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A Perinatal Growth Chart for International Reference*

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The need for an international reference chart to represent normal growth throughout late fetal and early postnatal life has long been recognised[1]. Many charts, like that of Lubchenco and her colleagues[2], have been advanced during the last two decades. Such charts have usually been created from cross-sectional measurements of birthweight following delivery at different gestational ages. Typically they show a number of curves representing the distribution of birthweight between twenty-six and forty-three weeks' gestation. While some charts show a normal distribution over all or part of the gestational age range, others do not. In many, the curves have been smoothed. Any effort to superimpose these charts on each other reveals how dissimilar they are, especially in the lower gestational age range[3,4]. This should not surprise us in view of the inherent problems involved: the difficulty of determining gestational age accurately; the fact that pre- and post-term delivery is itself deviant and infants born early or late may well reflect aberrant growth; the ethnic, socioeconomic and other variations between the different populations studied; and the lack of uniformity in arbitrarily excluding groups of babies whose prenatal growth was suspected of being abnormal.

My own search for a perinatal growth chart that was versatile enough to serve as an international reference and at the same time simple to understand, to reproduce and to use, was undertaken between 1962 and 1966. Previous accounts may be found elsewhere[5-11].

At this time it will only be possible to sketch an outline of the arguments and hypotheses on which the chart is based.

A study of the various fetal growth charts that were available revealed a number of shared characteristics: a linearity of mean weight between twenty-eight and thirty-eight weeks' gestation indicating a steady incremental weight gain; a slope of the line which appeared remarkably constant; and a curved flattening of the line as term was reached and passed[3]. Moreover, a study of postnatal growth charts based on longitudinal studies showed that for the first eighteen weeks after term-delivery, the infant resumed a linear incremental weight gain very similar to that maintained between twenty-eight and thirty-eight weeks' gestation[12]. Prior to twenty-eight weeks' gestation and after eighteen weeks' postnatal age the line gradually flattened to produce a gentle S-shaped curve (Fig 1).

This observation, first recorded by McKeown and Record[12] and since confirmed by others[13], suggested that the flattening of the growth line at and after term with singleton infants, and before term with multiple births[14], was due to maternal/placental constraint of normal fetal growth[3]. Support for this hypothesis comes from the observation that when very normal populations are

