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Birthweight and Perinatal Mortality: I. On the Frequency Distribution of Birthweight

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Wilcox A J (National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina 27709, USA) and Russell I T. Birthweight and perinatal mortality: I On the frequency distribution of birthweight. *International Journal of Epidemiology* 1983, **12:** 314–318.
Perinatal mortality is closely related to birthweight. Hence the study of perinatal mortality requires a sound understanding of the influence of birthweight on perinatal mortality. This paper discusses one aspect of this problem—the frequency distribution of birthweight. This distribution is essentially Gaussian but with additional births in the lower tail. It can therefore be divided into two components—a predominant (Gaussian) distribution and a residual distribution. The complete distribution can be summarized by three parameters: the mean and the standard deviation of the predominant distribution, and the proportion of births in the residual distribution.
This paper shows that the predominant distribution is composed largely of term births, while the residual distribution is composed almost entirely of small preterm births. It also shows that the three parameters together help to explain the apparent paradox that male infants suffer a higher perinatal mortality than females despite there being fewer light male births.

An infant's chance of surviving the perinatal period is closely related to its weight at birth. The study of perinatal mortality therefore depends upon the study of birthweight; in particular, it requires a sound understanding of the influence of birthweight on perinatal mortality. Unfortunately, efforts to characterize this influence have only been partly successful.

The commonest method of summarizing birthweight when studying perinatal mortality is to specify the proportion of births weighing less than some predetermined weight, usually 2500 grams (5.5 pounds). However, this approach oversimplifies the relationship between birthweight and mortality, not least because different populations have different frequency distributions of birthweight.[1]

Standardization is another method of taking birthweight into account when analysing perinatal mortality: groups with different birthweight distributions are compared by introducing either a common birthweight distribution (direct standardization) or a common birthweight-specific mortality curve (indirect standardization). The aim of both methods of standardization is to separate the effects of a difference in birthweight from other effects on mortality. However, we have shown elsewhere[2] that the relationship between birthweight and perinatal mortality does not satisfy the conditions essential for standardization.[3,4]

In this and the following paper,[5] we therefore introduce an alternative approach to the analysis of birthweight and perinatal mortality. We identify a set of parameters, some describing the birthweight distribution and others describing weight-specific mortality. When taken together, these parameters provide a means of investigating social and environmental influences on perinatal mortality. In this paper, we discuss the parameters of the birthweight distribution; in the following paper,[5] we discuss the parameters of the weight-specific mortality curve.

REVIEW OF THE LITERATURE

The distribution of birthweight can be described as essentially Gaussian, but slightly peaked and with additional births in the lower tail (eg Figure 1). This distribution has been recognized for many years.[6,7]

More precise descriptions of the birthweight distribution have been developed by Adams *et al*[8] and by Ashford and his colleagues in Exeter.[9–11] In effect, both groups treat the birthweight distribution as a mixture of two distributions, of which the predominant distribution is Gaussian and the residual distribution has the smaller mean. Both estimate the parameters of the predominant distribution by truncating the observed distribution of births at a point above the range in which the residual

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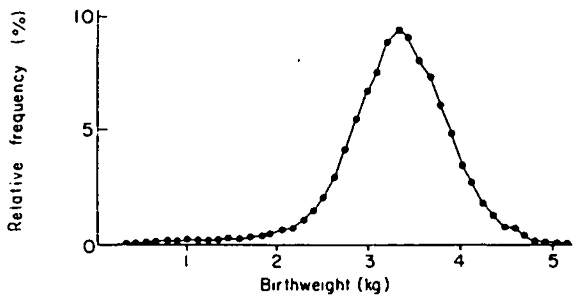

FIGURE 1 *An empirical birthweight distribution. (Newcastle upon Tyne, 1960–1969)*

distribution is assumed to lie. Both select this truncation point empirically: Adams uses 2500 grams (5.5 pounds), the Exeter team 2636 grams (5.8 pounds). The distribution above the truncation point is then used to estimate a complete Gaussian distribution, as illustrated in Figure 2 by data from the Newcastle Maternity Survey.[12,13]

Once the predominant (Gaussian) distribution has been estimated, the residual distribution can be characterized. Adams does so by calculating the probability that a given birthweight comes from the predominant distribution. This produces a table of probabilities, rather than a concise definition of the residual distribution.

