Correlation-Based Estimation of Early Infant Mortality

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IT IS NOT UNCOMMON in developing countries, and particularly in those with a high proportion of births occurring in the absence of a physician, to observe an apparent underregistration of the deaths of very young infants. This underregistration occurs despite existing laws and the fact that deaths of older infants, as well as deaths at any age, are completely registered.

This paper describes a technique through which the extent of such underregistration can be estimated. It also analyzes the findings during successive steps of the application of the technique. The method is based on the assumption that a certain relationship should exist between the levels of infant mortality at earlier and later ages.

Theoretically, during the course of development in a country or an area, the rate for late infant mortality (whatever is defined as "late," usually after the 28th day of life) declines far faster than the rate for early infant mortality. Because of this lag, the time relationship between these two fractions of mortality in infancy tends to be a nonlinear one with a curve toward the axis of the early rates.

One can plot such a line by following a country for an adequate period or by considering various countries at a given year or period of years. One example of the first approach is Canada where during 1956–65 mortality rates for ages 6 days to 1 month declined 47 percent, compared with a decline of only 4 percent for infants less than 1 day old and 29 percent for those 1 to 6 days old (*1*).

However, a second type of approach, a cross-sectional one, has been employed in this paper. Thus, 16 countries were selected from the U.N. Demographic Yearbooks (*1*) on the basis of the accepted authenticity of their vital registrations. The countries were carefully scrutinized to exclude those presenting estimated instead of registered data, or data by year of registration, or countries that exclude liveborn infants dying before registration (such as France). These 16 countries are only a suggested list; the list can always be modified. Nevertheless, after careful scrutiny, one can consider very few countries as candidates for the list.

Mortality rates for five age groups in infancy (less than 1 day, 1 to 6 days, 7 to 27 days, 28 days to 6 months, and 6 to 12 months) were computed as averages of the annual rates for three periods, 1956–59, 1960–62, and 1963–65 (table 1).

The chart shows the dispersion for the 16 countries of average rates of infant mortality for infants less than 1 day old and those 6 to 12 months old during 1963–65. It is apparent that the points describe a slight nonlinear course. Italy, the one point outside the mainstream, shows a rather high late infant mortality associated with an unexpect-

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edly low early one. This disparity probably indicates that Italy does not completely register these deaths, or that the World Health Organization's definition of a live birth is not always applied exactly in that country.

Italy's case is not unique. In most countries with a high late mortality the rates for the first 24 hours of life are very low (Albania, Bulgaria, and Rumania are examples of such countries); in fact someone reviewing their data gets the impression that the two mortalities are negatively correlated, as if the decline of the late one was associated with an increase in the early one. This impression, however, is undoubtedly illogical (considering that these are rates, not proportions).

