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FACTORS RELATED TO BIRTH WEIGHT AND PERINATAL MORTALITY

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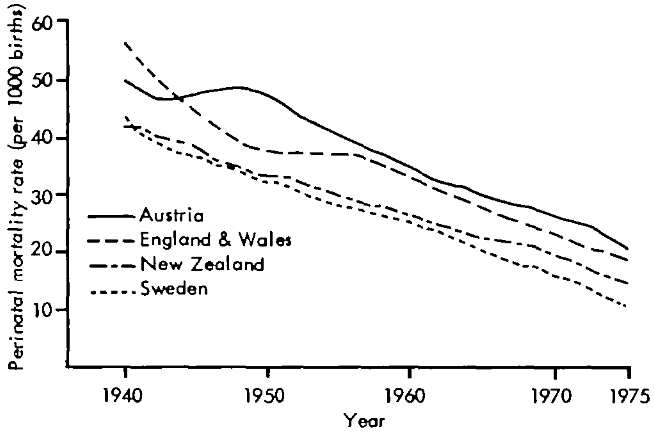
In the few countries with reliable statistical reporting systems extending back to the Second World War, perinatal mortality rates have continuously fallen. Figure 1 illustrates this for four such countries. This trend, which is typical for industrialized and many semi-industrialized countries, coincides with, and presumably largely results from, an increased standard of living and improvements in preventive and curative medicine. By the late 1970s the rates had become very low, with that in Sweden reaching around 10/1000 child births (World Health Organization, 1980).

In order properly to understand the reasons for this trend, two kinds of studies need to be distinguished. Firstly, there are studies which relate observed perinatal mortality rates, or changes in rates, to social, demographic and other factors. Secondly, there are studies which set out "experimentally" to manipulate related factors and to study the effect on perinatal mortality rates. An example of the latter would be a health education experiment which attempted to persuade a randomly selected experimental group of smoking women to give up cigarettes during pregnancy and then compared the pregnancy outcome (say, in terms of perinatal mortality or birth weight) with a randomly selected control group not subject to this persuasion. Unfortunately, such studies are rare and difficult to operate successfully (Donovan, 1977), so that most of our knowledge derives from the first, "observational" type of study. This paper is concerned exclusively with observational studies.

Observational studies, of course, suffer from the drawback that while they can establish associations between various factors and birth weight or mortality, they do not allow us unequivocally to claim a corresponding "causal" connection. Thus, for example, one may find a mean birth-weight difference between first babies born to mothers aged 20 and to those aged 30 of 100g in favour of the latter. However, it does not necessarily follow that, if all the older mothers were to have their babies 10 years earlier without any change in other social or demographic characteristics, the average birth weight of their babies would be the same as that of the first group. There may be other factors, which are not measured, which are responsible both for the mothers having their babies later and for a higher average birth weight. Such factors are often referred to as

FIG. 1. Perinatal mortality rates (per 1000 births) during 1940–75: five-year moving averages



"confounding" or "nuisance" factors, and one of the more important objectives of an observational study is to try to identify and measure these so that their effects can be allowed for when studying the more central relationships. A detailed discussion of this point is given below. To begin with some of the basic associations are outlined.

1 Factors Associated with Birth Weight

There are two distinct approaches to the study of birth weight. The one that has been most widely used chooses a threshold value, usually 2500g[1], and studies the proportion of births below that value. The other approach studies differences in mean birth weight.

While the analysis of mean birth weight tends to make more efficient use of available data, it has two drawbacks. Firstly, it is often difficult to collect reliable birth-weight information, except in special surveys and, secondly, it is perfectly possible for the mean birth weight to remain constant while the variability of the birth-weight distribution changes, thereby producing changes in the proportions of very light and very heavy babies. Since, for many purposes, there is a particular interest in the very light babies, for reasons given in section 3, a direct measurement of their number is often the most appropriate approach.