The Exeter team are more specific. In all three papers,[9–11] they assert that the residual distribution is a second Gaussian distribution, overlapping the predominant Gaussian distribution. Although the evidence cited in support of this assertion is plausible, it falls short in two respects. First, the extent to which the data fit the proposed model is not submitted to a rigorous statistical test; instead, the authors appeal to a series of plots on Gaussian probability paper. Secondly, although the first paper[9] estimates the parameters of the residual distribution on the assumption that it is Gaussian, the third paper[11] concedes that these estimates are unreliable.

The Exeter workers therefore 'adopt an alternative and less elegant representation of the birthweight distribution.'[11] They use three parameters—the mean and the standard deviation of the predominant (Gaussian) distribution, and the proportion of all births weighing less than 2000 grams (4.4 pounds). Unfortunately, their third parameter provides only a crude summary of the residual distribution; the lower tail of the predominant distribution extends below 2000 grams, while the residual distribution extends above 2000 grams (eg Figure 2). Thus, although both Adams and the Exeter team define the predominant distribution more or less precisely, neither gives an adequate summary of the residual distribution. This paper therefore proposes the adoption of a new third parameter, namely that proportion of all births which is represented by the residual distribution.

DATA AND METHODS

Any large, reliable set of birthweight data would suffice as a means of demonstrating the methods and findings of this paper. To illustrate that these methods do not depend on the particular choice of dataset, we use data from three sources. The first, comprising 42 595 singleton births in the decade 1960–1969 to mothers resident in Newcastle upon Tyne,[12,13] has already been displayed in Figures 1 and 2. The second consists of 13 578 singleton births from the 1970 British Births Survey for which the date of the last menstrual period was regarded as 'certain'.[14] The third comprises the 13 370 singleton births occurring at University College Hospital, London between 1935 and 1946, and analysed

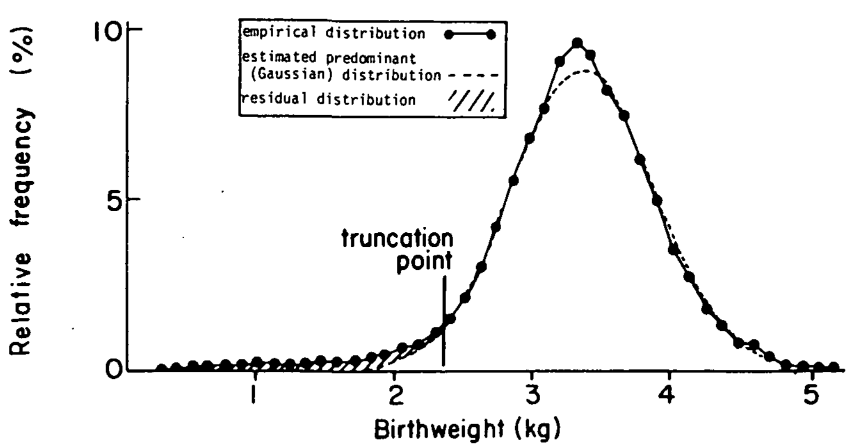

FIGURE 2 *An empirical birthweight distribution with its estimated predominant and residual distributions. (Newcastle upon Tyne, 1960–69)*

by Karn and Penrose in their classic study of birthweight and mortality.[15] The first and third of these datasets were originally collected in pounds and ounces, converted here to grams.

A maximum likelihood procedure for estimating the parameters of a truncated Gaussian distribution was published by Fisher[16] and subsequently tabulated by Hald.[17] It was adapted to grouped data by Grundy.[18] These papers assume that one has access only to the truncated data. In the study of birthweight, however, one has access to the entire distribution. Consequently, one is faced with a choice of truncation point: if one chooses too low, the estimated parameters of the predominant distribution will be contaminated by the residual distribution; if one chooses too high, the estimated parameters of the predominant distribution, although uncontaminated by the residual distribution, will be less precise.

The parameters of the predominant (Gaussian) distribution can best be estimated by using a decreasing series of truncation points starting just below the mean. At first, each successively lower truncation point yields a better fit of the predominant distribution than the previous (higher) truncation point. As soon as the truncation point falls within the residual distribution, however, the quality of the fit deteriorates. Hence the best truncation point of the series is that which lies just above the residual distribution. Consequently, the use of a fixed truncation point would unnecessarily sacrifice some precision of estimation. (This is particularly true of the proposed third parameter, the proportion of all births in the residual distribution, discussed below.)

Figure 2 shows how this estimation procedure subdivides the observed distribution of births from the Newcastle Maternity Survey[12,13] into two components—the estimated predominant distribution and an empirical residual distribution. The residual distribution, shown alone in Figure 3, does not appear Gaussian even in this population—a population three times bigger than that analysed by the Exeter team[9,10] and much less prone to digit preference. Hence their hypothesis that the residual distribution is Gaussian remains unconfirmed.