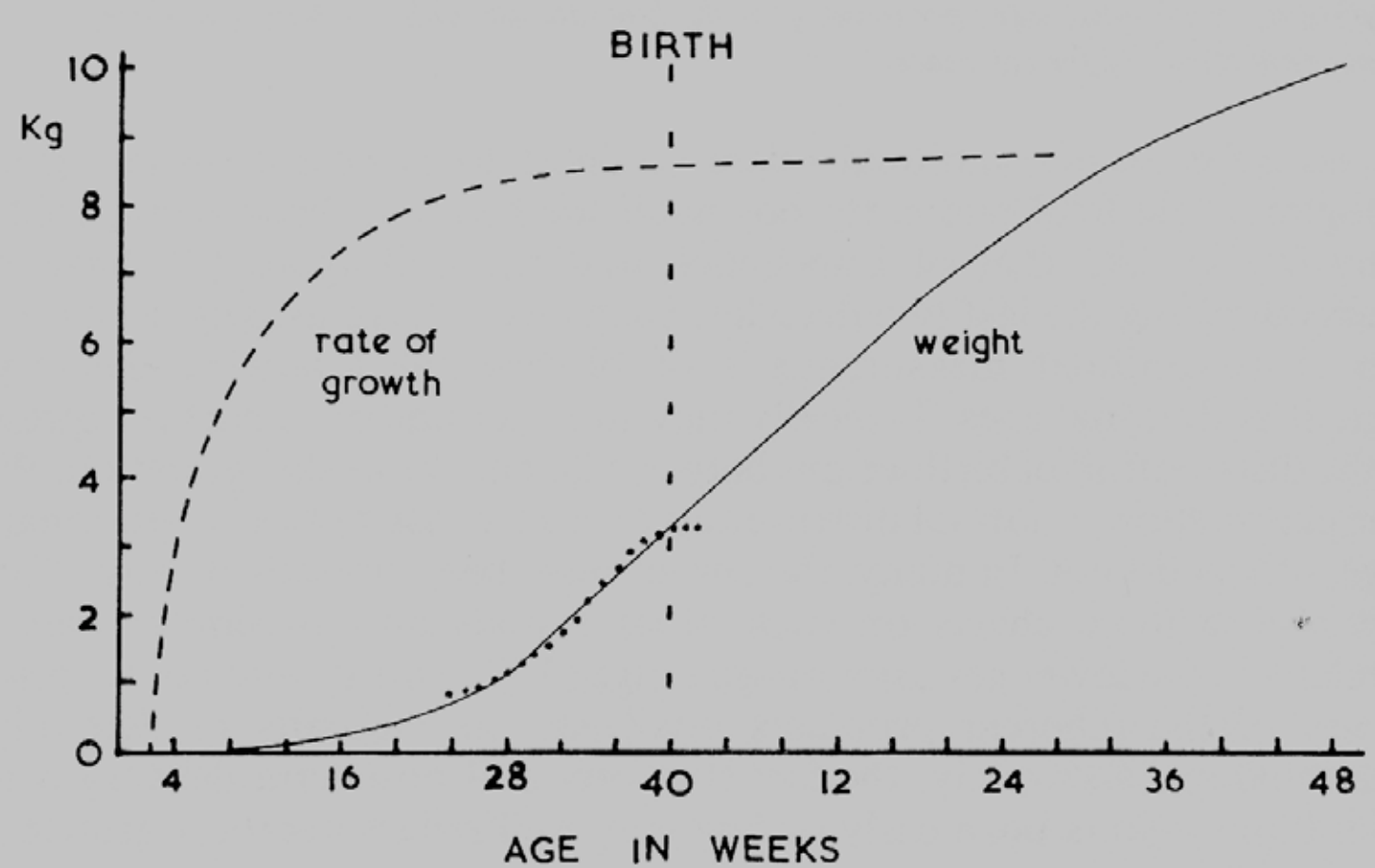

Fig. 1 Normal weight gain and rate of growth (see text) during prenatal and early postnatal life. The median from the chart of Lubchenco et al. (2) has been superimposed on the weight line (24-43 weeks' gestation).

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studied, the linear period of growth in the 3rd trimester is maintained until forty or even forty-one weeks[15-17]. As in the case of an individual infant, it is a matter of chance whether or not he or she remains in-utero long enough to experience this period of terminal growth constraint and as the intention was to base the reference line on normal unconstrained growth throughout the perinatal period, it seemed reasonable and indeed necessary to ignore this late term and post-term flattening of the growth curve. The same applied to the short pause in growth that typically follows birth while feeding is becoming established. There remained then the task of determining the position and slope of a line representing normal weight gain over the period being discussed. While the final precise position and slope might be determined arbitrarily, it was necessary that it should closely reflect normal observed weight gain over the whole period. In this sense 'normal' was equated with 'average', since it is known that both growth acceleration and retardation may be associated with increased perinatal mortality and morbidity. The reference line that was ultimately chosen commended at 1.1 kg at twenty-eight weeks and demonstrated a steady incremental weight gain of 1.1 kg every six weeks until reaching a weight of 6.6 kg at eighteen weeks' postnatal age.

It is thus easy to remember as well as to reproduce (Fig 2).

The average weight for age of the fetus and infant soon after birth is shown in Fig 1. Also shown is the rate of growth as judged by the time taken to successively double body weight. Note that while incremental weight gain is proceeding rapidly in the perinatal period, the rate of growth at that time has greatly slowed as compared with the rate in early pregnancy (see also Fig 2). It is possible to explain the whole normal distribution of weight-for-age observed throughout the period in terms of a very small variation (+ 1-2%) in the growth velocity from conception onwards[5]. When this knowledge is combined with the fact that about 95% of all relative prenatal growth has taken place by twenty-eight weeks' gestation[5,7], then we can afford to assume that for all practical purposes normally growing fetuses have almost identical potential growth velocities during the last trimester and differ significantly from each other only in the weight they have achieved at the start of that period. Again, one can argue that within any population there must be normal sub-groups, as for instance males and females, with growth lines balanced above and below the central tendency. The lines for these sub-groups would tend to diverge progressively from each other as time went on[18,19]. The same applies to postnatal weight charts[20,21]. If these observations are applied, it should

