

4. The newborn infant

4.1 Introduction

It is universally acknowledged that size at birth is an important indicator of fetal and neonatal health in the context of both individuals and populations. Birth weight in particular is strongly associated with fetal, neonatal, and postneonatal mortality, and with infant and child morbidity (1, 2).

Size at birth reflects two factors: duration of gestation and rate of fetal growth. It must therefore be considered with respect to gestational age, otherwise the increase in size that occurs with age will lead to severe confounding of growth and maturity. In general, bigger babies are more mature babies and – since it is well known that immature infants (particularly extremely preterm infants, i.e. those born at <32 weeks) are at much higher risk for mortality, morbidity, and impaired development – failure to consider gestational age leads to major problems in interpretation that can hinder decision-making at both clinical and public health levels (3).

Growth is defined as an increase in size over time, and documentation of increasing size thus requires two or more serial measurements. During fetal life, however, serial measurements are feasible only with ultrasound and have not proved to be sufficiently valid or precise (ultrasound estimation of fetal weight has a high coefficient of variation) to serve as a standard for assessing fetal growth (4). Moreover, ultrasound measurements are not truly anthropometric and are thus beyond the scope of this report.

Body size is obviously proportional to age, not only in the fetus but throughout childhood until the time of skeletal fusion. Thus an infant's size at birth reflects the *average* growth rate for that infant from conception to birth, although not necessarily a steady rate, since there may have been periods of rapid and slow growth. Problems will arise, however, if the distribution of size at birth of different infants born at different gestational ages is used to make inferences about “normal” fetal growth. It is important to stress the limitations of a cross-sectional approach based on different infants, and to question how well any chart derived in this way reflects the longitudinal growth of fetuses of the same gestational age (5). There is some evidence that preterm infants are somewhat smaller than fetuses of the same gestational age who remain *in utero* (6-8). This may partly reflect the fact that some of the determinants of fetal growth and length of gestation overlap: pre-eclampsia, for example, and other hypertensive disorders that impair fetal growth also increase the risk of preterm delivery (9, 10). Although this overlap may reflect shared underlying biological mechanisms, it is common practice in modern obstetrics for labour to be induced in mothers in whom poor fetal growth has been diagnosed. Thus if infants whose delivery is induced because of retarded growth are not excluded from the data, their

smaller size for gestational age will reduce the average size of all infants born at that age (11).

At the other end of the gestational age spectrum, there is also some (albeit more indirect) evidence that fetuses who remain unborn post-term may not have grown at the same rate as those born earlier. Fetal size is considered to be one of the determinants of the onset of labour, and the flattening (or even negative slope) of some fetal growth curves after 40 or 41 weeks of gestation may reflect both the slowing of growth due to placental insufficiency (as demonstrated by the presence of oligo-hydramnios, placental grade III, meconial amniotic fluid, or abnormal Doppler indices), and the earlier birth of faster-growing fetuses.

This inherent problem of deriving fetal growth standards from anthropometric measurements of newborn infants may have less relevance to the first 20–24 weeks of gestation, when elective, induced abortions are performed for indications unrelated to fetal growth (i.e. for reasons other than chromosomal or other genetic abnormalities of the fetus). This should not affect measurements of fetal weight or other body dimensions provided that abortion is induced by means of prostaglandin or hysterotomy rather than saline (which dehydrates the fetus). The situation changes, however, when *all* fetuses are included, since a large number of births during weeks 20 to 24 are spontaneous and probably related to factors that *do* affect fetal growth. From week 24 onwards, however, it should be kept in mind that fetal growth curves based on anthropometric measurements of different infants born at different gestational ages may not be valid, particularly pre- and post-term.

The determinants of fetal growth have been the subject of considerable research (2, 9, 12–17), and it is now clear that, despite some of the areas of overlap alluded to above, these differ considerably from the etiological determinants of gestational duration (10, 12, 15–19). In particular, maternal stature, prepregnancy weight, and energy intake during gestation all have important influences on the rate of fetal growth (9, 12–17), but much less, if any, effect on the duration of gestation (10, 12, 15–19). Genetic (including racial) and inter-generational effects also bear primarily on fetal growth (12, 20–24); cigarette smoking affects both fetal growth and gestational duration, but the effect is considerably greater on the former (9, 10, 12, 19). Only a few other determinants, such as infections (25, 26), maternal cocaine use (27, 28), and prepregnancy and gestational hypertension (particularly severe pre-eclampsia) (9, 10) also affect both outcomes.

Impairments in fetal growth can have adverse consequences in infancy and childhood in terms of mortality, morbidity, growth, and performance (1, 2, 29). It has even been suggested that restriction of fetal growth may increase the risk of ischaemic heart disease, hypertension, obstructive lung disease, and diabetes in adulthood (30, 31). This is an important area for future follow-up studies of growth-retarded infants or, where reasonable perinatal information is available, for retrospective cohort studies.

4.2 Using anthropometry in individual newborn infants

Weight-for-gestational-age at birth is often used to categorize an individual infant as having experienced normal, subnormal (small-for-gestational age or intrauterine growth retardation), or supranormal growth *in utero*. The classification most frequently used is: small-for-gestational-age (SGA or IUGR), appropriate-for-gestational-age (AGA), and large-for-gestational-age (LGA), although, strictly speaking, SGA and IUGR are not synonymous (33). Some SGA infants (e.g. those born to short mothers) may merely represent the lower tail of the “normal” fetal growth distribution, while other infants who have been exposed to one or more growth-inhibiting factors may actually meet the criteria for AGA (e.g. those born to tall, well nourished cigarette-smokers). In individual cases, however, it is usually very difficult to determine whether or not the observed birth weight is the result of true *in utero* growth restriction, and classification of an infant as IUGR is therefore based on the established cut-off for SGA. In fact, the higher the SGA rate, the greater the likelihood that SGA is a result of IUGR.

Various criteria (i.e. cut-off points) have been used as the dividing lines between these three categories. Those most commonly used are based on percentiles of a distribution of birth-weight-for-gestational-age derived from an accepted reference population; the 10th percentile is used most frequently as the cut-off between SGA and AGA, and the 90th percentile between AGA and LGA. Other definitions, such as < -2 or $> +2$ standard deviations (Z-scores) from the reference mean, have also been applied. One recent approach has based the classification on relative weight (the so-called fetal growth ratio or, more correctly, “relative birth weight ratio”), in which the birth weight of an infant is expressed as a fraction or percentage of the mean birth weight (again derived from some reference population) for that infant’s gestational age (32). Thus, infants who weigh $< 85\%$ of the mean can be classified as SGA, and those weighing $> 115\%$ of the mean as LGA. These latter definitions are analogous to those used to classify under- and overnourished populations of older children and adults. However, although 85% of the mean birth weight at term is very similar to the 10th percentile, for preterm infants this cut-off could represent a much higher percentile. If this principle is applied across a range of gestational ages, the prevalence of SGA and LGA will vary with maturity. The use of 85% of the mean as a cut-off point therefore cannot be recommended for use without evidence that the coefficient of variation for birth weight remains fairly constant at different gestational ages.

Regardless of which definition is used, the classification of a newborn as either SGA or LGA has implications for diagnosis, prognosis, surveillance, and treatment. SGA infants are more likely to have congenital anomalies (34), and the observation that an infant is growth-retarded often prompts a more careful physical examination or even laboratory tests such as karyotype determination to ascertain whether

such an anomaly is present. Laboratory cultures of biological samples and serological tests of the mother and infant may occasionally reveal a previously unsuspected intrauterine infection. The diagnosis of SGA may also prompt closer examination of the placenta and reveal evidence of infarction, single umbilical artery, velamentous insertion of the cord, or previously unsuspected disease in the mother.

