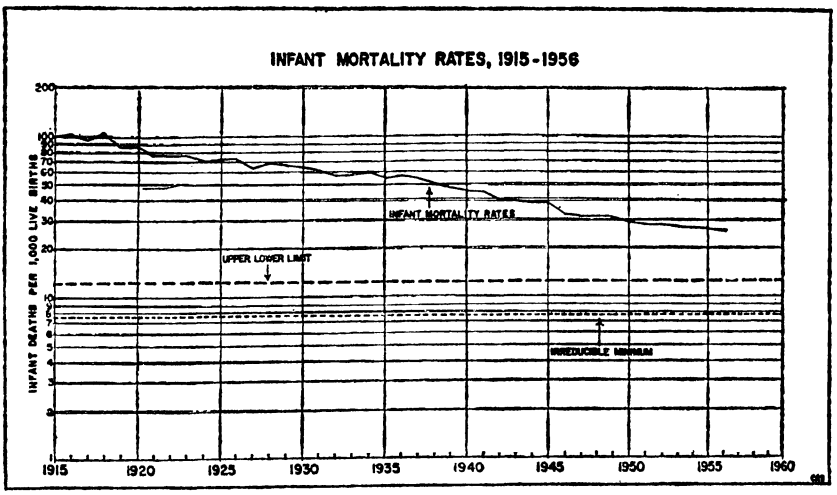

Fig. 1. Infant mortality rates, birth registration states of the United States, 1915–1956 and predicted lower limits.

recent paper states that the present neonatal mortality rate can be reduced considerably by efficient application of present medical knowledge.[4] As a final example of this type of general statement, a 1950 bulletin suggested that ". . . it is not utopian to expect that the infant mortality rate in the United States will be reduced much further before too long."[5]

The hesitancy of writers to attempt to predict numerically the lower limit of infant mortality is understandable.[6] Never-

Appleton-Century-Crofts, Inc., 1956, p. 17. One reason for limitations on infant salvage is the lack of knowledge as to the underlying mechanism which initiates labor prematurely; a second reason is the obscure causes which are responsible for many neonatal deaths; and a third is the lack of medical knowledge concerning the causes of selected complications.

[4] However, to make further progress, according to the authors, basic research must furnish information on prematurity, hyaline membrane disease, intra-uterine infection of the fetus, and fetal erythroblastosis. This same paper reported neonatal mortality rates for 1955 as follows: Norway and Sweden, 13; New Zealand, 14; England and Wales, 17; United States, 19; and Canada, 19. It was stated further that premature infant deaths account for 50 to 75 percent of the neonatal mortality rate. *See* Medovy, Harry and Briggs, J. Nixson: Reduction in Neonatal Mortality—the Present and the Future. In (Alan Ross, editor): SYMPOSIUM ON RECENT CLINICAL ADVANCES, PEDIATRIC CLINICS OF NORTH AMERICA. Philadelphia: W. B. Saunders Co., 1958, pp. 259–277.

[5] Metropolitan Life Insurance Company: How Much Safer Can Maternity and Infancy Be? *Statistical Bulletin,* December, 1950, 31, pp. 8–10.

[6] This paper is in no way a criticism of writers for not furnishing "wild estimates." When the infant mortality rate was "high," the lack of estimates of the

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theless, this paper presents materials which have been formulated in such a manner as to make a quantitative guess at the lower limit of the infant mortality rate, viz., that the infant mortality rate in the United States will not fall below 7.0 in the foreseeable future (and, probably not that low—more likely between 7.6 and 12.3).

Definitions and Notation[7]

Infant Mortality Rate. The infant mortality rate is usually defined as follows:

$$\text{Infant Mortality Rate} = \frac{\text{Number of deaths under 1 year of age reported during a given year}}{\text{Number of live births reported during the same year.}} \times 1{,}000.$$

In order to explain more easily how certain estimates were made, this rate can be stated symbolically as a "specific infant mortality rate":

$$m_i = \frac{d_i^z}{B^z} k,$$

where:

m_i = that part of the infant mortality rate computed from deaths assigned to the *i*th cause of death,

d_i^z = number of deaths at ages between birth and one year (exclusive of stillbirths) among residents in a community during calendar year *z* assigned to the *i*th cause of death,

B^z = total number of live births occurring in the specified community during the same calendar year,

k = a constant usually equal to 1,000 for the total infant mortality rate, but sometimes equal to 100,000 for a specified cause.

lower limit is understandable but it is a little surprising that more estimates have not appeared recently. This is especially true since many demographers seem to feel a compulsion to make rash predictions and of course the estimates suggested in this paper "fit the category."

[7] Notation is similar to that of Linder and Grove, *op. cit.*, pp. 41–47.