2 Components of the Birth-Weight Distribution

Before describing birth-weight associations in detail, some recent approaches to the study of birth weight deserve comment. These attempt to distinguish a so-called "normal" component of the distribution from an "abnormal" one (Rooth, 1980; Fryer *et al.* 1981). The argument is that the regular or normal process of reproduction would produce a symmetrical distribution of birth weight in a population. This can be identified with the bulk of the observed distribution. The secondary or "abnormal" distribution is centred in the lower part of the observed

[1] It is now commonly accepted that a "low birth-weight" baby is one with a birth weight of less than 2500g. Earlier studies sometimes used the criterion of a birth weight less than or equal to 2500g, which makes a negligible difference except where birth weight is only measured approximately, e.g. to the nearest 100g.

distribution. The percentage of birth weights belonging to the primary distribution (typically about 80%) is identified, the mean and standard deviation of the distribution are calculated (it is usually assumed to be Normal or Gaussian), and this distribution is regarded as the standard one and is used for population comparisons, percentile estimation, and so on.

While this method of "fitting" or describing the over-all observed distribution has practical uses, for example to provide efficient estimates of extreme percentiles for the observed distribution, the attempt to attribute a substantive reality to the two components seems dubious. In common with other "clustering" methods, the values of the parameters of the resulting separated distributions depend on the chosen assumptions about the shape of the distributions and the number of component distributions. There seem to be no compelling reasons for choosing a symmetrical distribution, or for choosing only two components. There is also a logical difficulty which arises if we consider dividing a population into subpopulations, for example, by region. If the method has any generality it should apply at least as well to such subpopulations as to the total population. If it does so apply, however, then when the subpopulations are combined in whatever proportions are appropriate to form the total population, the latter will consist of a mixture of all the subpopulation distributions and in general that cannot be made to yield just two distributions of the required type. This difficulty is compounded by the fact that a total population can normally be divided into natural subpopulations in very many ways. Thus, while these component procedures may be able to provide useful summary graduations of a birth-weight distribution, their claims to represent substantive reality need to be viewed rather critically.

3 Population Studies

Although there are numerous studies of birth weight and perinatal mortality, there are relatively few which have used adequate random sampling techniques allowing valid statements to be made about well-defined populations. Typically, and especially with the early studies, hospital or clinic patients or other "captive" groups such as servicemen's wives were used, but all these are to some extent self-selected or biased in various ways. Whilst such studies were very important during the early history of birth weight and mortality research, their usefulness has diminished with the advent of large and adequately designed population studies. I shall, therefore, concentrate on the results from a few large-scale population studies. In particular, the results of the 1958 British Perinatal Mortality Survey will be used (Butler & Alberman, 1969) together with the results of the 1973 World Health Organization's (WHO) International Collaborative Perinatal Study (World Health Organization, 1978a). The former study used a whole week's births in Great Britain (about 17000 babies) and studied the joint effects of social, demographic and biological factors. The latter study analysed data on all the births in 1973 for each of eight countries. It is by far the most comprehensive comparative study available and enables reliable conclusions to be formed about differences in associations between these countries.

Table I, from the 1958 British Perinatal Mortality Survey, shows the mean birth weight and proportion of low-birth-weight babies for groupings of age, parity, social class, smoking habit after the 20th week of pregnancy, pre-eclampsia and maternal height. All these factors intervene, and can be measured, before birth and hence are of interest for purposes of prediction and are

TABLE I. 1958 British Perinatal Mortality Survey

Factor	Percentage ≤2500 g	Mean birth weight (g)
Age		
<20	8.0	3205
20–29	6.3	3320
30–34	7.1	3345
>34	7.3	3375
Parity		
0	7.6	3230
1	5.4	3375
2–3	6.8	3375
>3	7.4	3375
Social class		
I–II*	4 9	3380
III	6.6	3320
IV	7.2	3320
V	8.2	3290
Maternal height (cm)		
<156	9.3	3210
156–164	6.1	3320
>164	4.7	3450
Pre-eclampsia		
None or mild	5.4	3345
Moderate	5.8	3345
Severe	18.0	3120
Smoking habit after 20th week of pregnancy		
Non-smoker (<1 a day)	5.4	3375
Smoker	9.3	3205

* General Register Office (1966) *Classification of occupations, 1966.* HMSO, London

relevant also to any causal understandings of birth-weight variations. For this reason gestation length is not included since, like birth weight, it is an outcome of pregnancy. I shall, however, consider gestation in relation to birth weight when I come to discuss perinatal mortality in section 6.