Regardless of the cause of the growth retardation, a severely growth-retarded fetus or infant is at markedly increased risk of death, hypoglycaemia, hypocalcaemia, polycythaemia, and neurocognitive complications of pre- and intrapartum hypoxia (i.e. *in utero* malnutrition is associated with *in utero* deprivation of oxygen) (2, 35). Close monitoring of blood glucose, calcium, haematocrit (erythrocyte volume fraction), and circulatory adequacy in the neonatal period will allow timely intervention and should reduce the risk of adverse secondary sequelae. Diagnosis of SGA should prompt actions to support breast-feeding and – in affluent populations where weaning foods are hygienically safe – may indicate the need for instituting a high-energy diet to maximize the potential for catch-up growth in the first few postnatal months. Over the long term, growth-retarded infants may exhibit permanent mild deficits in growth and neurocognitive development (2, 29).

The diagnosis of LGA can also be important for the individual infant. Large infants are at increased risk of birth trauma (including clavicular fracture and brachial plexus injury), and of asphyxia secondary to obstructed labour. The most common concern is maternal diabetes, which may or may not have been diagnosed before or during pregnancy; here, too, monitoring (particularly for the development of hypoglycaemia) may be important to permit prompt institution of glucose therapy and thus prevent adverse sequelae.

Various proportionality indices have been used to relate different dimensions of fetal growth, particularly among growth-retarded infants. The most commonly used of these is Rohrer's ponderal index, which is defined as 100 times the birth weight (in grams) divided by the cube of birth length (cm^3). Infants with high ponderal indices are relatively heavy for length (or, equivalently, relatively short for weight); those with low ponderal indices are thin, with low weight-for-length. Although the ponderal index at birth is usually evaluated with reference to the gestational age of the SGA infant, it may be preferable to refer it to birth weight (32). Since body proportions change during the course of gestation, proportionality for size may provide a better index than proportionality for age for assessing how growth following the onset of some growth-inhibiting influence is distributed among different body compartments, compared with its distribution in infants who continue to grow normally.

Several publications have developed the concepts of proportionate (also called Type 1, symmetric, or “stunted”) and disproportionate (Type 2, asymmetric, or “wasted”) growth retardation (36–38), although the

importance of the distinction is still under discussion. Body proportionality at birth may capture information about the timing of growth retardation as well as the nutritional status of the newborn. Much of the discussion about the effect of timing of onset of IUGR on body proportionality has been based on early data from Streeter (39) and more recent data from Gruenwald's report on body weight, length, and placental and organ weight (40), both of which are in agreement with the diagrammatic velocity curves published by Tanner (41). Recent evidence indicates that proportionality among IUGR infants is strongly confounded by the severity of the growth retardation or deficit in nutritional status (32) and that, given reliable estimates of gestational age, disproportionate IUGR infants tend to be more severely growth-retarded than their proportionate counterparts. Analysis of data thus requires that the severity of IUGR be controlled. For example, data from Canada demonstrate that, once severity has been accounted for, proportionality appears to be of little if any etiological (9) or prognostic (35) importance; in the latter study, however, an independent increased risk of stillbirth was associated with a high length-for-weight ratio (OR 1.24, 95% CI 1.03-1.48).

A recent small study that used three ultrasound measurements to monitor the fetal growth pattern of 71 SGA infants (most of them with adequate ponderal index), concluded that, given the birth weight and gestational age of the newborn, body proportionality (e.g. ponderal index) does not contribute further to the judgement of fetal growth rate (42). On the other hand, several large studies from different populations support the independent association between indicators of body proportionality at birth and a number of important neonatal or infant health outcomes. In the USA, Conlisk (43) studied the risk of neonatal mortality for proportionate and disproportionate infants using stratified analysis by 400-g groups and logistic regression analysis to control for birth weight. The results showed that both black and white disproportionate infants are at higher risk of mortality at lower birth weights than proportionate infants, but at lower risk at birth weights above 2400 g (black) and 2800 g (white). Interaction of birth weight and proportionate groups was significant for both blacks ($P=0.05$) and whites ($P=0.04$). The effect of birth weight on mortality was significantly greater for disproportionate than for proportionate infants at birth weights < 2200 g (black) and < 2600 g (white); risk was lower at higher birth weights.

In a cohort of 5539 term newborns studied in Argentina (44), an increased risk of postnatal morbidity was demonstrated in infants who were SGA and of low ponderal index (LPI) compared with the groups of normal birth weight and of SGA/adequate ponderal index (API), adjusted for sex, birth weight, gestational age, and hospital of birth. A study of 3450 term SGA infants in Guatemala (45) again demonstrated that, after adjusting by birth weight, the risk of neonatal morbidity was higher in the SGA/LPI than in the SGA/API group. In both developing and developed

countries, SGA newborns estimated to have experienced slow head growth before the 26th week of gestation (as documented by serial ultrasound measurements) and those with API at birth (indicating proportionate retardation of growth in weight and length) have consistently demonstrated the lowest developmental performance during childhood (46-49).

Finally, Williams et al. (50) classified IUGR infants by their ponderal index at birth and followed them up at 7 and 18 years of age to study their blood pressure patterns. At age 7 years, sex- and weight-adjusted systolic and diastolic blood pressure were significantly higher in those who were classified IUGR/API. By age 18, the mean adjusted systolic blood pressure was 121.8 mmHg (16.2 kPa) in the IUGR/API group compared with 118.8 mmHg (15.8 kPa) in the IUGR/LPI group ($P=0.13$; $n=29$). No differences were observed in diastolic blood pressure.

Proportionality indices may well prove to be useful for predicting outcome in SGA babies, particularly where there is no reliable information on gestational age, but further research is clearly needed on this subject.

Where valid assessment of gestational age is unavailable (as in many settings in developing countries), size at birth, and particularly birth weight, can be used as the basis for decisions regarding surveillance and referral of small infants. Birth weight below 2500 g (LBW) is a reasonable cut-off for instituting surveillance and/or referral for the detection and treatment of early complications of preterm birth or IUGR. However, it should be noted that, because of “rounding”, the prevalence of LBW will be underestimated. In settings with a very high prevalence of fetal growth retardation, a locally determined lower cut-off (e.g. <2250 g or <2000 g) may be preferable to avoid overwhelming the health care system with mildly growth-retarded infants who are at lower risk for serious adverse sequelae. Local cut-offs and the methodology for their selection have already been discussed in section 2.

Surveillance of LBW, preterm infants for complications should include monitoring of oxygenation and respiratory status (including the signs and symptoms of respiratory distress syndrome and neonatal apnoea), indications of neonatal sepsis (e.g. apnoea, poor feeding, vomiting, jaundice), and neurological complications possibly caused by intra-ventricular haemorrhage (coma, seizures, apnoea, or focal neurological deficit). Where adequate surveillance and treatment are not possible locally, or the response to treatment is unsatisfactory, infants should be referred to an appropriate health care establishment. Surveillance and referral are even more important for very-low-birth-weight (VLBW) infants, i.e. those with birth weights below 1500 g, who are usually extremely preterm.

Table 11 summarizes the recommendations for the use of anthropometric measures in individual newborn infants.

Table 11
Summary of recommendations for screening individual newborn infants for interventions

1	2	3	4	5	6	7	8
Uses: what will be done for the individual?	For what purpose?	Target group and setting	What to measure and how often	Indices	Criteria for judgement (out-offs)	Rationale for anthropometry	Other factors for interpretation
Determine how well the infant grew <i>in utero</i> and whether it is at risk for complications of IUGR or preterm birth. Monitor blood glucose, Ca, Hb; refer if necessary; prescribe high-energy diet; follow growth; or monitor oxygenation, respiratory status, and signs of sepsis; refer if necessary	Reduce morbidity/mortality, optimize long-term growth and performance	All newborn infants Hospital, home, or other birth setting, as soon as possible after birth	Gestational age, sex, birth weight, length Single measurement	1. Birth weight and ponderal index for gestational age and sex 2. Birth weight	1. <10th, >90th percentile; Z-score <-2, >+2 2. <2500 g, <1500 g	Size for gestational age	Validity of gestational age; race; reliability of length measurements

4.3 Neonatal anthropometric assessment in populations

The prevalence of SGA (based on a common reference population) can be used to select populations that should be targeted for interventions. Fetal growth is clearly influenced by maternal size, health, and nutrition; data consistently show larger fetuses (particularly at term) in developed countries than in developing countries (9). When SGA rates are unavailable, the prevalence of LBW can be used as a proxy. Preterm birth rates also appear to be higher in developing countries (51, 52) and among poor populations in developed countries (2), although most of the difference in the incidence of LBW between developed and developing countries is due to a disproportionately high incidence of LBW/SGA (52). However, SGA prevalence is preferable both for targeting and for assessing response, because few interventions have been found to prevent preterm birth.