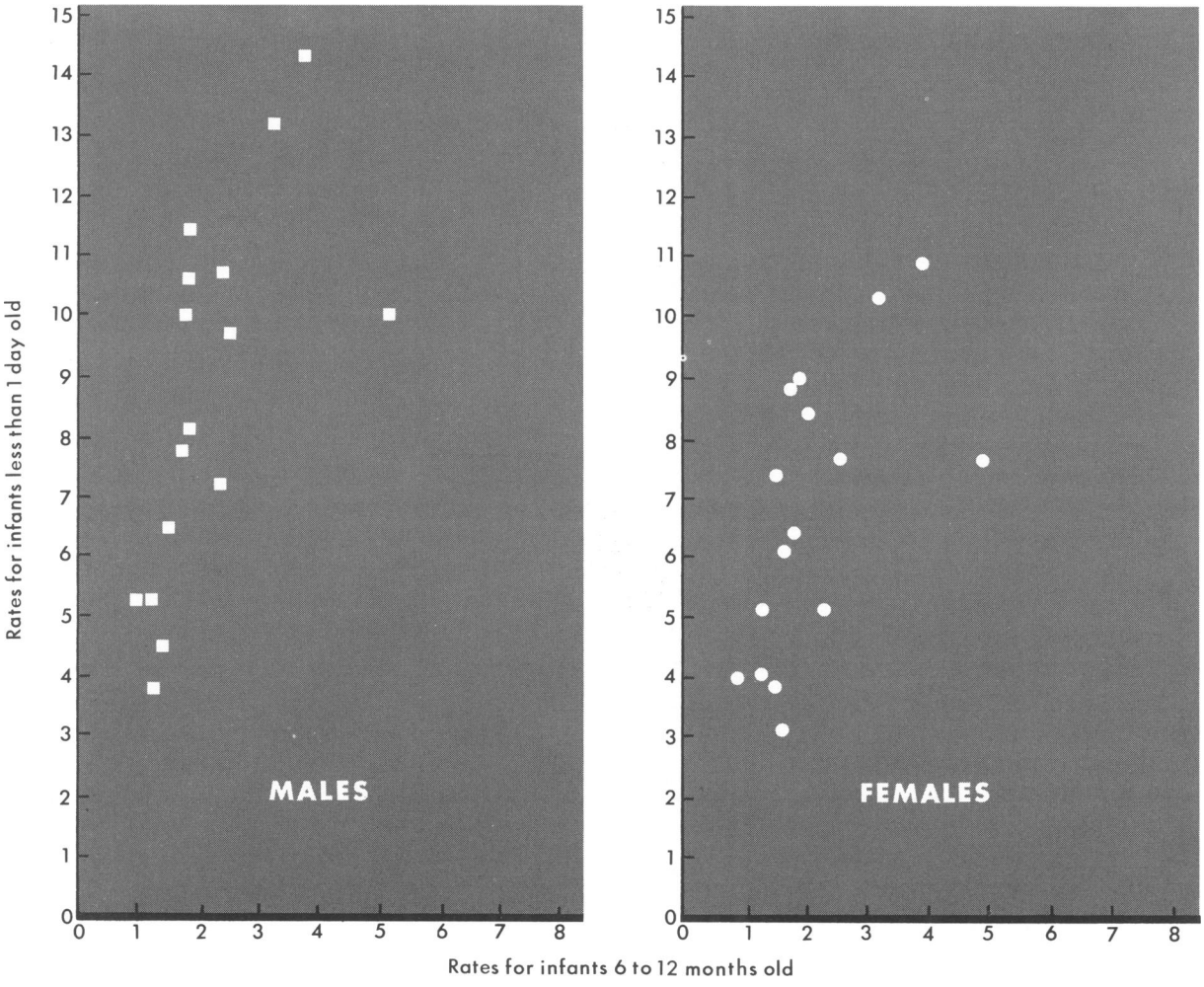
Interesting also are the cases of two other countries, France and Japan (table 1); they were excluded from the computations in this paper. The rates for both countries for the two mortalities, although lower than Italy's, have the same sort of disparity, and if plotted on the scatter diagram give the impression that the theoretical trend line curves again at its other end. If these two rates are accurate, one is tempted to think that highly advanced means of protection (reflected in the extraordinarily low first-day mortality in these countries) can lead to the later death of an infant otherwise poorly equipped for survival; however, it is more logical to accept that the causes of the disproportions are similar to the causes of Italy's.

In this paper a correlation is applied between the average rates of mortality for the age group 6

Table 1. Mortality rates per 1,000 live births for five age groups of infants in 16 countries