An interesting pattern emerges from Table I when the means and proportions of low birth weights are compared. For age and parity, which are themselves highly correlated, the mean birth weight increases sharply from the youngest age to the next age-group and then more steadily with increasing age, with a similar pattern for parity. Likewise, the proportion of low birth-weight babies decreases from the youngest age-group to the next group but then rises, so that in the last group it is nearly the same as in the first group, with a similar pattern for parity. Thus, for both age and parity there is a change in the spread of birth weights as the mean birth weight rises and, as we shall see in section 6, this is reflected in the relationship between these factors and perinatal mortality. For the remaining factors there is a similar pattern for the mean and the proportion of low birth weights.

It should be noted that for age and parity, each category, except the last, includes a mixture of women, some of whom go on to have babies at later ages or parities and others of whom do not. This may account, at least in part, for the changing distribution shape. For example, Billewicz & Thomson (1973) suggest that the percentage of low-birth-weight babies at parity 0 increases as the number of subsequent pregnancies increases, and that the mean birth weight at parity 0 also decreases as the number of subsequent pregnancies increases.

4 Joint Effects of Several Factors

The factors in Table I are associated among themselves, and it is of interest to study the effects of each one, for given categories or combinations of categories of the others. For example, we can study the changes with social class, say, for all babies of parity 0 and mothers aged 20–24 and for other age–parity combinations. This will help to establish how far

TABLE II. 1958 British Perinatal Mortality Survey

Factor	Category "constants" for predicting mean birth weight in a combined analysis of the factors shown
Parity	
0	134
1	259
2–3	280
>3	325
Pre-eclampsia	
None or mild	323
Moderate	309
Severe	117
Coefficient	
Height (cm)	15.7
Smoking habit after 20th week of pregnancy	
Non-smoker	333
Smoker	166

social class differences can be explained by the fact that the higher-status social groups tend to have babies at older ages, with a smaller percentage of high-parity babies. The statistical procedures for studying associations of any one factor with birth weight, within all given combinations of other factors, are known as "adjustment" procedures and can be thought of as making allowance for these factors. Analyses of variance and covariance are commonly used for this purpose. The same approach can be used when comparing whole populations. Since these may differ in terms of their distributions of age, parity, and so on, clearly it is important to adjust for such factors when attempting to interpret differences. At the time of writing, a full-scale analysis of the 1973 international data, with adjustments for a number of factors, is under way but not complete. Some results on perinatal mortality using adjustments for age and parity are available, however, and are discussed below.

Table II shows the results of a joint analysis of the first four factors in Table I. An analysis of covariance (in which maternal height was treated as a continuous rather than grouped variable) eliminated age and social class, as contributing very small differences after adjusting for the other factors, so that results for only four factors are shown. Since it is mean birth weight only which is analysed, we are not justified in concluding that adjusting for age and social class does not affect the over-all distribution of birth weight. Nevertheless, the elimination of age and social class in this analysis does suggest that these may be secondary variables, where effects arise indirectly through their associations with one or more of the other variables, and the obvious variables which might be principally responsible are parity and height.

Table II may be used to obtain either the predicted birth weight for a given combination of factor categories or to study the adjusted differences between categories. Thus, a parity 0 baby, whose mother had severe pre-eclampsia, is 155 cm tall and smoked during pregnancy, has a predicted birth weight of $134 + 117 + 155 \times 15.7 + 166 = 2851$ g. Likewise a parity 1 baby is 125 g heavier on average than a parity 0 baby after adjusting for the other factors. This is very similar to the unadjusted difference in Table I. Likewise for the other factors, the adjusted differences are similar to the unadjusted ones, leading us to conclude that for none of these factors can the observed mean birth weights be explained by the other factors.