Recommended cut-off levels for triggering public health action have not been established, but it seems reasonable to target those populations with double the prevalence (i.e. >20% for SGA and >15% for LBW) found in developed countries. Population-wide interventions might include nutritional supplementation, antismoking campaigns, and malaria prophylaxis. Within a given population, response to intervention can be assessed by monitoring SGA rates (or VLBW and LBW if gestational age is not available) over time.

Targeting of interventions and assessing response can also be based on LBW and VLBW rates used not as proxies for SGA but as indicators of the need for health care facilities to treat the complications of SGA or preterm birth. LBW and VLBW rates in excess of 15% and 2%, respectively, suggest a population at high risk for fetal and infant mortality and morbidity, and for long-term adverse effects on childhood growth and performance. Trends in developed countries over the past 20 years show that, with no reduction in the prevalence of LBW and VLBW, fetal and infant mortality can be dramatically reduced by optimal care of such infants. Monitoring overall and birth-weight-specific fetal and infant mortality is therefore essential in assessing the response to interventions.

Anthropometric assessment of newborn infant populations is an important research tool for studying the determinants and consequences of impaired (or excessive) fetal growth. Although many of the determinants (maternal height, prepregnancy weight, gestational weight gain, smoking, etc.) and early consequences (stillbirth, birth asphyxia, neonatal hypoglycaemia and hypocalcaemia, etc.) probably retain their importance across different populations, their prevalence varies considerably and so, therefore, does their public health importance as reflected by the etiological fraction (population attributable risk). Moreover, specific local factors may play an important etiological role that would justify new epidemiological studies in settings where novel

risk factors are suspected, such as maternal tobacco-chewing, exposure to indoor smoke, malaria or other tropical diseases, and HIV infection.

Similarly, although the immediate, life-threatening sequelae of severe IUGR are probably similar in all populations, the longer-term consequences for child growth, development, and performance may differ across populations because of interaction with adverse postnatal influences in disadvantaged populations, including socioeconomic and nutritional factors as well as the level of medical care available. Investigation of such environmental factors and of interventions that reduce adverse health sequelae should receive high priority in developing countries where the prevalence of SGA is high.

Anthropometric assessment of newborn infants can also be important in the context of nutritional surveillance. Periodic assessment of a population over time may reveal changes in the prevalence of SGA (or LBW as a proxy) that could signal the effects of famine, epidemic infectious disease, or other adverse environmental circumstances.

Table 12 summarizes the uses of anthropometric measurements for assessment in populations.

4.4 Selection of anthropometric indicators

4.4.1 *Gestational age*

Although the assessment of gestational age does not come under the heading of anthropometry, it is mentioned first because any size-for-age measurement requires a reasonably valid and precise measure of age. In most cases, particularly in developing countries, gestational age is assessed by calculating the number of completed weeks since the beginning of the last menstrual period (LMP). Because of potential difficulties with maternal recall and biological problems such as delayed ovulation, early non-menstrual bleeding wrongly interpreted as a period, and undetected miscarriages (i.e. without bleeding), gestational age calculated on this basis is often erroneous, particularly at the extremes of the gestational age distribution (i.e. preterm and post-term) (53).

Early (<20 weeks) ultrasonic measurement of the biparietal diameter (and/or femoral length, crown-rump length, or abdominal circumference) could be considered the “gold standard” for assessment of gestational age (53–56). Unfortunately, rigorous evaluation of this “better” assessment in randomized controlled trials has failed to reveal any benefit to maternal and perinatal health (57–60), and it cannot be recommended for routine use in all pregnant women. Other methods, such as assessment of fundal height or quickening, are often used in clinical practice to confirm (or discredit) LMP-derived gestational age. Physical or neurological examination of the newborn infant has also been commonly employed in hospitals in both developed and developing countries, although this has been found to produce significant overestimates of gestational age for

Table 12
Summary of recommendations for uses of anthropometry in populations of newborn infants

1	2	3	4	5	6	7	8
Uses: what will be done for the population?	For what purpose?	Target group and setting	What to measure and how often	Indices	Criteria for judgement (cut-offs)	Rationale for anthropometry	Other factors for interpretation
Targeting of interventions							
Improve maternal nutrition, reduce maternal smoking, provide malaria prophylaxis: to improve fetal growth	Reduce morbidity/mortality, and optimize long-term growth and performance	Newborn infants in populations with high prevalence of SGA (or LBW)	Gestational age, sex, birth weight, chest circumference	1. Birth weight for gestational age and sex	1. >20% below 10th percentile; gestational age > 5% with Z-score < -2	Size for age or size only	Validity of gestational age assessment; racial distribution
Develop facilities (including transport and other infrastructure) for care of IUGR and preterm infants		Hospital, home, or other birth setting, as soon as possible after birth	Single measurement	2. Birth weight	2. >15% below 2500 g; >2% below 1500 g		
				3. Chest circumference	3. >15% below 29 cm		

Table 12 (continued)

1	2	3	4	5	6	7	8
Uses: what will be done for the population?	For what purpose?	Target group and setting	What to measure and how often	Indices	Criteria for judgement (cut-offs)	Rationale for anthropometry	Other factors for interpretation
Assessing response to an intervention							
Determine whether size at birth (fetal growth) has improved and whether fetal or infant mortality has declined	Reduce morbidity/mortality and optimize long-term growth and performance	Newborn infants in populations with high prevalence of SGA (or LBW)	Gestational age, sex, birth weight Measured every 1-2 years	1. Birth weight for gestational age and sex 2. Birth weight	1. >20% below 10th percentile; > 5% with Z-score <-2 2. > 15% below 2500 g; >2% below 1500 g	Size for age or size only	Changes in methods of gestational age assessment or in racial distribution
Discontinue, modify, or continue intervention		Hospital, home, or other birth setting, as soon as possible after birth					

Table 12 (continued)

1	2	3	4	5	6	7	8
Uses: what will be done for the population?	For what purpose?	Target group and setting	What to measure and how often	Indices	Criteria for judgement (cut-offs)	Rationale for anthropometry	Other factors for interpretation
Ascertaining determinants of malnutrition							
Identify the determinants of IUGR	Reduce morbidity/mortality, and optimize long-term growth and performance	Newborn infants in populations with high prevalence of SGA (or LBW)	Gestational age, sex, birth weight Single measurement	Birth weight for gestational age and sex	>20% below 10th percentile; > 5% with Z-score < -2	Potential maternal or environmental determinants of IUGR	Validity of gestational age assessment; racial distribution
Improve maternal nutrition, reduce maternal smoking, provide malaria prophylaxis, modify other determinants		Hospital, home, or other birth setting, as soon as possible after birth					

Table 12 (continued)

1	2	3	4	5	6	7	8
Uses: what will be done for the population?	For what purpose?	Target group and setting	What to measure and how often	Indices	Criteria for judgement (cut-offs)	Rationale for anthropometry	Other factors for interpretation
Ascertaining consequences of malnutrition							
Determine whether IUGR impairs child health, growth, and performance	Reduce morbidity/mortality, and optimize long-term growth and performance	Newborn infants in populations with high prevalence of SGA (or LBW)	Gestational age, sex, birth weight Single measurement	Birth weight for gestational age and sex	>20% below 10th percentile; > 5% with Z-score <-2	Fetal, infant, and child mortality, morbidity, growth, and development	Validity of gestational age assessment; racial distribution
Improve infant nutrition and stimulation		Hospital, home, or other birth setting, as soon as possible after birth					

Table 12 (continued)

1	2	3	4	5	6	7	8
Uses: what will be done for the population?	For what purpose?	Target group and setting	What to measure and how often	Indices	Criteria for judgement (cut-offs)	Rationale for anthropometry	Other factors for interpretation
Nutritional surveillance							
Determine whether there is evidence of recent problems impairing fetal growth	Reduce morbidity/mortality, and optimize long-term growth and performance	Newborn infants in populations at risk for increased prevalence of SGA	Gestational age, sex, birth weight	Birth weight for gestational age and sex	>20% below 10th percentile; > 5% with Z-score < -2	Size for gestational age	Validity of gestational age assessment; racial distribution
Detect new adverse influences (e.g. famine, increased maternal smoking, malaria epidemic)			Measured every 1-2 years				

very preterm infants (61–63). Nevertheless, these methods, particularly in some of their simplified versions (64, 65), could be most useful for assessing gestational age of infants weighing ≥ 1500 g at birth in large field evaluations where other methods are not available (45).