Country and sex	Mean rate 1956–59					Mean rate 1960–62					Mean rate 1963–65				
	Less than 1 day	1 to 6 days	7 to 27 days	28 days to 6 months	6 to 12 months	Less than 1 day	1 to 6 days	7 to 27 days	28 days to 6 months	6 to 12 months	Less than 1 day	1 to 6 days	7 to 27 days	28 days to 6 months	6 to 12 months
Male															
United States	11.4	7.8	2.5	5.9	2.1	11.6	7.2	2.1	5.8	1.9	11.4	6.9	1.9	5.7	1.9
Austria	14.2	9.5	4.9	13.3	4.8	13.4	8.0	3.6	9.8	3.7	13.2	7.2	2.6	6.6	3.2
Belgium	11.1	8.1	4.4	11.4	3.6	10.4	9.2	3.4	8.1	2.8	9.7	7.1	2.6	7.5	2.5
Canada	10.7	7.8	3.4	8.8	3.0	11.2	6.8	2.5	7.6	2.5	10.6	6.1	2.0	6.4	1.9
Czechoslovakia	5.2	7.5	4.2	12.9	3.9	5.1	7.1	3.1	8.0	2.7	7.2	6.5	2.9	6.9	2.3
Finland	6.4	8.6	2.7	6.6	4.0	6.9	8.4	2.0	3.8	2.0	6.5	7.7	1.6	2.7	1.5
West Germany	15.5	8.0	3.8	9.6	3.5	12.5	9.8	2.9	7.0	2.9	10.7	8.7	2.1	5.0	2.4
Hungary	14.3	11.3	8.6	22.3	7.9	14.2	10.7	5.7	15.5	5.3	14.3	10.8	5.2	11.4	3.8
Italy	10.6	10.2	7.1	15.8	8.3	10.4	9.6	6.0	13.6	6.5	10.0	9.8	5.5	11.2	5.1
Netherlands	5.3	6.6	2.1	3.8	2.1	5.0	6.6	1.7	2.9	1.7	5.3	6.5	1.6	2.2	1.3
Norway	6.7	5.5	2.2	5.6	2.6	5.1	6.8	2.0	4.6	2.1	3.9	7.4	1.9	3.8	1.3
Sweden	5.6	7.5	1.8	2.7	1.6	6.3	7.0	1.5	2.3	.9	5.3	6.4	1.3	2.1	1.0
Switzerland	11.1	5.9	2.2	4.7	2.4	11.2	5.5	1.7	3.5	2.1	10.0	5.5	1.5	3.4	1.8
England and Wales	8.4	7.5	2.6	5.2	1.9	8.5	6.6	2.3	5.1	1.7	7.8	5.8	2.0	5.2	1.7
Denmark	6.5	10.2	2.6	5.4	2.2	5.7	10.3	2.1	4.1	1.7	4.5	10.5	1.8	3.4	1.4
Australia	8.5	6.2	2.1	4.3	2.2	8.3	6.0	2.0	4.0	2.1	8.1	5.7	1.6	4.0	1.8
Female															
United States	8.8	5.7	2.0	4.8	1.9	9.0	5.1	1.7	4.6	1.7	8.9	4.9	1.7	4.5	1.7
Austria	11.4	7.1	4.0	10.2	4.3	10.9	6.6	3.0	6.9	3.3	10.3	5.5	2.0	5.1	3.1
Belgium	8.3	5.7	3.8	8.6	3.3	8.1	6.2	3.1	6.3	2.3	7.7	4.9	2.2	5.7	2.6
Canada	8.4	5.7	2.9	7.2	2.6	8.7	4.8	1.9	6.1	2.3	9.0	4.2	1.6	5.1	1.8
Czechoslovakia	3.5	5.2	3.4	10.8	3.6	3.4	5.0	2.5	6.6	2.4	5.1	4.7	2.3	5.6	2.2
Finland	5.3	6.8	2.1	5.1	3.2	5.3	6.0	1.5	3.5	1.9	5.1	5.3	1.1	2.5	1.2
West Germany	12.5	6.0	3.1	7.4	3.0	9.8	7.5	2.5	5.3	2.5	8.4	6.7	1.8	3.8	2.0
Hungary	11.3	8.2	7.1	18.1	6.8	10.7	8.1	4.6	13.2	4.6	10.9	8.3	4.3	9.5	3.9
Italy	8.1	7.7	6.3	14.1	7.8	8.0	7.1	5.1	10.7	6.2	7.7	7.2	4.8	9.7	5.0
Netherlands	4.3	4.5	1.6	3.2	1.7	3.9	4.3	1.4	2.6	1.5	4.1	4.5	1.2	1.9	1.2
Norway	4.8	4.0	1.8	4.5	2.3	3.7	4.6	1.6	3.6	2.0	3.1	5.5	1.8	2.8	1.6
Sweden	4.3	5.3	1.4	2.3	1.3	4.8	4.9	1.3	1.8	.8	4.0	4.9	1.0	1.6	.9
Switzerland	8.9	4.3	1.7	3.3	1.9	8.5	3.8	1.2	2.9	1.8	7.4	4.1	1.2	2.7	1.5
England and Wales	6.6	5.2	2.2	4.3	1.6	6.5	4.6	1.9	4.1	1.6	6.1	4.0	1.6	4.1	1.6
Denmark	4.7	6.9	2.1	3.9	1.8	4.3	7.4	1.9	3.1	1.6	3.9	6.4	1.5	2.7	1.4
Australia	7.2	4.5	5.7	3.5	2.0	6.5	4.5	1.5	3.3	1.7	6.4	4.3	1.3	3.0	1.7
Not included in the computations:															
France, male	3.2	9.4	4.3	9.6	5.4	2.6	8.9	3.3	6.9	3.4	2.4	8.5	3.1	6.1	2.8
Japan, male	3.4	10.2	9.0	12.3	5.3	3.0	8.8	6.3	9.3	4.0	2.7	7.1	4.3	5.9	2.8
France, female	2.4	7.0	3.4	7.4	4.5	2.1	6.3	2.6	5.2	3.0	1.8	6.1	2.5	4.7	2.5
Japan, female	2.8	8.0	7.8	10.8	4.6	2.3	6.6	5.0	7.9	3.3	2.0	5.3	3.7	4.9	2.4