A final interesting finding is that for the purpose of predicting birth weight, Table II does not give much precision; a 95% "prediction interval" has a range of 2085 g centred on the predicted birth weight. For the purpose of predicting birth weight for an individual baby, the birth weight of the immediately preceding pregnancy is much more useful, the correlation between consecutive birth weights being about 0.5 (Billewicz & Thomson, 1973).

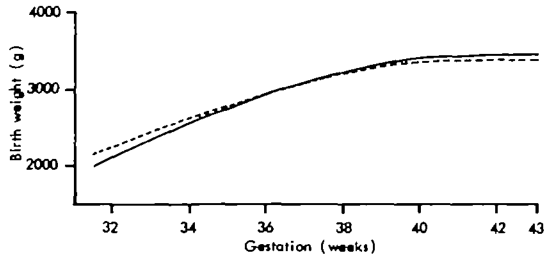
5 Birth Weight, Gestation and Mortality

Figure 2 shows the mean birth weight by gestation length based on data from the 1970 British Births Survey (Chamberlain, 1975), a cohort of one week's births in Great Britain. One of the difficulties of assessing the effect of length of gestation on birth weight (and mortality) is that it is often reported incorrectly, owing to inaccurate recall of the time of the mother's last menstrual period. The 1970 survey found that about one-sixth of the mothers were uncertain of their reported gestation length and when these are excluded, giving the unbroken line of fig. 2, the birth-weight:gestation relationship becomes stronger. Thus, where we wish to use gestation to predict, say, neonatal or perinatal mortality, then we will obtain a better prediction by distinguishing reliable from unreliable information, although few studies to date have been able to do this.

I mentioned earlier that gestation length ought to be considered an "outcome" of pregnancy, like birth weight. Thus, despite common practice, it is misleading to describe curves such as those in fig. 2 as "growth" curves since they do not represent true intra-uterine growth. The common practice of presenting percentiles of birth weight for given gestation length is questionable for the same reason, since it suggests that babies at the same percentile value are in some sense equivalent. In particular, it may be taken to imply that the risk of neonatal or perinatal death or subsequent handicap is best predicted by using the percentile value, whereas, as we now demonstrate, this is not the case.

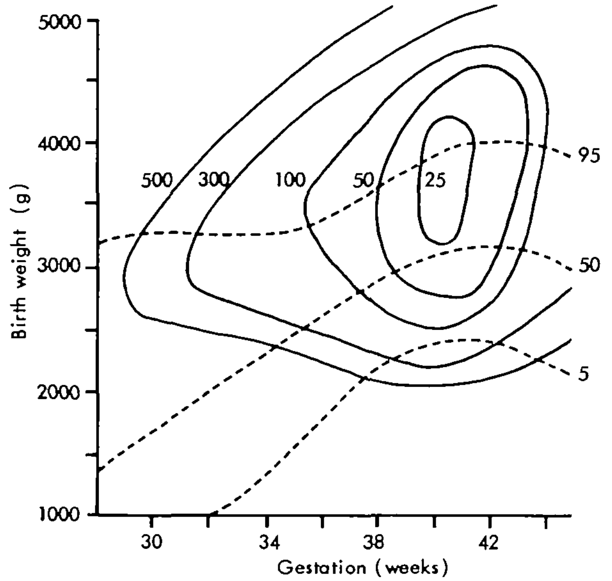
Figure 3 presents "contours" of perinatal mortality on which the mortality rates are constant and expressed as a percentage of the average rate. The data are taken from the 1973 WHO study using results from Cuba, New Zealand and Sweden. The birth-weight-for-gestation percentile lines are also shown and it can be seen clearly that these provide a very inefficient and indeed misleading prediction of mortality risk. In fact, the use of birth weight alone gives a better prediction of perinatal mortality as can be seen by the manner in which the high-mortality contours tend to become parallel to the gestation axis. The relatively rapid increase in the perinatal mortality rate for small changes in birth weight below 2500 g is also evident in fig. 3, and this reinforces the point made earlier with regard to