4.4.2 **Birth weight**

The most widely used anthropometric indicator of size is birth weight, for which mechanical and electronic scales provide reasonably valid and precise readings. As discussed above, most diagnostic classifications of fetal growth for both individuals and populations are based on birth-weight-for-gestational-age.

4.4.3 **Birth length**

Birth length is another indicator of neonatal size, which can be used when birth weight is not available and which frequently provides useful additional information, since some infants with low weight-for-age may be of relatively normal length at birth. Several authors have argued that a discrepancy between weight and length deficits may be of etiological and prognostic importance. However, birth length is measured far less precisely than birth weight (32), owing to variations in posture and muscle tone among newborn infants, and considerable training is required to obtain reasonably reproducible measurements.

4.4.4 **Birth head circumference**

Birth head circumference-for-age can be measured more reproducibly than birth length (32, 66), although the presence of head moulding (particularly after a difficult or forceps-assisted delivery) may affect the measurement. As with birth length, head circumference (as an indicator of brain volume) may provide important diagnostic and prognostic information beyond that provided by birth weight alone.

4.4.5 **Proportionality indices**

The most commonly used index of neonatal body proportionality relates birth weight to birth length: Rohrer's ponderal index = 100 times the birth weight (in grams) divided by the cube of birth length (cm^3). Other proportionality indices that relate head circumference to length, for example, or chest circumference to length have been studied occasionally, but further research would be needed to show that they offer any advantage over the indicators already mentioned.

4.4.6 **Other measurements**

Skinfold thickness has been used to assess newborn adiposity, but the determinants and consequences of variation in this measurement have not been shown to differ from those of the anthropometric indices discussed

in the foregoing paragraphs. Since measurement of skinfold thickness is relatively imprecise, it is not currently recommended for purposes of routine assessment.

In developing countries, where scales may be unavailable for measuring birth weight, other anthropometric measurements – including chest, arm, thigh, and calf circumferences – have been used as proxy measures of newborn size (67-70).

Arm and chest circumferences were considered as surrogates for birth weight in a recent multicentre WHO study of 400 births (67). Both indicators demonstrated high correlation coefficients with birth weight and high positive predictive values for LBW. The use of chest circumference alone is recommended, however, because it is simpler to measure and because little additional information is provided by the arm measurement. Cut-offs of 29 and 30 cm are suggested, with <29 cm for the identification of “highly at risk” and ≥ 29 but <30 cm for “at risk” newborns. Studies in India (69, 70) have evaluated the usefulness of calf circumference of the newborn as a proxy indicator for birth weight; results showed a strong correlation between the two. The sensitivity of calf circumference for identification of LBW infants is as high as 95%, compared with 80-85% for other measurements, while specificity is similar to that of other measurements, i.e. 80%. Using a cut-off of 10 cm, it was possible to identify 98% of infants with birth weights below 2.5 kg. Thus, calf circumference can be also used as a simple screening tool for LBW.

A recently published report established interesting data on abdominal circumference at birth; small circumference was associated with raised serum concentrations of low-density lipoprotein cholesterol in adult life (71).

4.5 Reference data for size at birth

4.5.1 *Criteria for evaluating existing references*

Over the past 40 years, many investigators have proposed reference data as standards for assessment of fetal growth by clinicians, public health practitioners, and researchers. Most data have come from North America or western Europe, but have varied considerably in terms of sample size, representativeness (some being hospital- or clinic-based and others population-based), racial and socioeconomic characteristics of the population studied, sex stratification (unisex or sex-specific references), inclusion or exclusion of multiple births and of infants with major congenital anomalies or intrauterine infections known to reduce fetal growth, and methods for assessing gestational age. Unfortunately, few investigators have attempted to relate these reference data (or deviations therefrom) to subsequent infant and child mortality, morbidity, and performance.

Clear trade-offs in sample size, representativeness, and validity of gestational age estimates are involved in choosing between hospital- and population-based sources of reference data. For example, data derived from a single hospital centre are likely to be based on relatively small sample sizes that may or may not be representative of the larger population of infants to whom the references are to be applied. Differences between one hospital (or even one delivery room) and another in calibration of balances, terminal digit preference, and rounding practice may lead to small differences in birth weight distributions. On the other hand, data quality control for gestational age measurement is often better than for population-based measurements. In most older references, gestational age was based on maternal recall of LMP, whereas many recent references have modified the LMP estimates by prenatal clinical assessment, exclusion of infants with improbable birth weights for their gestational age, or, more recently, early (before 20 weeks) ultrasound measurement of the fetal biparietal diameter and/or other body dimensions.

References derived from geographically-based populations usually rely on information provided by birth certificates; these have the advantages of large sample populations and improved representativeness. The large numbers are essential for reasonably precise estimation of birth weight (and other anthropometric measurements) at very early gestational ages, particularly in the tails of the distribution (e.g. SGA and LGA). Unfortunately, quality control of assessment of gestational age is often much poorer than in studies based on a single hospital. Misleading interpretations are likely unless it is recognized that data for pre- and post-term births are less likely than data for term infants to provide valid indications of average growth *in utero*.

These trade-offs in sample size, representativeness, and validity of gestational age estimation are highlighted in discussion of specific reference data in section 4.5.3. The references discussed do not comprise a complete list, but represent a selection of those most frequently used or mentioned by clinicians and researchers, or those with one or more noteworthy characteristics.

4.5.2 **Size at birth in early gestation**

The most frequently cited early fetal growth reference is that for length (and length velocity) suggested by Tanner (41) in his textbook on human growth. Despite Tanner's statement that "between 18 and 28 weeks, there are almost no useful data", several earlier and more recent studies based on prostaglandin and hysterotomy abortions appear to provide pertinent and valid information (72-74). Tanner's curves, which he describes as "diagrammatic, based on several sources of data", include detailed information from Gruenwald (40) and suggest a slowing of length growth velocity by 20 weeks; other published studies, however, are extremely consistent in showing no fall-off in velocity of linear growth (length,

biparietal diameter) and continued exponential growth in weight from 6 or 8 weeks until well into the third trimester. Nevertheless, it is clear from ultrasound measurements of biparietal diameter and crown-heel length, as well as from anthropometric data on preterm newborns, that length reaches 70% of its mean value at term by 26–28 weeks, while only 32% of the term weight is achieved by this time. Although the evidence is fairly meagre, no large sex- or race-specific anthropometric differences are apparent in the first two trimesters.

4.5.3 **Size at birth in later gestation**

Tables 13 and 14 summarize the relevant characteristics of selected fetal growth references published in the literature. One of the earliest references for later gestation is based on all births that occurred during 1947 in Birmingham, England, for which sex, birth weight, and gestational age of the babies were known ($n = 16\,749$) (75). Because it is population-based, the original reference sample (*all* Birmingham births for 1947) is probably representative, at least of urban England at the time. Unfortunately, however, the fact that gestational age was unknown for nearly 25% of that original sample may have biased the curves upwards if those infants were undergrown relative to those included in the reference, whose gestational age was known. Moreover, gestational age was apparently based on maternal recollection of LMP. The sample size is reasonable, but the small number of births at low gestational age leads to considerable instability of the curves at those gestations. Although the curves are sex-specific, they are not restricted to singletons, and infants with congenital malformations are not excluded.