Association between mortality rates per 1,000 live births for infants less than 1 day old and 6 to 12 months old for 16 countries, 1963–65



to 12 months (considered as the independent variable) and the corresponding rates of mortality for each of the four younger age at death groups; the observations refer to data for the 16 selected countries. The use of the age group 6 to 12 months instead of the typical postneonatal one, 28 days to 1 year, is an effort to secure as far as possible complete death registrations for the country whose early infant mortality is under investigation by the technique. Even in the presence of early underregistration a late infant death has an increased probability of being registered.

The correlation coefficient r and the slope of the regression line b (slope b will be applied later in the estimation process) as well as their statistical criteria are shown in table 2. Notice first that the correlation—regardless of sex, age group, or period—is always positive and statistically significant (assuming independent normal distributions of the two variables, that is $\rho = 0$, the 5 percent one-sided significance level of r for $N = 16$ is 0.426; reference *2*). As a reflection of increasing similarity in causes of death, the coefficient r rises gradually to almost unity as the two correlated age groups become more adjacent. In almost all instances its range between the 95 percent confidence limits is on the positive side.

The coefficient r remains unchanged during the three periods and at high levels for the later age groups, while it increases in the case of the first one. There the increasing value of r probably is generated by a gradual decline in the preventable causes of death in the late age group so that the causes of mortality in the youngest and oldest age groups become more alike. Considering this greater similarity, it is advisable that the period

1963–65 be used in the application of this technique.

As for slope b, it attains its greatest value in the fourth age group, 28 days to 6 months. The ratio $SD(b)$ to (b) is highest in the first age group because of the great variability of mortality under 1 day in the countries selected. However with the passing of time, the ratio declines rapidly from about 50 percent to about 30 percent, thus reflecting gradual stabilization of the respective rates. In all instances the range between the 95 percent confidence limits is on the positive side.

With only two exceptions, the slope is always higher for males than females. Though considerable overlapping in the respective confidence limits makes the differences statistically insignificant, still the uniformity of the differences possibly suggests two factors: greater reduction of male infant mortality in younger age groups (since among them the sex differentials are most prominent) for a unit's reduction of their late mortality and/or generally higher infant age group death rates for males (table 1).

Finally the slope increases over time, but the individual differences appear of no significance, viewed statistically or otherwise.