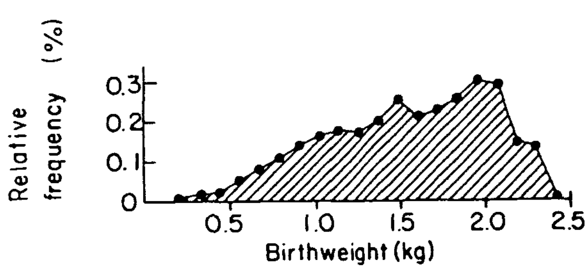

FIGURE 3 *A residual birthweight distribution. (Newcastle upon Tyne, 1960–1969)*

We propose to summarize the residual distribution by the proportion of all births which it contributes. For the Newcastle Maternity Survey[12,13] we have estimated this proportion as 2.7%; in general, it lies between 2% and 5%.[19] Although the residual distribution contributes only a small proportion of all births, it contributes a substantial proportion of all perinatal deaths. This is because it includes the smallest infants, ie the infants at highest risk.

Thus we propose that birthweight distributions should be summarized by three parameters. We now discuss the potential contribution of this formulation to the analysis of perinatal mortality.

FINDINGS

One of us has shown elsewhere[19] how the two parameters of the predominant (Gaussian) distribution provide an adequate description of the major part of the birthweight distribution (ie excluding the lower tail) for a wide range of populations, including racial and social sub-populations. This reinforces and extends the findings of Adams *et al*[8] and Pethybridge *et al.*[11] Since our third parameter is intended to summarize the residual distribution rather than to define it, goodness of fit is not an issue. Instead, the statistical potential of this parameter is suggested by the finding that it varies consistently with such variables as race and social class.[19]

Adams *et al*[8] and Pethybridge *et al*[11] make no specific claims concerning the biological relevance of their parameters. However, the predominant distribution, which they first identified, turns out to be very similar to the actual distribution of births with gestational ages of 37 weeks or more. This finding appears widely true,[19] and will be illustrated using data from the British Births Survey.[14] Figure 4 shows the lower tails of the empirical distribution of all births, of the estimated predominant distribution, and of the empirical distribution of all births at term (ie births occurring 37 weeks or more after the last menstrual period). The distribution of births at term is closely approximated by the predominant distribution. It follows that virtually all births in the residual distribution occur before term. Since preterm births occur at all birthweights, the residual distribution, which is constrained to lie below the truncation point, represents only that proportion of preterm births, roughly one third, that are also small. In short, the residual distribution is essentially equivalent to all births that are both preterm and small.

A birthweight of 2500 grams (5.5 pounds) is commonly used to identify infants of high perinatal risk.[20] Although this use of a fixed critical weight was criticized by Rooth,[1] it has recently been supported on empirical gounds by Goldstein.[21] As a way of summarizing small high-risk births, however, the proportion of births in the residual distribution is more helpful than the proportion

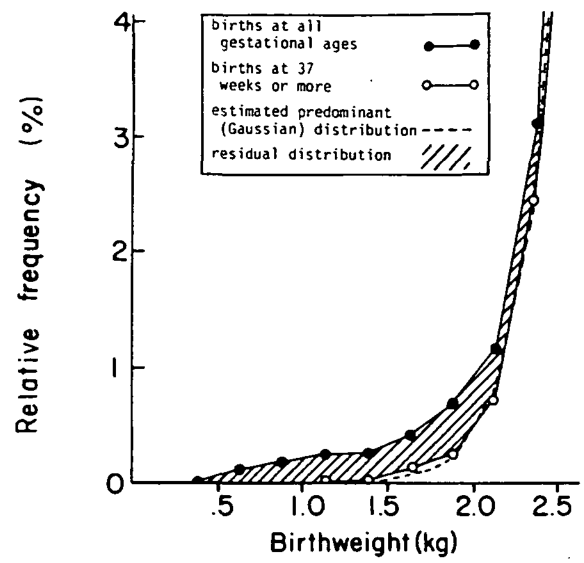

FIGURE 4 *Births weighing less than 2500 grams with estimated predominant distribution and empirical distribution of term births. (United Kingdom, 1970)*

of births weighing less than 2500 grams, This may be illustrated by an analysis of male and female birthweights. Females are more likely than males to weigh less than 2500 grams. For example, Karn and Penrose[15] record 7.2% of females as weighing less than 2500 grams compared with 6.7% of males. Despite this apparent disadvantage, females consistently experience lower perinatal mortality than males. This well known paradox may be resolved by estimating the parameters of the male and female birthweight distributions from the data of Karn and Penrose[15] (Table 1).