A second reference that is still in common use, particularly in the United Kingdom, is based on the weight of 46 703 singleton births in Aberdeen, Scotland, from 1948 to 1964 (76). Its advantages over the earlier reference (75) include a larger sample size, restriction to singleton births, fewer infants of unknown gestational age, and correction of uncertain gestational ages (in completed weeks) on the basis of available obstetric information. It also provides separate references according to parity. (As discussed below, it is clear that average birth weights are lower in first than in subsequent births, but less clear whether birth-weight-specific mortality, morbidity, and other health outcomes differ according to parity and therefore whether parity-specific references should be used.)

Perhaps the most widely used reference is that of Lubchenco et al. (77, 78), which is derived from a single hospital and constructed from weights, lengths, and head circumferences of 5635 liveborn Caucasian infants of white and Hispanic mothers of predominantly low socio-economic status living at moderately high altitude near Denver, Colorado, USA. Multiple births were included, but infants with incompatible birth weight/gestational age combinations were excluded. Gestational ages are based on LMP and reported to the nearest week. The appeal of this reference is twofold: the published graphs are easy for

Table 13

A comparison of selected fetal growth reference data characteristics

Reference	Location	Source	Characteristics	Exclusions	Measurements	Stratification	Gestational age	No. of subjects, <i>n</i>
Gibson & McKeown (75)	Birmingham, England	All births 1947	Urban, white	None	Birth weight	Sex	Completed weeks (LMP)	16 749
Thomson et al. (76)	Aberdeen, Scotland	90% of births 1948-1964	Urban, white	Illegitimate and multiple births, macerated stillbirths, fetal malformations	Birth weight	Sex, parity	Completed weeks (confirmed LMP)	46 703
Lubchenco et al. (77, 78)	Denver, CO, USA	1 hospital 1958-1961	High altitude, low socioeconomic status, white and Hispanic	Stillbirths, malformations affecting BW, maternal diabetes, "incompatible" BW/GA	Birth weight, length, and head circumference	None	Nearest week (LMP)	5 635
Gruenewald (81)	Baltimore, MD, USA	1 hospital late 1950s to early 1960s	[not specified]	Multiple births, malformations affecting BW	Birth weight	None	Nearest week (corrected LMP)	13 732
Usher & McLean (82)	Montreal, Canada	1 hospital 1959-1963	Urban, white	Stillbirths, multiple births, major congenital anomalies, maternal diabetes, severe IUGR	Birth weight, length, head circumference, and others	None	Nearest week (LMP)	300

Table 13 (continued)

Reference	Location	Source	Characteristics	Exclusions	Measurements	Stratification	Gestational age	No. of subjects, <i>n</i>
Babson et al. (83)	Portland, OR, USA	2 hospitals 1959-1966	Urban, white, high socioeconomic status	Stillbirths, multiple births	Birth weight	Sex	Nearest week (confirmed LMP)	39 895
Brenner et al. (73)	Cleveland, OH, USA	1 hospital 1962-1969	Urban, white (high socioeconomic status) and black (low socioeconomic status)	Antepartum stillbirths, multiple and breech births, congenital anomalies, pre-eclampsia	Birth weight	Corrections for sex, race, and parity	Nearest week (LMP)	30 722
Williams et al. (84)	California, USA	All births 1970-1976	Mixed races and socioeconomic status	None	Birth weight	Sex, non-Hispanic white, singleton vs. multiple birth	Completed weeks (corrected LMP)	2 288 806
David (85)	North Carolina, USA	All births 1975-1977	Mixed races and socioeconomic status	Stillbirths	Birth weight	None	Completed weeks (corrected LMP)	195 867
Lawrence et al. (86); Niklasson et al. (87)	Sweden	Healthy 79% of all births 1977-1981	Predominantly white	Stillbirths, multiple births, pregnancy complications affecting BW, major malformations	Birth weight, length, and head circumference	Sex	Completed weeks (confirmed LMP)	362 280

Table 13 (continued)

Reference	Location	Source	Characteristics	Exclusions	Measurements	Stratification	Gestational age	No. of subjects, <i>n</i>
Arbuckle et al. (88)	Canada	All births 1986-1988	Mixed races and socioeconomic status	Stillbirths	Birth weight	Sex, singleton vs. twin	Completed weeks (corrected maternal or physician reports)	1 110 093

Table 14

Selected fetal growth reference data: comparison of birth weight (in grams) for gestational age (GA)

Reference	Stratum ^a	GA = 28 weeks			GA = 32 weeks			GA = 36 weeks			GA = 40 weeks			GA = 42 weeks		
		10%ile	50%ile	90%ile	10%ile	50%ile	90%ile	10%ile	50%ile	90%ile	10%ile	50%ile	90%ile	10%ile	50%ile	90%ile
Gibson & McKeown (75)	B		1262 ^b		1966 ^b		3087 ^b		3559 ^b		3623 ^b		3428 ^b		3487 ^b	
	G		1230 ^b		1857 ^b		2996 ^b									
Thomson et al. (76)	B		1360	1930	2610	2380	2950	3580	2920	3490	4110	3010	3590	4220		
	G		1270	1900	2660	2270	2850	3480	2780	3340	3930	2850	3410	4020		
Lubchenco et al. (77, 78)	B	915	1205	1570	1320	1760	2280	2105	2745	3385	2700	3290	3880	2730	3310	3995
	G	870	1140	1530	1250	1675	2330	1960	2630	3335	2630	3160	3720	2630	3210	3840
Gruenewald (81)	Overall		1075 ^b		1770 ^b		2876 ^b				3270 ^b				3411 ^b	
Usher & McLean (82)	Overall		1113 ^b		1727 ^b		2589 ^b				3480 ^b				3513 ^b	
	Overall	695	1118	1691	1351	1861	2453	2173	2697	3414	2880	3448	4045	3039	3618	4288
Babson et al. (83)	Overall	770	1150	1660	1310	1810	2500	2190	2650	3290	2750	3280	3870	2830	3410	4060
Brenner et al. (73)	Overall															
Williams et al. (84)	W, non-Hispanic B	762	1184	1661	1348	1979	2727	2278	2910	3591	2944	3534	4154	3086	3665	4276
	W, non-Hispanic G	678	1102	1645	1219	1861	2619	2169	2788	3450	2817	3389	4005	2936	3513	4094

Table 14 (continued)

Reference	Stratum ^a	GA = 28 weeks			GA = 32 weeks			GA = 36 weeks			GA = 40 weeks			GA = 42 weeks		
		10%ile	50%ile	90%ile	10%ile	50%ile	90%ile	10%ile	50%ile	90%ile	10%ile	50%ile	90%ile	10%ile	50%ile	90%ile
David ^c (85)	Overall	840	1107	1360	1320	1789	2240	2200	2812	3420	2830	3380	3930	2960	3551	4170
Lawrence et al. (86); Niklasson et al. (87)	B		1152 ^b			1941 ^b			2875 ^b					3646 ^b		3810 ^b
	G		1070 ^b			1833 ^b			2769 ^b					3506 ^b		3642 ^b
Arbuckle et al. (88)	B	880	1190	1480	1460	1910	2360	2300	2830	3450	3030	3580	4170	3200	3790	4420
	G	800	1100	1420	1350	1790	2320	2210	2750	3360	2910	3430	4000	3070	3620	4200

^a B = boys, G = girls, W = white

^b Mean value.

^c Cited publication gives no tables for 10th and 90th percentiles; for these percentiles, birth weights were estimated from graphs.

clinicians to use, and birth weight/gestational age categories are related to neonatal mortality (79) and long-term morbidity (80). Despite recognition that the curves are considerably lower than the other references under discussion, because of the low socioeconomic status of the reference sample and the fetal growth-restricting effect of high altitude, they continue to be used by many clinicians and researchers.