Summing over all *i*, the above becomes the infant mortality rate and can be written as follows:

$$m_1 + m_2 + \ldots + m_n = \frac{d_1^x + d_2^x + \ldots + d_n^x}{B^x} k.$$

Since $\sum_{i=1}^{n} m_i = m$ and $\sum_{i=1}^{n} d_i^x = d^x$, then $m = \frac{d^x}{B^x} k$.

Note that the "specific infant mortality rate" m_1 is the number of infant deaths assigned to cause number 1 divided by the number of live births during the calendar year and may be written as follows:

$$m_1 = \frac{d_1^x}{B^x} k.$$

Assumptions

Assumption 1. No marked changes in definitions, statistical classifications, coding, or medical certification. The estimates made in this paper are based upon the state of knowledge and practices during the middle of the Twentieth Century.

Assumption 2. No marked improvement in preventing premature birth. Since this study is limited to live births, it is assumed that there will be no marked improvement in controlling pregnancies which terminate in premature births of 1,000 grams or less.

This is a most questionable assumption and may not be justified by current lack of knowledge. Nevertheless, even if premature births were preventable to a considerable extent, the effect might be to increase the "specific infant mortality rate" subsumed under other assumptions. For example, the number of deaths assigned to congenital malformations might be increased if it is true that many malformed fetuses are delivered prematurely (although there is no certainty that such premature births would result in live births at term).

Assumption 3. Part 1. For births of 1,000 grams or less, $m_1 = 4.1$. As explained below, it is assumed that at least 4.1 infants

per 1,000 live births will die within the neonatal period.[8] In early 1950 out of 837,786 live births, 3,928 weighed 1,000 grams or less which amounts to about 4.7 per 1,000 live births of all weights.[9] Of these nearly four thousand births, 3,424 or approximately 87 per cent died at an age of less than 28 days. Thus, 4.7 × .87 = 4.1 per 1,000 live births.

Part 2. For births over 1,000 grams, $m_2 = 0.0$ with exceptions as specified under other assumptions. It is assumed that medical care might advance to the place that, if an infant weighs more than 1,000 grams and is not severely malformed, it can and will be kept alive.[10]

Assumption 4. Deaths assigned to congenital malformations, $m_3 = 2.7$. It is assumed that the rate from congenital malformations, as specified, will not decline further. It is further assumed that all infant deaths assigned to the cause known as congenital malformations will occur among infants of less than 60 days of age (suggested for operational use in this paper only).

In 1956 there were 11,451 infant deaths under two months of age assigned to congenital malformations.[11] Since there were 4,218,000 live births, the infant deaths assigned to congenital malformations amount to 2.7 per 1,000 live births.[12]

[8] The neonatal period as used in this paper is the period from birth up to, but not including, the 28th day of life.

The term "pre-viable" has been used to apply to liveborn premature infants with a birth weight of less than 2¾ pounds (about 1,250 grams). Over a six-year period at Simpson Maternity Hospital, 7.9 per 1,000 live births were pre-viable with a death rate of 966 per 1,000. The writer stated that "better figures are attainable, but the mortality of infants weighing less than 2¾ pounds at birth will always be very high." *See* Henderson, J. L.: The Definition of Prematurity. *Journal of Obstetrics and Gynaecology,* February, 1945, 52, No. 1, p. 35.

[9] Shapiro, Sam and Unger, Jeanne: Relation of Weight at Birth to Cause of Death and Age at Death in the Neonatal Period: United States, Early 1950. *Vital Statistics—Special Reports, Selected Studies,* February 23, 1956, 39, No. 6, pp. 249 and 259.

[10] No doubt a rate of m_2 equal to zero will never be attained but the topic of premature infants has been extensively discussed, both philosophically and objectively, in the literature. One example with supporting data is that of Crosse, Mary: Is the Premature Baby Worth Saving? *American Journal of Public Health,* August, 1954, 44, pp. 1010–1014.

[11] "Infant Mortality," *op. cit.,* p. 355.

[12] Natality: United States and Each State, and Alaska, Hawaii, Puerto Rico,

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Limitation. Note that some of the above deaths were from births which weighed 1,000 grams or less and thus might be included under Assumption 3. However, in early 1950 only 30 out of 3,424 deaths whose birth weights were 1,000 grams or less were assigned to congenital malformations.[13] Since this is less than one per cent, the overlap is judged to have relatively little influence.

Assumption 5. Accidents and homicide, $m_4 = .83$ *and* $m_5 = .03$. It is assumed that the proportion of the total infant mortality rate assigned to accidents and homicide will be no less than it was in 1956. The rates under this assumption have relatively little influence upon the computation of the lower limits but were utilized because the data were easily available.

Part 1. Accidents, $m_4 = .83$. In 1956 there were 3,498 deaths under one year of age assigned to accidents.[14] This is .83 per 1,000 live births.