FIG. 2. Mean birth weight for gestation
(Based on data for singletons in the 1970 British Births Survey)



The unbroken line is for women (84%) with "accurate" gestation lengths, the broken line for all women

FIG. 3. Constant perinatal mortality contours (100 = average) and three selected birth-weight-for-gestation percentiles
(Based on 1973 data from Cuba, New Zealand and Sweden: see Hellier & Goldstein, 1979)



the importance of changes in the proportion of low-birth-weight babies as opposed to changes in mean birth weight. There is also evidence (Goldstein & Peckham, 1976) that subsequent physical and educational development is associated only very slightly with gestation length but rather more strongly with birth weight.

6 Perinatal Mortality

For purposes of comparability, the 1973 WHO study has shown clearly that the use of separate late fetal death rates and neonatal death rates can be misleading. This results from the use of different methods for identifying signs of life, often related to various social and religious factors in different populations. Thus, the same baby might be regarded in one population as being born alive and dying immediately after birth and hence a neonatal death, and be regarded in another population as a fetal death. The use of a perinatal rate overcomes this problem. Of course, within a population where similar criteria are used, the separate study of late fetal and neonatal deaths is perfectly proper. In the present paper, however, only perinatal mortality will be used.

The definition of a perinatal death is that of a baby born alive and dying within the first week of life or born dead at or after 28 weeks of gestation. Of course, the problem of defining signs of life for pre-28 week babies creates difficulties but it affects so few births as to have a negligible influence on mortality rates. More serious, however, is the difficulty associated with measuring gestation length and this could be responsible for some observed differences in perinatal mortality rates, although there seems to be little reliable information on the extent of such possible sources of bias. One consequence has been a suggestion that all births with a weight of 1000 g or more be used for the purpose of computing mortality rates. Despite its superficial attractiveness, however, such a definition has serious

TABLE III. Perinatal mortality rate (per 1000 births)* for selected factors: 1973 WHO study

Factor	Cuba	New Zealand	Sweden
Sex			
Male	29 7 (110)	18.8 (109)	13.5 (107)
Female	23.9 (89)	15 7 (91)	11 8 (94)
Plurality			
Singletons	27.0 (100)	17.3 (100)	12 6 (100)
Twins	163 8 (606)	84 6 (489)	100.2 (795)
Other	183.7 (680)		
Parity			
0	24.6 (91)	18.9 (109)	13 2 (105)
1	21 8 (81)	11 8 (68)	10 8 (86)
2	24.4 (90)	15.1 (87)	13.1 (104)
3	28.1 (104)	16.7 (97)	20.1 (160)
4	31 1 (115)	24 8 (143)	
5	32 9 (122)	22 2 (128)	21.3 (169)
≥6	49.5 (183)	28.0 (162)	
Age of mother			
≤17	30 6 (113)	21.3 (123)	14.1 (112)
18	25.4 (94)	23.1 (134)	
19	25.4 (94)	16.7 (97)	15 8 (125)
20–24	23.2 (86)	16 6 (96)	11.7 (93)
25–29	25.7 (95)	14 7 (85)	11.8 (94)
30–34	29.8 (110)	18 0 (104)	12.6 (100)
35–39	37.5 (139)	23.2 (134)	19 2 (152)
≥40	41.2 (153)	43.1 (249)	33.1 (263)
Interval since last birth (months)			
<12		40.6 (235)	24 0 (190)
12–17		14.4 (83)	17 9 (142)
18–23		11.3 (65)	12 5 (99)
24–35		12.4 (72)	8 5 (67)
36–47		12 9 (75)	10 4 (83)
48–59		15.5 (90)	13 2 (106)
≥60		25.3 (146)	13.0 (103)
Residence			
Urban	25.4 (94)	17 3 (100)	12 5 (99)
Rural	29.2 (108)	17 4 (101)	12.9 (102)
Place of delivery			
Hospital or other institution	26 5 (98)	16 9 (98)	12.6 (100)
Home	41.8 (155)	117.3 (678)	
Total	27.0 (100)	17 3 (100)	12 6 (100)