Gruenwald (81) developed a birth weight reference from singleton births in the late 1950s and early 1960s, based on a combination of data on 1232 surviving infants obtained in an earlier study and on 12 500 consecutive births at a single hospital in Baltimore, Maryland, USA. Estimation of gestational age (to the nearest week) was based on corrected LMP; the modest sample size results in few births at early gestational ages. Gruenwald was one of the first investigators to note the apparent bimodality of the birth weight distribution in preterm infants and to attribute this to errors in gestational age assessment based on LMP. He was able to smooth the reference curves for early gestational ages by basing them on the predominant distribution at each gestational age, which suggested that the higher, second mode was the result of underestimation of true gestational age in a significant proportion of the births alleged (on the basis of LMP) to be preterm.

Usher & McLean (82) based their reference curves on liveborn, singleton, white infants at a single hospital in Montreal. Gestational age to the nearest week was estimated on the basis of LMP. The sample size was only 300, and there was no separation of the sexes. Although consecutive births were used for higher gestational ages during a single year (1959), recruitment of subjects continued for four additional years to increase the numbers of infants born at low gestational age. Despite its very small sample size, this study has the advantages of including birth length, head and chest circumference, and a variety of proportionality indices, and of relying on a single trained observer using standardized measurement techniques.

One popular American birth weight reference is based on nearly 40 000 singleton, liveborn, Caucasian infants of middle-class mothers delivering in two maternity hospitals in Portland, Oregon, USA, in 1959-1966 (83). Gestational age was calculated to the nearest week from maternal recall of LMP. Birth weight distributions at early gestational ages did not exhibit true bimodality, but were positively skewed.

A study of 30 722 singleton, liveborn infants without malformations at a single hospital in Cleveland, Ohio, USA, from 1962 to 1969 (73) provides another popular American birth weight reference. Breech deliveries and infants of mothers with pre-eclampsia were excluded. All gestational ages were based on LMP and reported to the nearest week. The sample was about half white and half black; most white, but few black, mothers were private patients. Sex- and race-specific references are not provided, but "correction factors" are given to adjust the single curve for these variables.

A more recent multiracial birth weight reference has the dual advantages of being population-based and of using an extremely large sample (more than two million births in California over the study period 1970-1976 (84)). Gestational ages are reported in completed weeks; a computer algorithm was used to adjust any that seemed suspicious (those associated with high birth weights belonging to a second mode, as previously reported (81)). Curves are presented separately for singleton boys and girls (Figs. 18 and 19) and for multiple births (Fig. 20). Race-specific curves are not presented, but data are provided for non-Hispanic whites. A distinctive feature is the availability of neonatal mortality at various gestational ages and birth weights.

In a population-based reference of all live births 1975-1977 in North Carolina, USA, a computer algorithm was again used to correct underestimated LMP-based gestational ages (in completed weeks) of preterm infants (85). However, this approach resulted in the exclusion of, rather than adjustment for, infants whose birth weights appeared to correspond to a second (higher) mode. The resulting curves are unisex and not race-specific.

A recently published Swedish reference (86, 87) is based on birth weight, length, and head circumference measurements in 362280 "healthy" Swedish infants born 1977-1981. Stillbirths and multiple births were excluded, as were infants with congenital malformations and those whose mothers had growth-inhibiting complications of pregnancy. One major advantage of this reference is that gestational age (in completed weeks) was based on LMP only when the LMP estimate was in agreement (± 2 weeks) with the results of ultrasound or other clinical assessment. Statistical techniques were used to transform the skewed distributions of birth weight into normal distributions and to derive objectively smoothed curves. However, the exclusion of infants whose mothers experienced pregnancy complications appears to have resulted in reference curves that are somewhat higher at term than the others under discussion. Moreover, there is no information on perinatal viability in the various birth-weight-for-gestational-age categories.

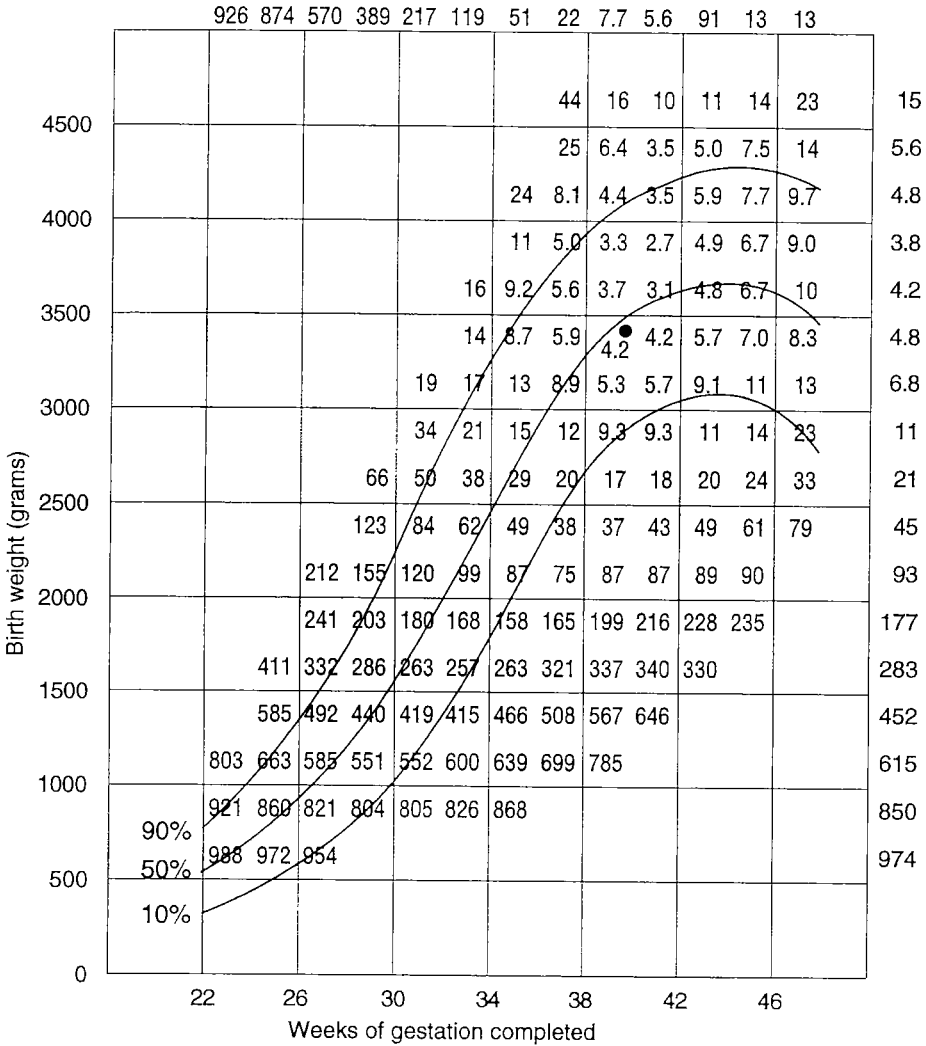
Over one million births in Canada from 1986 to 1988 have provided another recent reference (88). Gestational ages in completed weeks were reported by mothers or, in Quebec, by the attending physicians, and thus reflect ultrasound and other obstetric estimates as well as LMP. Exclusion from the analysis of infants with birth weights more than two interquartile ranges above the 75th percentile or below the 25th percentile reduced the otherwise falsely elevated 90th percentile curves for preterm infants. No statistical or other smoothing procedures were used.

Two additional references are currently under development. In Montreal, Usher and colleagues are deriving a new reference based on more recent births at the same hospital as their earlier reference (82), but using a much larger sample size and sex stratification. Most importantly, data are being restricted to infants whose gestational age, estimated by LMP, has

Figure 19

Birth weight percentiles and perinatal mortality rates (per 1000) for single male births^a

Note: For explanation, see Fig. 18.