Part 2. Homicide, $m_5 = .03$. Also in 1956 there were 125 infant deaths assigned to homicide. This is a rate of .03 per 1,000 live births.

Limitation. Possibly some of the deaths considered under Assumption 5 were of infants of 1,000 grams or less at birth. However, since in early 1950 only 29 out of 3,424 deaths of 1,000 grams or less were assigned to "all other causes," including accidents and homicide (that is, the 3,395 other deaths were as-

and the Virgin Islands (U. S.), 1956. *Vital Statistics—Special Reports, National Summaries,* October 15, 1958, 48, No. 14, p. 396.

There is some evidence that this rate is too high. As a matter of interest only, 5,067 births were reported by the L.S.U. Perinatal Committee during a 12-months period of 1957–1958. Nine deaths (which occurred during the period of observation in the hospital) were assigned to congenital malformations yielding a "rate" of 1.8 per 1,000 live births. The records of seven of these deaths were reviewed (limitations recognized) independently by two members of the Pathology Department and the following question answered: "Is there a severe congenital abnormality incompatible with life?" One of the pathologists reported "yes" on five of the seven cases; the other reported "yes" on four of the same group.

On the other hand, it was noted in Australia that in the present state of medical knowledge, no truly effective measures can be used against the class of deaths known as congenital malformations. Thus the 4 deaths per 1,000 in Australia from this cause form a lower limit to the infant death rate. *See* Lancaster, H. O.: Mortality from Congenital Malformations in Australia. *Medical Journal of Australia,* September 8, 1951, 11—38th Year, No. 10, pp. 318–320.

[13] Shapiro and Unger, *op. cit.,* p. 258.

[14] "Infant Mortality," *op. cit.,* p. 356.

signed to the broad classes of "congenital malformations" and "certain diseases of early infancy"), it is clear that there is little duplication.[15]

Estimated "Irreducible Minimum" Level of the Infant Mortality Rate

It should be obvious from the discussion up to this point that this estimate is predicated on the idea that as the infant mortality rate has fallen, the relative importance of specified "causes of death" has increased. Therefore, on the basis of the foregoing assumptions, it is estimated that on the average for each 1,000 live births, at least the following "cause specific infant mortality rates" will prevail:[16]

1. Due to such small size, they lack sufficient strength to survive	$m_1 = 4.1$,
2. Due to size of more than 1,000 grams (with exceptions)	$m_2 = 0.0$,
3. Due to congenital malformations, life beyond one year (i.e., 60 days) is "impossible"	$m_3 = 2.7$,
4. Due to accidents	$m_4 = .83$,
5. Due to homicide	$m_5 = .03$,
Combined rate: $m_1 + m_2 + m_3 + m_4 + m_5 = m$	$m = 7.6$.

A More Realistic Lower Limit

The "irreducible minimum" infant mortality rate estimated above was based primarily on national vital statistics data. Although not ignoring these data, it is of interest to estimate the lower limit by combining them with assumptions derived from physicians' estimates as to the salvage of infants. Some of the assumptions used above will be used again although rates m_3, m_4, and m_5 are not used explicitly.

Assumptions 1, 2, and 3 will again be utilized. Assumption 3 applies to infants of 1,000 grams or less and the rate, $m_1 = 4.1$.

[15] Shapiro and Unger, *op. cit.*, p. 258.

[16] Obviously, m_1 and m_2 are not true "cause-specific rates" but are classes; m_2 really amounts to an assumption of no deaths for all other causes.

It should be recalled that this rate, m_1, assumes that deaths in this weight group will occur during, and only during the neonatal period.

Assumption 6. Fifty-two per cent of neonatal deaths in the 1,000 to 2,500 gram group and 45 per cent in the 2,500 gram group and above are preventable.[17]

Part 1.—Deaths among infants 1,000 to 2,500 grams, $m_6 = 4.2$. In early 1950, out of 837,786 live births, there were 7,282 neonatal deaths in the group 1,001 (sic) to 2,500 grams.[18] If 52 per cent could be prevented, it would be expected that 48 per cent or 3,495 deaths would occur. This is a rate of 4.2 per 1,000 live births.

Part 2.—Deaths among infants of 2,501 grams or more, $m_7 = 4.0$. Among the same births, there were 6,035 neonatal deaths in the group 2,501 grams or greater. Fifty-five per cent of these deaths would be expected to occur under this assumption producing 3,319 deaths and a rate of 4.0.

Assumption 7 (Partially Redundant). No deaths after the neonatal period. It is assumed that there will be no deaths to infants if they live to the age of 28 days or more.

Lower Limit. If it is assumed that no deaths occur beyond the neonatal period for births of 1,000 grams or less, and if this rate $m_1 = 4.1$ is combined with $m_6 = 4.2$ and $m_7 = 4.0$, the lower limit of the infant mortality rate might be expected to be about 12.3.