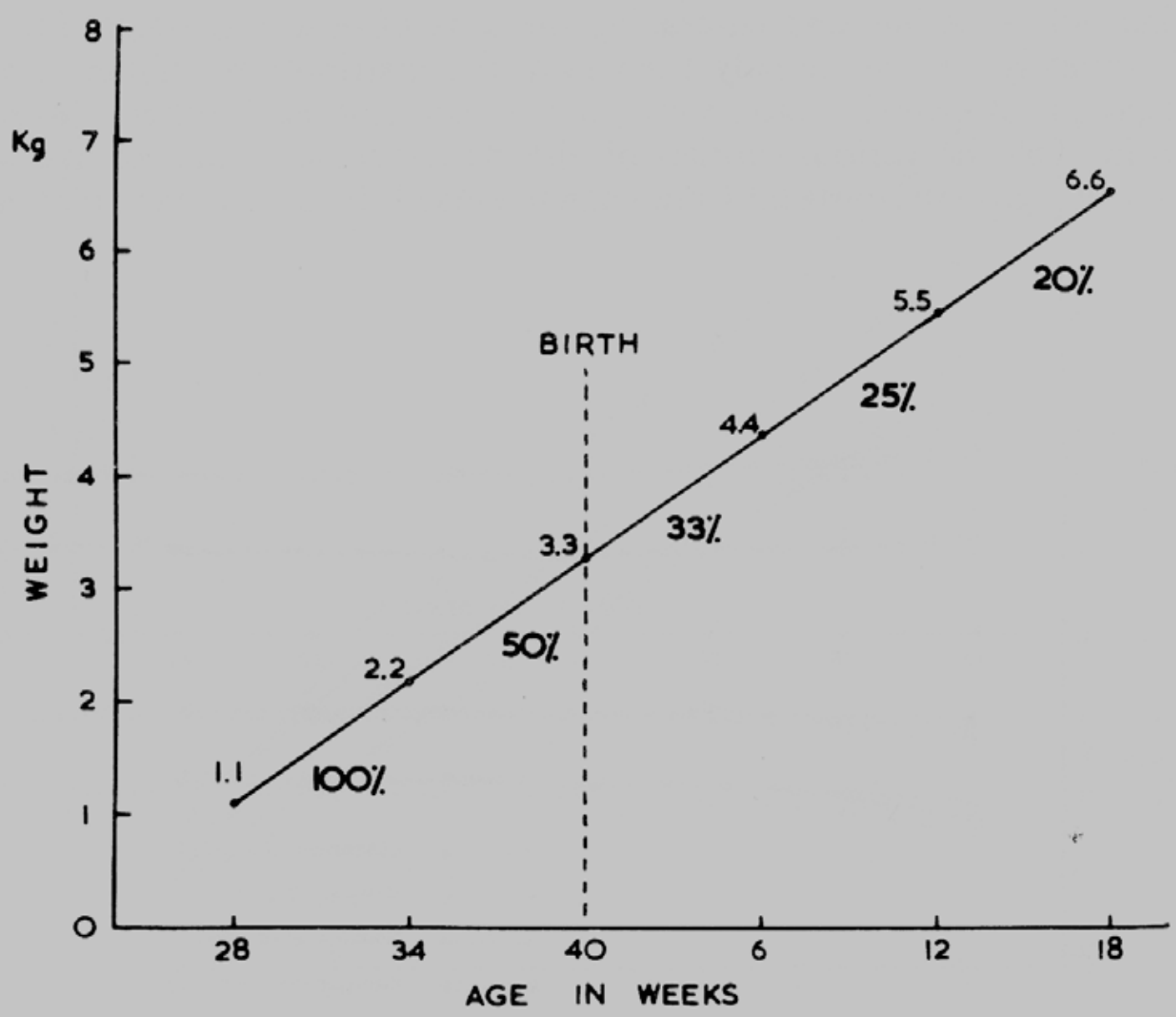

Fig. 2 Line representing the normal weight gain of the average Caucasian infant during the period before and after birth. The weights are given at 6-week intervals from 28 weeks' gestation to 18 weeks' postnatal age. The percentages indicate the steady deceleration in the rate of growth expressed as the ability to double weight during each period.

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be possible to construct diverging lines relating to the original reference line and embracing the area of observed weight-for-age. Unfortunately, as has already been said, the distributions of the various published fetal growth charts vary enormously from each other. However, when in 1969 the various centiles of birth-weight-for-gestation of five well-known fetal growth charts for Caucasian infants[3,19,22-24] were plotted as a plus or minus percentage of their own medians, a remarkable correspondence was revealed (Fig 3).

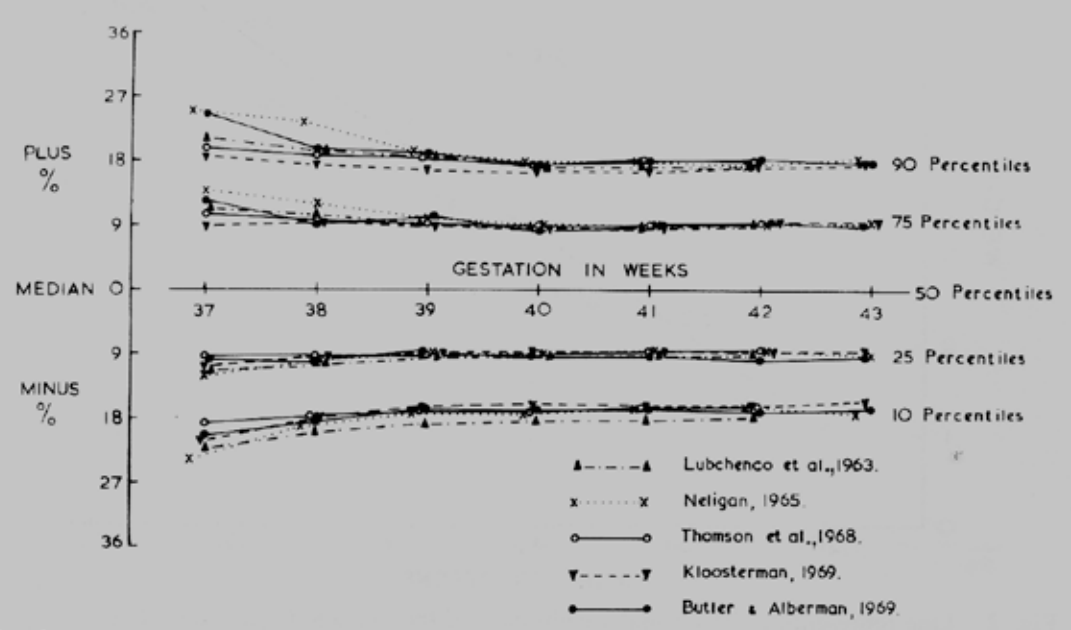

Fig. 3 The 10th, 25th, 75th and 90th centiles of birthweight-for-gestational age (37–43 weeks) from five studies in the 1960s are shown plotted as plus or minus percentages of their own median weight curves.