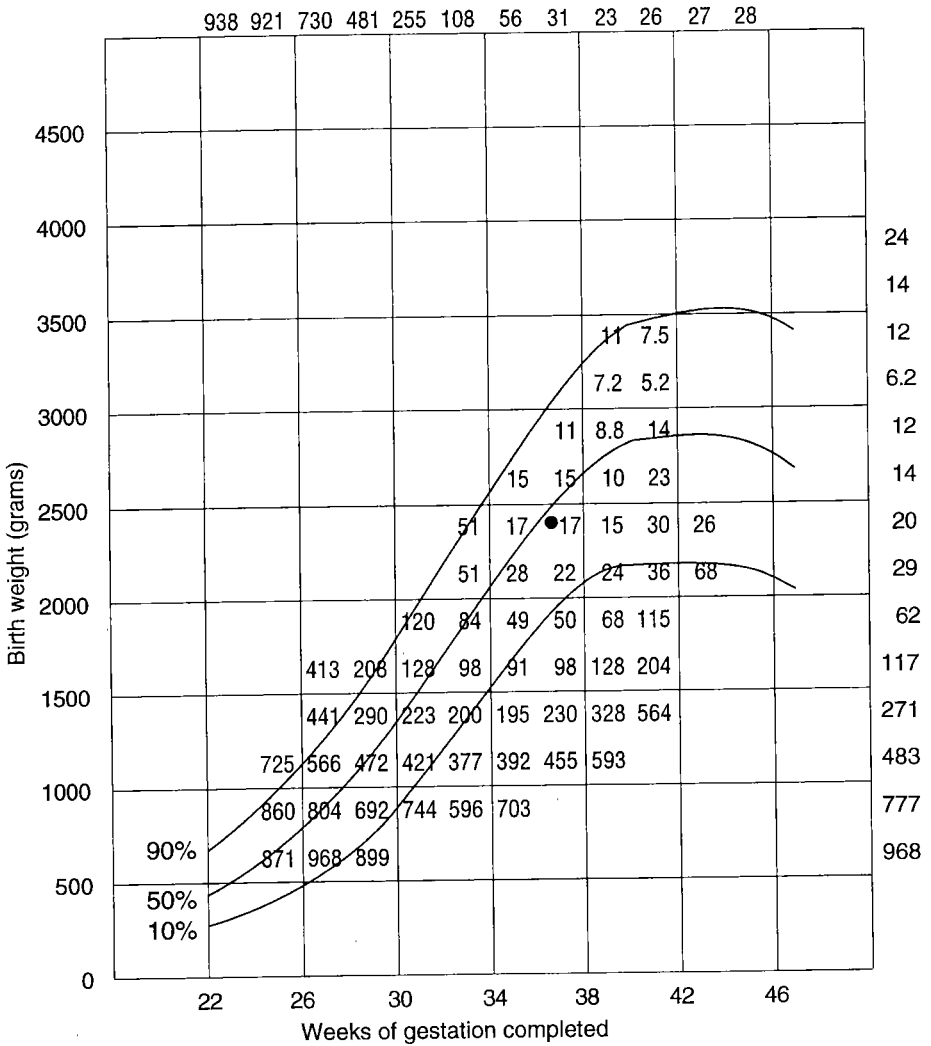
WHO 94695

^a Reproduced from reference 84 with permission from the American College of Obstetricians and Gynecologists.

Figure 20

Birth weight percentiles and perinatal mortality rates (per 1000) for multiple births^a

Note: For explanation, see Fig. 18.



^a Reproduced from reference 84 with permission from the American College of Obstetricians and Gynecologists.

been confirmed (± 7 days) by ultrasound, early in the second trimester. This reference would be most applicable to infants whose mothers are confident of their menstrual dates and those whose gestational age has been determined by early ultrasound. However, the routine use of ultrasound is rare in developing countries and may decrease in developed countries in the light of recent published clinical trials that have shown it to produce no improvement in perinatal outcomes (57-60).

A very different, but equally valuable, approach is being taken by Yip and colleagues (unpublished data) at the Centers for Disease Control in the USA. Sex-, race- and altitude-specific references are based on vital records of singleton, socially advantaged infants for the whole USA over the period 1980-1987; this is highly advantageous in terms of both sample size and representativeness. Problems with determining gestational age are dealt with by a regression approach that allows extrapolation of growth curves from newborns of higher gestational ages to those (such as preterm deliveries) whose gestational ages have been overestimated.

Despite the many differences in calendar time, population characteristics, exclusions, and methods of estimating gestational age, the similarities among the various references are more striking than their differences (Tables 13 and 14). Several distinct patterns emerge. Girls weigh less than boys, even at 28 weeks of gestation, and the difference increases with advancing gestational age. The references of Lubchenco et al. (77, 78) and Brenner et al. (73) begin to lag behind the others by 32 weeks. In the former, the lag is probably caused by the growth-restricting effect of moderately high altitude, although low socioeconomic status may also play a role (probably mediated, at least in part, by maternal cigarette smoking). (The high 10th percentile values at 28 weeks suggest a systematic overestimate of gestational age.) In the latter case, the lag is probably due to the large proportion of black infants born to mothers of low socioeconomic status. The low 10th percentile values at 28 and 32 weeks in the reference from North Carolina (85) probably reflect the algorithm-induced exclusion of higher-weight infants at those gestational ages. Birth weights in the recent Swedish (86, 87) and Canadian (88) references do not exceed those of the other tabulated references until term; higher post-term birth weights may reflect the increasing availability of obstetrically confirmed gestational ages in those countries.

4.6 Conclusions

Because the effects on fetal growth of differing sex, race, and exposure to growth-promoting and growth-inhibiting environmental influences do not appear to diverge until the late second or early third trimesters, any of the recently published early-gestation reference curves (or a meta-analysis based on several of them) could be used for developing a single fetal growth standard up to at least 24-26 weeks (72-74). In later gestation, however, the existing curves differ to some degree. The fact

that growth varies according to fetal sex and race, and maternal height, weight, parity, gestational nutrition, cigarette smoking, and numerous environmental influences does not necessarily mean that separate curves are required for each specific combination of these determinants. Indeed, the recent suggestion that fetal growth curves should be “customized” according to maternal determinants (89) simply begs the question as to whether an infant who is small for age because the mother is short is “equivalent” to an infant who is small because the mother is from India, was thin before pregnancy, or smoked cigarettes during pregnancy.

Until more is known about determinant-specific fetal and child health outcomes, the use of determinant-specific growth curves may result in “controlling” out the adverse effects of growth-inhibiting influences during gestation, and lead to the under-identification of individual infants and populations in need of intervention. Such specific curves are therefore not recommended. Moreover, regional and international comparisons are facilitated by the use of a single reference (or, at most, a small number of references) for fetal growth.

The case for sex-specific curves, however, appears unassailable. Starting at about the third trimester, female fetuses are, on average, smaller than male fetuses. All else being equal, however, the prognosis for mortality and morbidity of girls is better than that of boys born at the same weight-for-gestational-age.

Many investigators have also argued for race-specific curves. Several within-country studies have shown that, before 34–36 weeks’ gestation, black infants are larger than white infants; thereafter the pattern reverses (2, 90–92). A similar pattern was recently reported among Hawaiian, Filipino, and Japanese infants (93). However, most of these studies have relied on gestational age estimated from LMP, and it is therefore possible that some gestational ages before 36 weeks may have been underestimated in black infants, although a very recent study of native and immigrant Chinese infants with gestational age confirmed by early ultrasound shows a similar trend (Wen SW, Kramer MS, unpublished data).

Although it has not been possible to distinguish nature from nurture in explaining the differences in mean birth-weight-for-gestational-age between different racial groups, it is difficult to imagine any environmental influence that would lead to faster growth early in the third trimester and slower growth later on. Unless evidence is produced to the contrary, differences in the rate of growth at different periods of gestation seem likely to be genetically determined. Such differences appear to support the case for race-specific curves, although a multiplicity of standards would hinder comparison at the international level. As Goldenberg et al. have shown (94), differences in method of assessing gestational age, socioeconomic status, and altitude, use of singleton versus multiple births, and inclusion versus exclusion of stillbirths or

infants with congenital anomalies are probably far more responsible than race for the differences between the existing reference curves.