Discussion

It is possible to compute as many lower limits as there are combinations of assumptions. In any case, the validity of the estimates is restricted by the validity of the assumptions upon which they are based.

[17] Estimates in this general range were reported as good guesses by Schuyler G. Kohl in Perinatal Mortality in New York City. Cambridge, Massachusetts: Harvard University Press for the Commonwealth Fund, 1955, pp. 18–19. Such responsibility factors for infant deaths as the following were used: inadequate prenatal care, errors in medical judgment, errors in medical technique, unqualified medical attendant, family at fault, intercurrent infection, unavoidable disaster, and unsatisfactory pediatric care.

[18] Shapiro and Unger, *op. cit.*, p. 250.

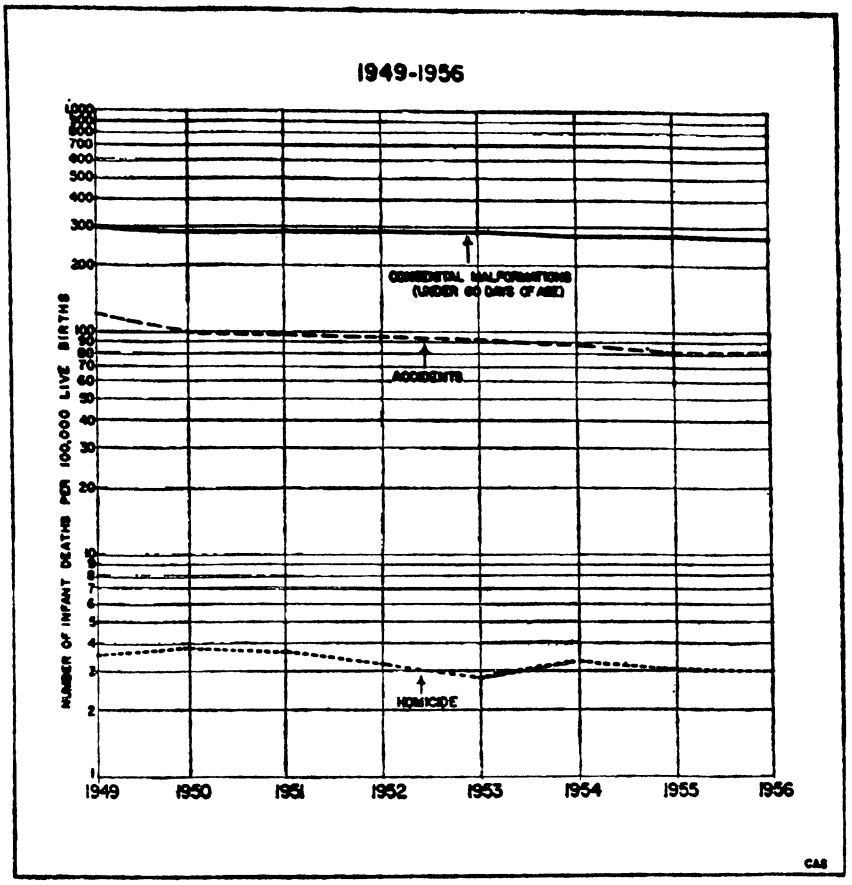

Fig. 2. Number of infant deaths, per 100,000 live births assigned to accidents, congenital malformations (under 60 days of age), and homicide, United States, 1949–1956.

As formulated within this paper Assumptions 3 and 4 are crucial. No doubt some deaths will always occur after the neonatal period. Apparently the death rate assigned to congenital malformations is still declining (see Figure 2) and this is not in agreement with Assumption 4. Because the extent of future decline is unknown, it was decided to use the 1956 rate rather than attempt to extrapolate. Furthermore, the prevalence of congenital malformations may be reduced in the future; for example, a vaccine for German measles might be developed or at least a universal custom of exposing all young females to

the disease before entering child-bearing ages might evolve. On the other hand, increasing exposure to radiation seems likely and may tend to increase congenital malformations. Such possibilities should suffice to remind the reader that there seems to be no end to such speculation. An obvious criticism of the assumption concerning malformations is that some deaths will occur at ages of 60 days or more. The assumptions concerning accidents and homicide are not in complete agreement with the data because these rates seem still to be declining (Figure 2). It might have been better to assume a continued reduction of these latter rates as economic conditions and education improve. However, these last two rates have little effect on the over-all rate.

Conclusion

Several different methods were considered for estimating the lower limit of the infant mortality rate. For the most part, they led to results which were in general agreement. The particular estimates reported in this paper are based upon assumptions that do not appear to be too unreasonable and have the advantage of having been computed from published data. Since these estimates are crude, no correction has been made for deaths of infants born the preceding year or for deaths of infants born during the year of estimate which occur during the succeeding calendar year.