Thus, the 25th and 75th centiles for infants 37-43 weeks' gestation lay at + 9.1% of the median value, while the 10th and 90th centiles lay at + 18.2%[10]. This knowledge was used to help construct the Bristol Perinatal Growth Chart. 1.1 kg plus 18.2% at 28 weeks is exactly 1.3 kg, while 1.1 kg minus 18.2% is 0.9 kg. If lines are now constructed + 18.2% from the reference line, they will be found to diverge steadily. Infants growing along them will again show an incremental weight gain every six weeks equal to their initial weight at twenty-eight weeks (e.g. 1.3 kg ⇒ 2.6 ⇒ 3.9 (term) ⇒ 5.2 ⇒ 6.5 ⇒ 7.8 kg at 18 weeks postnatal age; and 0.9 kg ⇒ 1.8 ⇒ 2.7 (term) ⇒ 3.6 ⇒ 4.5 ⇒ 5.4 kg at 18 weeks postnatal age). Once again, these lines are easy to remember, to reproduce and to use. In Fig 4 the 10th, 50th and 90th centiles of the Lubchenco chart[2] have been superimposed on the Bristol Chart up to forty weeks' gestation, while those of Tanner[20] are shown for the early postnatal period.

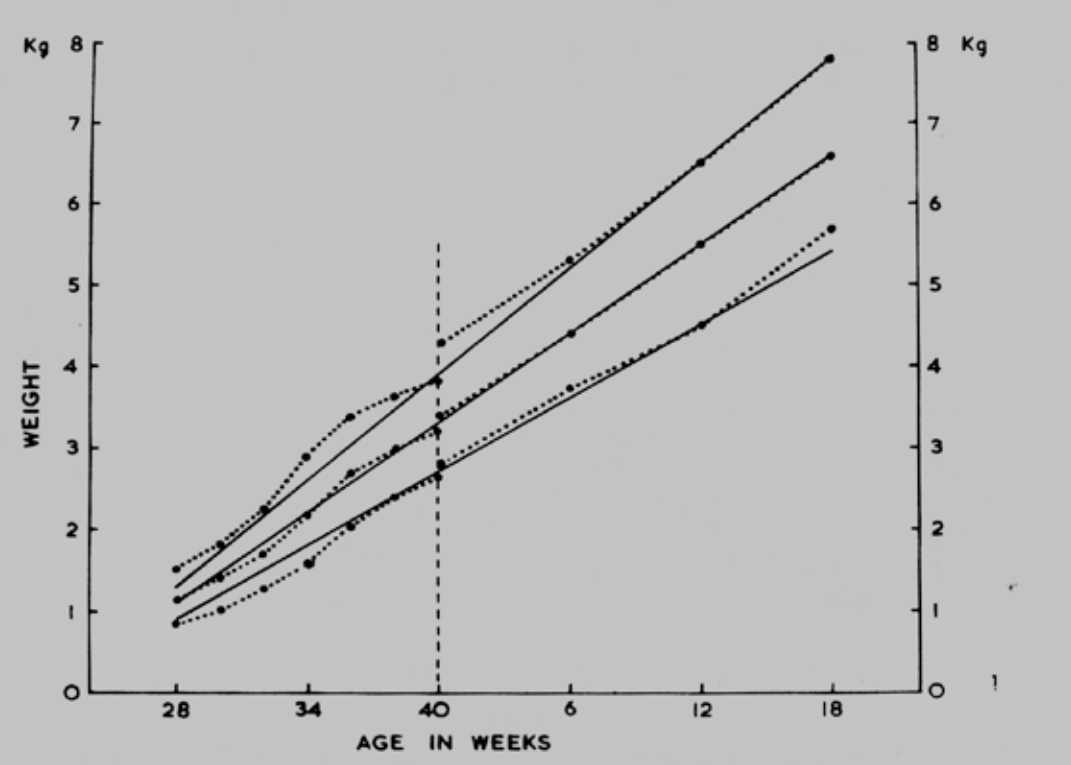

Fig. 4 The fetal growth curves (10th, 50th and 90th centiles) of Lubchenco et al. (2) and the early postnatal growth curves for boys and girls combined (10th, 50th and 90th centiles) of Tanner are shown superimposed on the Bristol Perinatal Growth Chart.

The close correspondence is striking. It is important to appreciate that while the incremental weight gain ranges from 21.4 g/day for infants on the lower line, through 26.2 g/day for the reference line, to 31.0 g/day for the upper line, the rate of growth expressed as g/kg/day is identical for all three lines, slowing from 23.8 g/kg/day in the first six week period to 4.8 g/kg/day in the last (Fig 5).