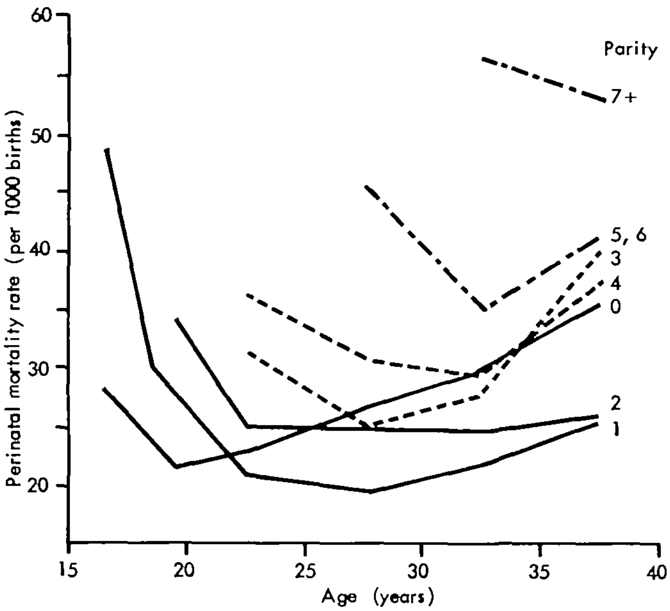
* For Cuba the perinatal mortality rate is based on the number of previous live births; for New Zealand it is based on the number of previous late fetal plus live births; and for Sweden it is based on the number of previous late fetal plus live births

Apart from plurality all rates are for singletons only Figures in parentheses are the percentage of average perinatal mortality rate

drawbacks, not the least being that its use would effectively destroy comparability with rates based on the old definition and distort between-country comparisons (see Goldstein & Butler, 1977). For all its deficiencies, the well-established definition seems the more appropriate one to follow and will now be used.

Table III shows how perinatal mortality rates vary across the categories of several factors for Cuba, New Zealand and Sweden in the 1973 WHO study. An important omission from Table III is father's occupation, for which there are two reasons. Firstly, it is unavailable for Cuba and Sweden and, secondly, it is based on a standard International Labour Organisation's definition which suffers from difficulties in interpretation due to non-comparability. I shall, however, discuss social class further when I study the combined effects of several factors using the data from the 1958 British Perinatal Mortality Survey. For sex, plurality, age, parity and interval since last birth, there are similar patterns for all three countries, although there are detailed differences in, for example, the age at which minimum mortality occurs and the ratio of rates for twins and singletons. For urban or rural residence, the Cuban advantage for urban dwellers stands out as does the great advantage for hospital or institutional deliveries in New Zealand. For both these factors we would expect the quality of social and health care to be of considerable importance and the other factors of lesser

FIG. 4. Perinatal mortality rates (per 1000 births) for Cuba in 1973 by age and parity



importance. Even for these, however, there are some interesting variations in pattern for the younger ages which will presumably reflect different cultural as well as other factors. From the point of view of predicting high perinatal mortality risk, these data suggest that twins, high age and high-parity mothers, and short inter-pregnancy intervals are common to all countries and that non-institutional birth carries a high risk for New Zealand. It should also be noted that the pattern of mortality rates with changing parity and age follows the pattern of the percentage of low-birth-weight babies rather than the mean birth weight.

The World Health Organization's (1978a) report also gives two-way tabulations for these variables and fig. 4 presents one of these, namely, parity by age of mother, for Cuba which has a sufficient total number of births to provide reasonably detailed and stable estimates. It shows a very clear interaction between age and parity. For the younger ages, under about 22, the highest risk is associated with parities 1 and 2, with above average risks for those under 20, compared with the below average risks for all parity 1 and 2 babies. The lowest risk age for parity 0 is 19, for parities 1 and 3, 25–30 years and for parity 2 there is little change between 25 and 35 years. For parities 4, 5 and 6 it is 30–35 years and for parity 7, 35–40 years where the risk is lowest. We see, therefore, how useful such a two-way analysis can be in describing risk and suggesting (with, of course, the previous reservations about observational studies) social and health policies aimed at minimizing it, for example, by discouraging second or third babies among very young mothers.