In summary, race-specific references should not be used where race is associated with other risk factors, such as poor nutrition or low socioeconomic status. Current knowledge does not confirm large genetic differences in birth weight among various populations and therefore does not support the use of separate, race-specific reference curves.

Further research is needed to identify those determinants of fetal growth that influence mortality, morbidity, and performance *independently* of their effects on growth. Although it is quite clear that the use of sex-specific reference curves is justifiable, additional research is needed using large populations and ultrasound confirmation of gestational age to assess whether infants of different races born at a particular weight-for-gestational-age are at substantially different risks for important health outcomes. Similar research is needed for infants born to mothers of different parity and stature, to determine whether infants who are born small because their mothers are primiparous or of short stature are at the same risk for adverse sequelae as those of equivalent size who are small because their mothers have pre-eclampsia or smoke cigarettes. Until the answers to those questions are available, the use of a single, sex-specific international reference has much to recommend it.

Although none of the reference curves published or under development meets all desirable criteria (Table 13), several appear to come close. The best are probably those from California (84), Sweden (86, 87), and Canada (88) (see Table 15). The Canadian reference is the most recent, but there are irregularities in extreme percentiles at low gestational ages because no smoothing technique was used. The Swedish reference is slightly dated, but the statistically smoothed curves and presentation of means plus and minus multiples of the standard deviations make it quite useful for the diagnosis of SGA and LGA. As this is based on a selected “healthy” population (of mothers and newborns) it could be of value when a growth chart from a population that has achieved a high level of its growth potential is needed for purposes of international comparison.

The Committee considered that the multiracial reference of Williams et al. (84) represents the best option presently available. Of the total births, 9.9% were blacks, 25.8% whites with Spanish surnames, 59.2% non-Spanish whites, and 5.1% other non-white minorities. The reference is well known, it is based on a large sample size at the lower end of the gestational age distribution, and it is comparable to many other candidate curves. More importantly, perhaps, it provides data on the relationship between birth-weight-for-gestational-age and neonatal mortality (unfortunately, not presented by sex). Thus, the criteria for diagnosis of SGA and LGA can be based on perinatal risk rather than arbitrary statistical cut-offs, as well as on considerations of cost that will ultimately determine the proportion of newborns for whom interventions can be made available (see section 2).

Table 15

Comparison of three selected reference data sets for newborn infants

Criteria	Williams et al. (84)	Lawrence et al. (86) Niklasson et al. (87)	Arbuckle et al. (88)
Years of data collection	1970-1976	1977-1981	1986-1988
Sample size	2 288 806	362 280	1 110 093
Representativeness	Population-based	Population-based, of "healthy" newborns	Population-based
Validity of gestational age	LMP and clinical estimation	LMP in agreement with ultrasound and clinical estimation	LMP, ultrasound, and clinical estimation
Smoothed for suspicious GAs	Yes	Yes	No
Race	Multiracial (9.9% black, 25.8% Hispanic whites, 59.2% non-Hispanic whites, 5.1% other)	Single-race (Swedish)	Multiracial (9% "visible minorities")
Socioeconomic status	All births	High	All births
Stratification by sex	Yes	Yes	Yes
Multiple births	Stratified	Excluded	Stratified
Congenital malformations	Included	Excluded	Included
Maternal pathologies and intrauterine infections	Included	Excluded	Included
Quality of data source	Birth registration certificate	Birth registration certificate	Birth registration certificate
Relates reference data to outcome	Yes	No	No
From a population where neonatal care and outcomes are "reasonably good"	Yes	Yes	Yes
Level of current use	Wide	Very limited	Very limited

Reference curves for singleton boys and girls, as well as multiple births, are provided in Figs 18-20.

The way in which a reference is interpreted and the clinical and public health decisions that will be based upon it are probably more important than the choice of reference. Criteria for diagnosis of SGA or LGA should be based on evidence of increased risk for mortality, morbidity, or

impaired performance. Future research should therefore attempt to identify a range of fetal growth associated with optimal long-term health outcomes, as well as ranges associated with specific adverse outcomes. These results may lead to the use of cut-offs other than the traditional 10th and 90th percentiles, these new cut-off points may vary with gestational age. New references should provide the 3rd, 5th, 10th, 15th and 25th percentiles so that health planners and practitioners can identify the portion of the population they need to work with, and should also present the information according to Z-scores (e.g. -3, -2, -1, 0 (mean), +1, +2, and +3) since the Z-score system will probably be more widely used in the future. Where management decisions for individual infants are based on their size for age, available options for intervention should be rigorously tested and shown to do more good than harm. Similarly, public health policy-makers should ensure that interventions designed to “improve” an abnormal fetal growth distribution are truly beneficial to mothers and their infants.

Based on all the above considerations, recommendations for specific activities and future research are made in section 4.7.

4.7 Recommendations

4.7.1 General

1. Any of the recently published data on early gestation can be used up to 26 weeks.
2. No “customized” curves or curves specific to particular determinants of birth weight should be used.
3. The birth-weight-for-gestational-age, sex-specific, single/twins curve developed by Williams et al. (84) is recommended. The 10th percentile of the curve should be used for the classification of SGA.
4. Race-specific curves are not currently recommended for most situations. However, the appropriateness of using race-specific reference data for some populations with low infant mortality should be evaluated.

4.7.2 For individuals

1. Percentiles of a distribution of birth-weight-for-gestational-age are recommended as the ideal indicator, with cut-offs at the 10th (SGA) and 90th (LGA) percentiles.
2. Where gestational age is unavailable, birth weight <2500 g is recommended as the LBW cut-off. However, in settings with a very high prevalence of SGA, a cut-off of <2250 g or even <2000 g can be applied to avoid overwhelming the health services. A cut-off of <1500 g is recommended as the VLBW cut-off for identifying newborn infants who should be given highest priority for referral to higher levels of care.

3. If scales are unavailable and birth weight cannot be determined, chest circumference should be measured; newborns with chest circumference <29 cm should be designated as “highly at risk” and those with circumference \geq 29 cm but <30 cm as “at risk”. It should be noted, however, that this measure has been validated only in terms of its relationship to birth weight and not to perinatal outcomes.

4.7.3 **For populations**

1. Prevalence of SGA in excess of 20% is recommended as the cut-off for triggering public health action. In the absence of information on gestational age, prevalence >15% of either LBW or chest circumference < 29 cm may be used as a proxy cut-off.
2. As indicators of the need for health facilities (rather than as a proxy for SGA), LBW prevalence exceeding 15% and VLBW prevalence exceeding 2% are recommended.
3. Birth-weight-specific fetal and infant mortality should be monitored for evaluating response to interventions.

4.7.4 **For WHO**

The Expert Committee recommends that WHO should promote the research needed in the following areas:

1. Assessment and development of fetal growth reference data suitable for international applications.
2. Birth weight coefficients of variation by gestational age.
3. Further development of the LBW/SGA databank at present organized by WHO.
4. Assistance to Member States in improving their reporting systems for data on birth-weight-for-gestational-age.
5. Producing the means and SDs (Z-scores) from the reference of Williams et al. (84).

4.7.5 **For Member States**

The Expert Committee recommends that Member States should:

1. Encourage the systematic collection of population-based data on birth-weight-for-gestational-age (or its proxy indicators).
2. Implement simplified data collection systems for all deliveries.
3. Encourage the collation of birth weight records and infant death certificates to relate birth-weight-for-gestational-age data to population-based outcomes.

4.7.6 **For future research**

The Expert Committee recommends research to:

1. Explore how risk factors that affect fetal growth influence newborn mortality, morbidity, and performance, independently of fetal growth effects.
2. Explore further the relationship between maternal morbidity and newborn anthropometric measurements.
3. Explore the association between size and proportionality at birth and long-term physical and developmental outcomes, including health conditions into adulthood.
4. Explore the association between birth-weight-for-gestational-age and newborn outcomes in developing countries.

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