By the application of slope b, derived as described, one can estimate the early infant mortality rate in a country with suspected underregistration. In this paper I have used Greece as an example, since evidence exists (*3*) that early infant deaths are underreported there while later deaths (as well as deaths at any age) are fully registered. Assuming that:

X = average mortality rate for each period for the age group 6 to 12 months, by sex, for the country in question; $\overline{X}$ = rate for the same age group and sex for the average of the 16 countries; $\overline{Y}$ = rate for any of the four younger age

Table 2. Correlation between rates of mortality per 1,000 live births for infants 6 through 12 months and rates for four younger age groups, by sex (averages for three periods) for 16 countries

Period, sex, and age group	Coefficient r	95 percent confidence limits of ρ estimated graphically [1]		Slope b	Standard deviation of b	90 percent confidence limits of B by computation [2]	
		Lower	Upper			Lower	Upper
1956–59							
Male:							
Less than 1 day	0.462	−0.04	0.78	0.783	0.401	0.08	1.49
1 to 6 days	.719	.35	.85	.586	.151	.03	.85
7 to 27 days	.952	.85	.98	.916	.078	.78	1.05
28 days to 6 months	.913	.73	.97	2.419	.288	1.91	2.93
Female:							
Less than 1 day	.424	−.05	.76	.640	.365	.00	1.28
1 to 6 days	.757	.42	.92	.507	.117	.30	.71
7 to 27 days	.816	.52	.93	.779	.147	.52	1.04
28 days to 6 months	.931	.78	.97	2.226	.232	1.82	2.63
1960–62							
Male:							
Less than 1 day	.551	.06	.82	1.213	.490	.35	2.07
1 to 6 days	.572	.01	.83	.646	.247	.21	1.08
7 to 27 days	.972	.93	.98	.913	.059	.81	1.02
28 days to 6 months	.934	.78	.97	2.462	.250	2.21	2.71
Female:							
Less than 1 day	.484	−.02	.78	.927	.447	.14	1.72
1 to 6 days	.617	.07	.85	.619	.211	.41	.83
7 to 27 days	.942	.78	.97	.818	.077	.68	.95
28 days to 6 months	.901	.72	.96	2.068	.266	1.60	2.54
1963–65							
Male:							
Less than 1 day	.667	.35	.90	1.933	.576	.92	2.95
1 to 6 days	.535	.25	.82	.846	.357	.22	1.48
7 to 27 days	.930	.78	.97	1.080	.114	.88	1.28
28 days to 6 months	.911	.77	.96	2.418	.291	1.91	2.93
Female:							
Less than 1 day	.600	.15	.85	1.325	.472	.49	2.16
1 to 6 days	.665	.23	.87	.753	.225	.36	1.15
7 to 27 days	.952	.85	.98	.947	.081	.81	1.09
28 days to 6 months	.940	.79	.98	2.080	.199	1.73	2.43

[1] Reference 2a. [2] Reference 2b.

groups, by sex, for the average of the 16 countries; then Y, the estimated corresponding early infant mortality rate for the country in question, is obtained by the equation

$$Y = \overline{Y} + b\ (X - \overline{X}).$$

The numerical values of this equation, using Greece as an example, are given in table 3.

Following are observations on the significant data in tables 3 and 4.

1. As expected, the 6- to 12-month mortality for male infants, averaged for 16 countries, is higher than the corresponding rate for female infants. Yet in Greece, the opposite is observed; the etiology of this peculiarity is not immediately clear, and it is investigated in another study (*3*).

2. All mean registered rates $\overline{Yi}$, Xi *and* $\overline{Xi}$ are declining, but this decline over time is undoubtedly expected.

3. The estimated values for Greece for 1956–59 for less than 1 day mortality for either sex are about four and a half times greater than the registered ones (table 4). During the subsequent periods the ratio declined but still remains two times greater. The difference between estimated and observed mortality reflects, of course, extensive underregistration, and its diminution suggests increasing effectiveness of the country's registration service. Furthermore, the fact that in all periods and for both sexes the registered rates are even lower than the lower 95 percent confidence limit of the respective expected ones verifies that the departure is significant and not attributable to chance.