Finally, we return to the 1958 British data for an analysis of several factors in combination. Because the data are more limited than those in the 1973 WHO study and because, when studying more than two factors, the kind of fine detail of fig. 3 is not possible, the following results are necessarily somewhat crude, but they do give some indication, as in the birth-weight analysis, of how the factors combine.

TABLE IV. Survival odds ratios for the joint effects of six factors on perinatal mortality

(Adapted from Butler & Alberman, 1969)

Factor	Categories	Category contrasts	Odds ratio
Maternal age	(a) <35	a:b	1 51
	(b) ≥35		
Parity	(a) 0	a.b	0 83
	(b) 1, 2, 3	b·c	1 28
	(c) ≥4	a c	1.06
Social class	(a) I, II	a·b	1 15
	(b) III	b.c	1.10
	(c) IV, V	a.c	1.27
Height	(a) ≤159 cm	a.b	0 83
	(b) >159 cm		
Pre-eclampsia	(a) None, mild or moderate	a:b	2 32
	(b) Severe		
Smoking	(a) Non-smoker	a·b	1 30
	(b) Smoker		

In order to achieve a satisfactory presentation of these results we need to introduce the idea of "survival odds". Consider the male and female perinatal mortality rates for Cuba in Table III (29.7 and 23.9/1000). For males the ratio of the probability of survival to the probability of death is $(1000 - 29.7)/29.7 = 32.7$; that is, there are odds of 33 : 1 on survival. For females, the odds are approximately 41 : 1. The survival odds ratio of female to male is therefore $41:33 = 1.24$, or, in other words, there is a 24% increase in the survival odds in females compared with that in males. When presenting the results of the combined effects of many factors it is convenient to express the contribution of each factor in terms of survival odds ratios. This is the analogy to the birth-weight analysis where the contribution of each factor was expressed in terms of average birth-weight changes. Table IV gives the survival odds ratios for the joint analysis of six factors in the 1958 study.

The contributions of each factor are in the expected directions. Some of the odds ratios are large, the highest being that for pre-eclampsia, followed by that for maternal age and then smoking. It should be remembered, however, that the survival odds themselves are all high in any case. It should also be noted that the odds ratio for a factor may not be constant over all the category combinations of the other factors. While the present data are not extensive enough to demonstrate this conclusively, for smoking during pregnancy there does seem to be a different odds ratio in different social classes, as it is lower in the higher-status social groups (Butler & Goldstein, 1973).

The odds ratios in Table IV multiply together when factors are considered jointly, so that in the extreme case for a baby of a smoking mother in social class IV or V, aged 35 years or more, with parity 4 or more, who is less than or equal to 159 cm and has severe pre-eclampsia, when compared with a baby who has all the corresponding most "advantaged" characteristics, the odds ratio is 8.9 which is rather high. As in the case of birth weight, the main function of such an analysis is to identify high-risk groups of babies so that available resources can be allocated optimally in programmes designed to reduce mortality.

7 Conclusions

This necessarily rather brief discussion of factors associated with birth weight and perinatal mortality has attempted to highlight those factors which have repeatedly shown themselves to be important. There are, however, some important differences between populations and this should caution us against extrapolating results from one country to another, particularly where these have different social, cultural or industrial systems. Ideally, each country should attempt to study its own population, using large and well-conducted surveys or properly controlled vital registration systems. Nor should such studies be regarded as "research luxuries" since, without the information obtained from such studies, socially progressive health programmes are handicapped. The present worldwide interest in "high-risk" maternal and child health care strategies (World Health Organization, 1978b) certainly needs such basic data if a reasonable allocation of resources is to take place. To concentrate resources where the risks are highest is both economically optimal and socially desirable, but cannot be done properly unless the risks themselves are known (Goldstein, 1972).

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