The proportion of each predominant distribution that falls below 2500 grams depends only on the mean and standard deviation of that distribution. The estimated mean of the female predominant distribution is lower than the corresponding male mean. As a result, more female births from their predominant distribution fall below 2500 grams than males from their predominant distribution. However, males have more births (2.9%) in their residual distribution than females have (2.4%) in their residual distribution. This male excess of 'residual' infants has previously been obscured by the difference in mean birthweight.

TABLE 1 *Comparison of male and female births (University College Hospital, 1935–1946)*

	Males	Females
% of low birthweight (<2500 gm)	6.7%	7.2%
Fetal and neonatal mortality	48/1000	41/1000
Estimated mean of the predominant (Gaussian) distribution	3366 gm	3257 gm
Estimated standard deviation of the predominant distribution	501 gm	472 gm
Estimated proportion in the residual distribution	2.9%	2.4%
% of births less than 37 weeks gestation	9.8%	8.3%

According to our interpretation of these parameters, the male excess of residual births should be associated with a male excess of preterm births. This is confirmed by the data of Karn and Penrose:[15] 9.8% of the males were born at gestational ages less than 37 weeks, compared with 8.3% of the females. Moreover, this male excess of preterm births is consistently found in other data sets.[22,23] It is ironic that a female excess of what has mistakenly been called 'prematurity' (ie births weighing less than 2500 grams) actually conceals a male excess of true prematurity defined by gestational age.

More specifically, the male excess of residual births indicates an excess of small, preterm births. This male excess cannot be detected by the conventional category of low birthweight. Furthermore, it was not identified by Pethybridge *et al*[11] when using an alternative critical weight of 2000 grams (4.4 pounds). However, our three parameters detect the male excess of high-risk births and thus correctly identify males as the more disadvantaged group.

DISCUSSION

The distribution of birthweight is usually summarized by a single statistic—sometimes the mean, more frequently the proportion of births weighing less than 2500 grams (5.5 pounds).[21] However, the birthweight distribution is more complex than such statistics suggest and contains more information than they can convey. In contrast, a few authors, notably Ashford *et al*,[9] have proposed a family of models that require five parameters to describe the birthweight distribution. While we agree that the birthweight distribution requires more than one parameter for adequate description, we question the practicality of five parameters.

We therefore propose that the birthweight distribution should be summarized by three parameters: the mean and standard deviation of the predominant (Gaussian) distribution (which includes between 95% and 98% of a typical population), and the proportion of the population not included in that predominant distribution. Of these, the first two are relatively insensitive to the quality of the birthweight data but the third is more sensitive to such problems as missing data and digit preference. This paper therefore uses three datasets[13–15] for which there is indirect evidence that few data are missing and direct evidence that digit preference is at a minimum. The resulting estimates of the third parameter vary consistently with such variables as sex and social class. Hence we believe that, at least in reliable datasets, these three parameters can help to explain how differences between populations in the distribution of birthweight lead to differences in perinatal mortality.

Just as the proportion of births weighing less than 2500 grams is too simple a summary of the continuous distribution of birthweight, the proportion of births occurring before 37 weeks of gestation (as used in this paper) is too simple a summary of the continuous distribution of gestational age. To overcome this simplification will require a full analysis of the bivariate distribution of births by weight and gestational age. In the meantime, however, the dichotomy of gestational age into births occurring at term and births occurring before term has provided some insight into the distribution of birthweight.

This insight suggests separate biological interpretations for the two components into which the proposed parameters divide the birthweight distribution. The predominant component, a Gaussian distribution composed largely of term births, hints at the workings of orderly biological processes. The residual component, an apparently more haphazard collection of small preterm births, may imply less organized, perhaps pathological, influences. Although this formulation of the birthweight distribution cannot allocate individual births to one component or the other, clinical features may yet be found to distinguish between these two groups of infants.

Even at this preliminary stage, these parameters help to explain the apparent paradox that male infants suffer a higher perinatal mortality than females, despite having fewer light births. The next step in the development of this formulation is to use these parameters to re-examine established relationships between birthweight and such factors as race, social class, parity, and smoking. Chapman and Fryer[24] have shown how multivariate statistical methods can be used to analyse similar parameters. The application of such methods to the biologically interpretable parameters described here has the potential to advance our understanding of social and environmental influences on birthweight.

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