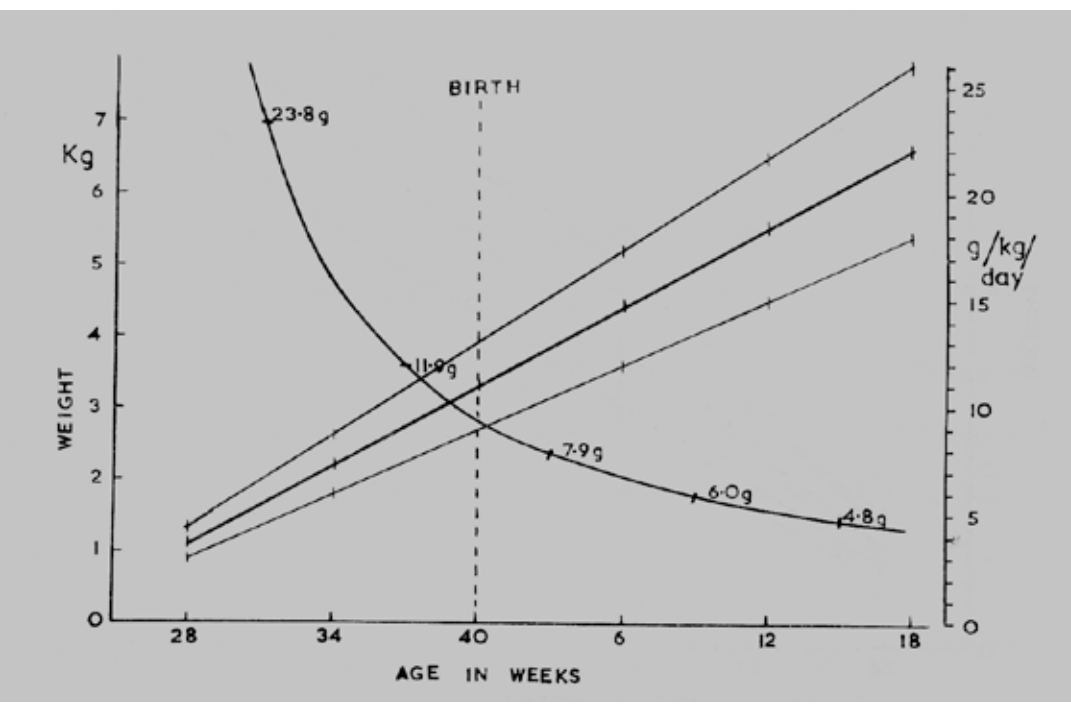

Fig. 5 The perinatal growth reference line and two related lines at plus or minus 18.2%. The incremental weight gains of a fetus growing along the lowest line would be 21.4 g/day, along the central line 26.2 g/day and along the upper line 31.0 g/day. Yet all three fetuses have an identical decreasing rate of growth expressed in g/kg/day and shown by the falling curved slope

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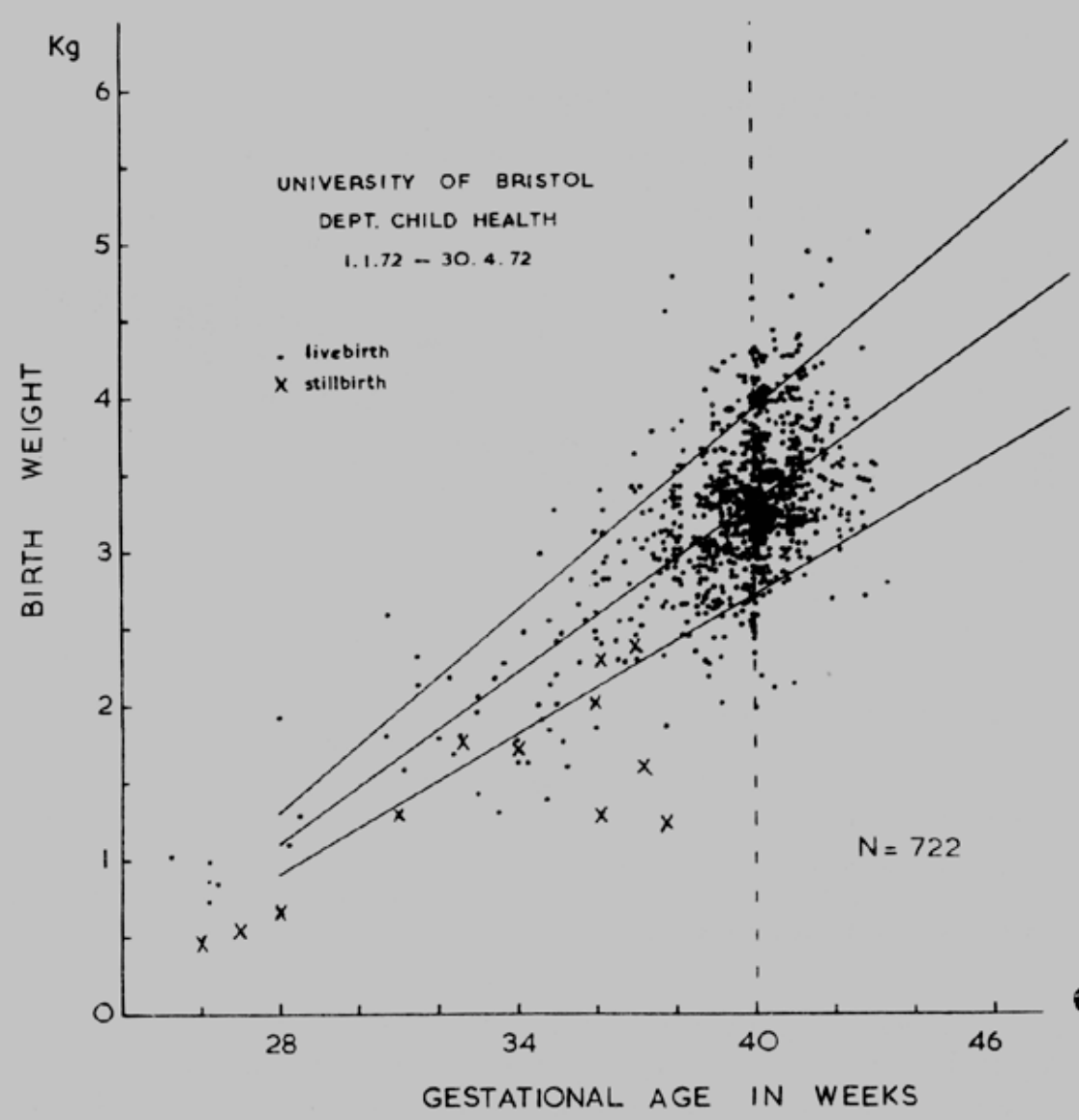