To accept the difference as a real biological one, not registration-made, would be illogical. There is no reason why 1-day-old Greeks should be inherently fitter to survive than the infants in any of the 16 countries, and definitely no claim can be made that in Greece, the prenatal or peri-

Table 3. Values for the equation $Y=\overline{Y}+b(X-\overline{X})$, by sex for four age groups of infants (mean mortality rates per 1,000 live births for three periods)

Period, sex, and age group	Yi	$\overline{Yi}$	b	Xi	$\overline{Xi}$
1956–59					
Male:					
Less than 1 day	11.75	9.47	0.783	6.42	3.51
1 to 6 days	9.72	8.01	.586		
7 to 27 days	6.24	3.58	.916		
28 days to 6 months	15.69	8.64	2.419		
Female:					
Less than 1 day	9.96	7.40	.640	7.07	3.07
1 to 6 days	7.83	5.80	.507		
7 to 27 days	6.32	3.20	.779		
28 days to 6 months	15.86	6.96	2.226		
1960–62					
Male:					
Less than 1 day	12.87	9.11	1.212	5.76	2.66
1 to 6 days	10.42	8.42	.646		
7 to 27 days	5.62	2.78	.913		
28 days to 6 months	14.23	6.61	2.462		
Female:					
Less than 1 day	10.25	7.01	.927	5.89	2.39
1 to 6 days	7.82	5.66	.619		
7 to 27 days	5.16	2.29	.818		
28 days to 6 months	12.27	5.29	2.068		
1963–65					
Male:					
Less than 1 day	12.56	8.66	1.933	4.20	2.18
1 to 6 days	9.12	7.41	.846		
7 to 27 days	4.56	2.38	1.080		
28 days to 6 months	10.35	5.47	2.418		
Female:					
Less than 1 day	9.14	6.76	1.325	4.40	2.09
1 to 6 days	7.08	5.34	.753		
7 to 27 days	4.15	1.96	.947		
28 days to 6 months	9.20	4.39	2.080		

NOTE: X=6- to 12-month rates for Greece; $\overline{Xi}$=6- to 12-month average rate for the 16 countries; Yi=rates for the 4 younger age groups in Greece; Yi=average rates for the 4 younger age groups for the 16 countries.

natal conditions, or both, medically or otherwise viewed, are superior to the ones in the other countries, thus assuring higher survival rates.

For the next age group, those 1 to 6 days old, the expected and registered rates are about equal, and the occasional small differences are of no significance (table 4). This similarity occurs because after the first 1 or 2 days of life, an infant's death cannot easily go unreported.

Finally, for the two remaining age groups the situation is reversed; the estimated values are smaller than the registered ones. In both age groups the ratio has declined during the 10-year period of observations, mostly because the expected rates diminished. This decline is in contrast with their stability over time in the two younger age groups. These observations were constant for both sexes.

The decline of the mortality rates of the two older age groups occurred despite the simultaneous increase of the slope b by the combined effect of two events. They are the decline of the average similar rates in the 16 countries ($\overline{Yi}$ of table 3 for these two groups) and the greater reduction proportionally of the late mortality rates in Greece (a great decrease of the difference $X - \overline{X}$). Inversely, the time constancy in the expected rates for the two earlier age groups was due to a similar constancy of the respective $\overline{Yi}$ rates and to a higher increase here of slope b.

In both the 7- to 27-day group and the 28-day to 6-month group the deviation of the registered rates from the expected ones is significant (above or in a few cases very close to the upper confidence limits). This deviation again seems to reflect that with complete registration—as in the advanced ages of infancy—the observed rates become reliable enough to show where the level of mortality in the country in question really lies; this occurs regardless of the faulty impressions conveyed by the rates for the earlier age groups.

Finally on the basis of these findings, one can

Table 4. Estimated and registered mortality rates per 1,000 live births for four age groups of infants in Greece, by sex (averages for three periods)