Fig. 6 Birthweight-for-gestation of 722 consecutively born infants plotted on the Bristol Perinatal Growth Chart. 10% of infants fall below the lower line and 10% above the upper line.

The Bristol Perinatal Growth Chart has many uses in addition to that as a standard against which other charts may be compared. For example, if the assumption of a normal distribution of weight for gestational age proves correct (as appears to be the case for monkeys[25] and for infants after birth[20,21]) then the chart may be used to categorise infants that are heavy, appropriate or light for their gestational age (Fig 6), (lines drawn at ±25% approximate to ±2 standard deviations).

Then it may be used to study special groups of infants as, for example, those born without malformation to women with polyhydramnios (Fig 7)[8,9].

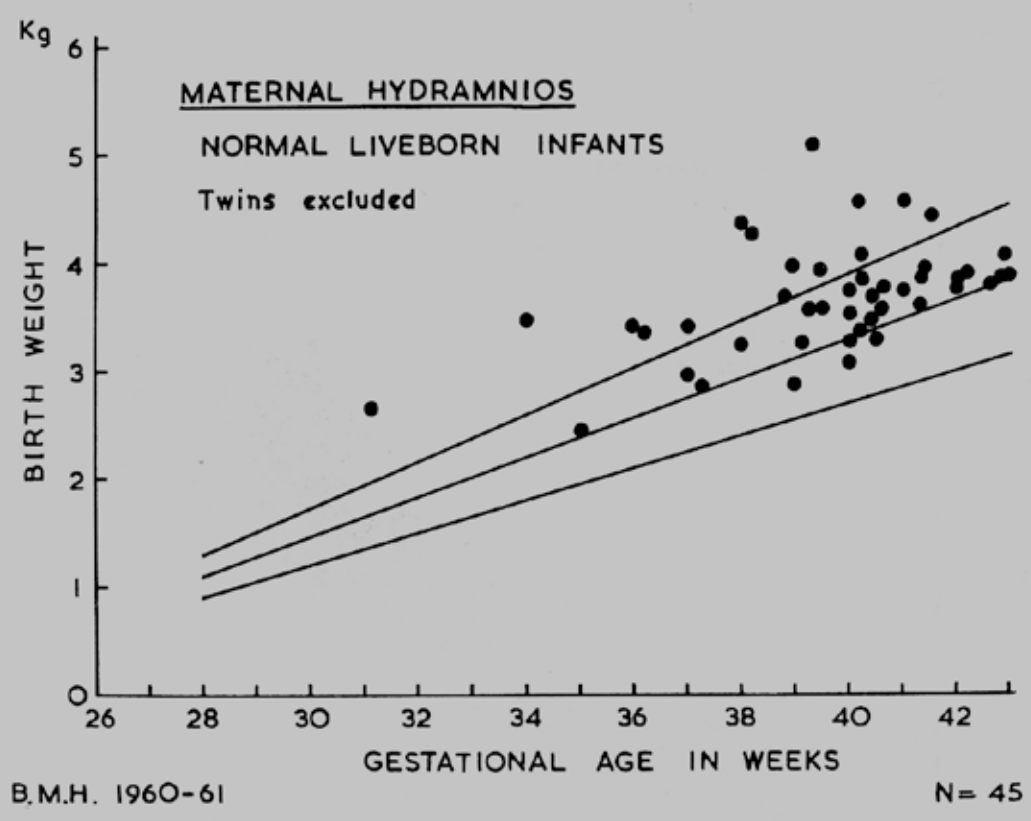

Fig. 7 Birthweight and gestational age of 45 normal liveborn singleton infants born to women with hydramnios at the Birmingham Maternity Hospital, 1960–61, superimposed on the Bristol Perinatal Growth Chart (28–43 weeks).