Sex, age group, and period	Estimated	Registered	Ratio estimated to registered	Standard deviation of estimate	95 percent confidence limits of estimate	
					Lower	Upper
Male						
Less than 1 day:						
1956–59	11.75	2.70	4.35	1.40	9.28	14.22
1960–62	12.87	4.20	3.06	1.22	10.72	15.02
1963–65	12.56	5.13	2.42	1.07	10.67	14.44
1 to 6 days:						
1956–59	9.72	8.80	1.10	.53	8.80	10.65
1960–62	10.42	9.82	1.06	.62	9.33	11.51
1963–65	9.12	10.42	.88	.66	7.95	10.29
7 to 27 days:						
1956–59	6.24	8.20	.76	.27	5.77	6.72
1960–62	5.62	7.39	.76	.15	5.36	5.87
1963–65	4.56	6.33	.72	.21	4.19	4.93
28 days to 6 months:						
1956–59	15.69	15.07	1.04	1.01	13.92	17.46
1960–62	14.23	14.88	.96	.62	13.13	15.33
1963–65	10.35	12.09	.86	.54	9.40	11.30
Female						
Less than 1 day:						
1956–59	9.96	2.12	4.70	1.18	7.88	12.04
1960–62	10.25	3.03	3.38	1.04	8.43	12.08
1963–65	9.14	4.03	2.27	.89	7.57	10.72
1 to 6 days:						
1956–59	7.83	7.88	.99	.38	7.16	8.49
1960–62	7.82	8.26	.95	.50	6.96	8.93
1963–65	7.08	8.02	.88	.43	6.33	7.88
7 to 27 days:						
1956–59	6.32	8.18	.77	.48	5.48	7.16
1960–62	5.16	6.76	.76	.18	4.84	5.47
1963–65	4.15	6.26	.66	.15	3.88	4.42
28 days to 6 months:						
1956–59	15.86	14.90	1.06	.75	14.54	17.19
1960–62	12.27	14.02	.88	.62	11.19	13.36
1963–65	9.20	11.92	.77	.38	8.54	9.87

estimate the number of missing early deaths and subsequently correct the rates of infant mortality in the country under examination. Thus, in Greece, the missing infant deaths so estimated were 3,760 for the period 1956–59, 1,929 for 1960–62, and 416 for 1963–65. The corrected rates and registered rates per 1,000 live births for the three periods were as follows:

Period	*Corrected rate*	*Registered rate*
1956–59	46.6	40.6
1960–62	43.3	40.1
1963–65	35.5	36.5

Unfortunately, the method appears not to be applicable to the estimation of the late fetal death ratio (28 weeks or more gestation). Thus a nonsignificant correlation was observed between mortality rates for infants of 6 months to 1 year and the late fetal death ratio in the case of 14 countries (selected as previously from the U.N. Demographic Yearbooks) on the basis of the reliability of their statistics. Coefficient r for the mean rates and ratios for the period 1956–59 equaled 0.252 and for 1960–64, 0.001. Assuming ρ equals 0, the 5 percent significance level of r is 0.426.

Although theoretically it should have been significant—late fetal mortality is a kind of backward projection of the very early one—apparently even in advanced countries these fetal death ratios are unreliable and inconsistent, thus showing independence from the mortality rates for infants of 6 to 12 months.

Discussion and Conclusions

An association exists between the rates for late and early infant mortality. Using the late rates as an anchor point, because of their reliability, one can estimate the level of early infant mortality, provided the association is established through use of data from countries with dependable registration.

The problem of partial registration of deaths occurring during the first few days of life is not uncommon. It explains why certain countries, having otherwise good vital registrations, show rates of infant mortality disproportionately low in relation to their other level of living indicators. It also explains the strange phenomenon of observing early infant mortality rates increasing over time, or being very low, when the late ones are very high. Considering the value of infant mortality as a health index of a country or an area, every effort to improve the quality and accuracy of this frequently underenumerated rate is a worthwhile undertaking.

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Underregistration of infant deaths during the first few days of life can occur in certain countries, even if later deaths are properly registered. Since the intensity of infant mortality is highest during these first days it is apparent that this underregistration distorts the whole rate to a point that it becomes disproportionate to the country's other health or socioeconomic indices.

This paper describes a technique to demonstrate the existence of this type of underregistration and to estimate the extent of it. It is based on the assumption of a nonlinear relationship between levels of late and early infant mortality. This is shown by the use of U.N. demographic data covering 16 countries selected for the completeness of their vital registrations. Using parameters of this correlation, the rate of mortality for under 1 day of life, 1–6 days, 7–27 days, and 28 days through 5 months is estimated for a country with deficient early infant death registrations. The results are discussed, explanations are suggested, and pertinent inferences are drawn.