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The Chart may also be used to study the longitudinal growth of individual infants (Fig 8)[9].

Its nature and symmetry also permit allowance to be made for biological variables influencing growth. For example, boys weigh on average 6% more than girls throughout the perinatal period[17].
It is thus possible to make a ±3% allowance according to the sex of the infants under study (Fig 9). Allowance may also be made for other biologic variables such as maternal height[24].

The mathematical simplicity and symmetry of the Bristol Chart makes it a convenient tool with which to study the metabolic requirements of the fetus/placenta or infant in relation to its growth. Elsewhere[11] it was speculated that when a fetus was growing at a rate which enabled its weight to be doubled in six weeks (28-34 weeks' gestation), perhaps half the total metabolic requirements were devoted to growth. It would appear from the review by Brooke[26] that this speculation falls within the bound of calculated probability.

Before leaving discussion of the uses to which the Bristol Chart may be put, it is worth pointing out that for the study of the immediate perinatal period, a truncated version may be more convenient (Fig 10).

It will be seen that for gestational ages of less than 28 weeks, interrupted lines have been used to indicate that linearity is progressively lost as gestational age falls to 20 weeks (Fig 1). Information on birthweight distribution in the second trimester is accumulating[27,28] and it should soon be possible to construct a standard for reference for this period too. In the same way standards for other parameters such as height and head circumference are also required for international reference[29].

Pecorari and his colleagues[30,31] have demonstrated the use of the Bristol Perinatal Growth Chart as an international standard for reference in respect to Caucasian populations. While more non-Caucasian data is still awaited it does appear as though the normal unconstrained growth in the perinatal period of other ethnic groups is very similar, observed differences being explained either by

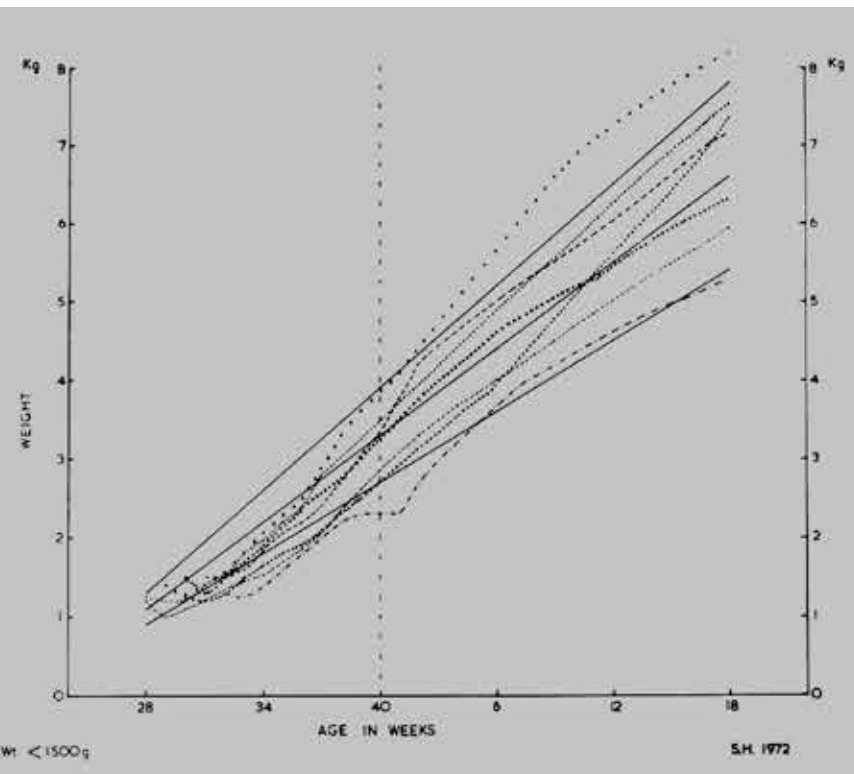

Fig. 8 Postnatal growth curves of 7 consecutively born very low birthweight infants superimposed on the Bristol Perinatal Growth Chart.

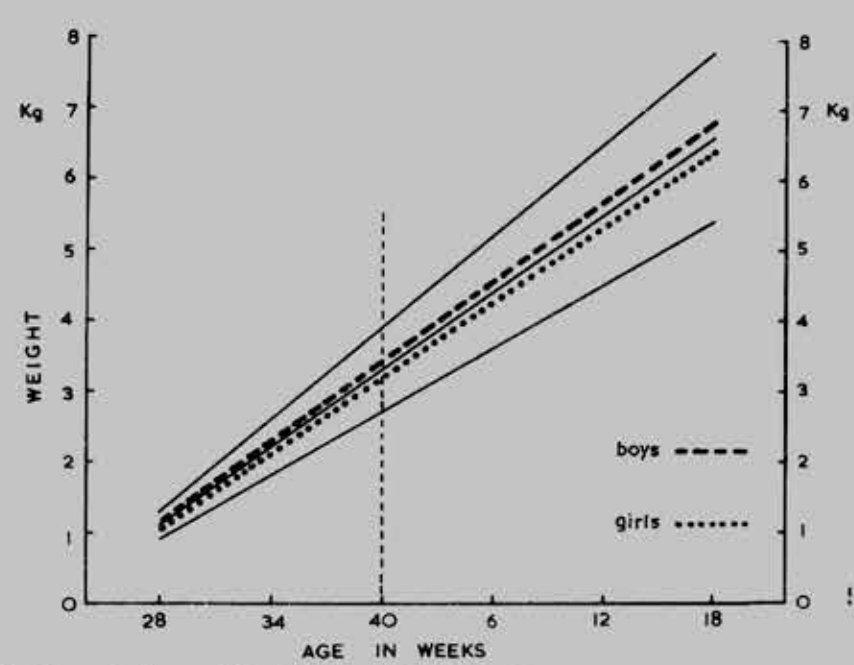

Fig. 9 Mean fetal growth lines for boys and girls (±3%) in relation to the Bristol Perinatal Growth Chart.

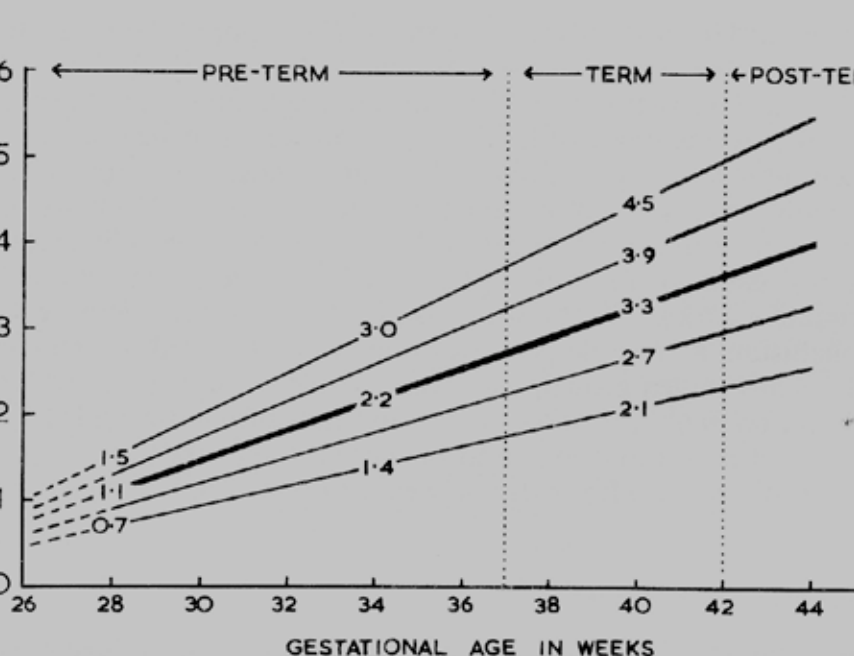

Fig. 10 A shortened version of the Bristol Perinatal Growth Chart (28–44 weeks).

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maternal size (for which allowance can be made) or by pathological or environmental influences (which are the factors requiring study). Thus, Bhargava[32] has demonstrated that the fetal growth curve of a privileged Indian population is very similar to that of Caucasian populations in developed countries, and Hendrickse[33] has written: 'Studies in Nigeria have provided conclusive proof that adverse environmental facts are the key determinants of the poor growth attainment of children in West Africa when compared with European counterparts. Comparisons between an 'elite' cohort of Nigeria-Yoruba children, who enjoyed good living standards, with the USA international reference population[34], show essentially similar growth and development in the preschool and primary age groups ...' He then rightly warned of the danger of judging the growth achievement of infants and children in developing countries against local standards based on populations whose growth has been profoundly influenced by their poor environment.

The possession of a perinatal reference chart for weight does not obviate the need to collect information on different populations. Indeed, this is essential in order to discover how the various populations relate to the reference standard. This may best be achieved by studying the birthweight (and subsequent growth) of healthy, normal, singleton infants born normally after a spontaneous onset of labour at 38-40 weeks to healthy, adequately nourished, non-smoking, multigravid women whose pregnancies have been free of complications. Even the study of as few as 100 such infants should be sufficient to determine a relationship. To give an example, it appears that the mean birthweight at 40 weeks' gestation for Scandinavian populations is approximately 3.6 kg(15,16), which is plus 9.1% on the reference line.

In conclusion, a versatile perinatal weight chart, based on the concept of normal unconstrained growth, has been created to serve as an international standard for reference purposes. It permits allowance to be made for biologic variables such as sex and maternal height, and appears to be applicable to difference ethnic groups. It is extremely easy to remember, to construct and to use.

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