Original Clinical Articles

Fetal Biometry and Intrauterine Growth Retardation

Current Concepts

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Monitoring fetal growth and detecting intrauterine growth retardation comprise a large percentage of the reasons for ultrasound examinations. Detecting intrauterine growth retardation can significantly reduce perinatal mortality and is facilitated by calculations of numerous fetal measurements.

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In the practice of obstetrics, a large percentage of referrals are for ultrasound examinations. "Size larger than dates" and "size smaller than dates" contribute a substantial proportion of reasons for fetal sonography, as detection of intrauterine growth retar-

Low-birth-weight infants have been grouped into two major categories: average size for gestational age and small for gestational age. The infants in the average-size-for-gestational-age group are born "prematurely" and perinatal mortality is chiefly related to respiratory distress syndrome. This group comprises 8% of all births. The infants who are small for gestational age constitute 4% of all births and 30% of newborn deaths; they are more mature than babies of comparable weight who are average size for gestational age.[1] Their morbidity and mortality are related to intrapartum asphyxiation, meconium aspiration, hypoglycemia, hypothermia and pulmonary hemorrhage. Ultrasonography provides a means of detecting intrauterine growth retardation by distinguishing the babies who are small for gestational age from those who are average size.

Human fetal development has four periods of growth[2]:

- *Slow growth*—0 to 15-16 weeks, less than 10 grams per week.
- *Accelerating growth*—16-17 to 26-27 weeks, 85 grams per week.
- *Maximum growth*—26-27 to 37-38 weeks, 200 grams per week.
- *Decelerating growth*—37-38 to 44 weeks, more than 70 grams per week.

The normal rate of fetal growth in an ideal case is limited by its internal constraints, which may be genetic in nature. Eventually, however, placental function is no longer sufficient to satisfy the demands of maximal fetal growth, which then decelerates.

The effect of the placenta on fetal size is well known. Thomson and co-workers showed the correlation between placental and infant birth weight.[3] Clearly, the sooner placental growth fails, the smaller the infant. Data suggest that an early insult to the placenta will cause significant damage to the organ and, therefore, to the fetus.[4] Factors associated with decreased fetal growth are listed in Table 1.[5]

Intrauterine Growth Retardation

In 1950 the World Health Organization defined "premature" infants as those with a birth weight of less than 2,500 grams. Approximately a third of these low-birth-weight infants are not premature but small for gestational age. These infants do not typically have respiratory distress syndrome and are often mature neurologically. A neonatologist relies on disparity between weight and maturity as indicated by Dubowitz's or other scoring systems to diagnose the syndrome. About a third of small-for-gestational-age infants exhibit Clifford's syndrome (postmaturity) in which "the

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ABBREVIATIONS USED IN TEXT

BPD′ = corrected biparietal diameter
SD = standard deviation

skin is parchment-like, too large for the body," the infant appears "malnourished," "having an old and worried look" and presents "the picture of recent weight loss."[6,7]

Intrauterine growth retardation has been divided into symmetric and asymmetric types. In the symmetric type, the head and body are both smaller than expected. This type occurs in about 25% of infants who have retarded growth in utero and is the result of early and often prolonged fetal insult such as maternal malnutrition, early and prolonged placental injury or limitation of the intrinsic growth potential of a fetus by a genetic or structural abnormality. Population studies in postwar Holland and Japan, and in Guatemala, have shown decreased fetal and placental size due to maternal malnutrition.[8-10] About 10% of these infants show an anatomic or genetic flaw[11] and most of those have the symmetric type. Because the insult occurs early in development, there is no brain sparing; the number of cells in brain and viscera is reduced and there is a likelihood of impaired intellectual development.[12]

The asymmetric form of growth retardation occurs in 75% of infants with intrauterine retarded growth. It is seen after 28 to 32 weeks' gestation and is the result of diminished placental-fetal blood flow, hypoxia or malnutrition (or all three). Fetal brain-sparing mechanisms are effective; cell number and size of the central nervous system are essentially normal, whereas visceral cell number and, to a degree, size are reduced. Consequently, there is head-body disproportion. When a sheep umbilical artery is ligated near term, buffering mechanisms preserve blood flow to the fetal brain although it is decreased in the viscera.[13] In humans, infants of mothers with toxemia have normal brain, kidney, pancreas and adrenal cortex whereas liver, spleen and thymus are decreased both in number of cells and cell size.[14]

A malnourished, hypoxic infant has insufficient body fat to resist hypothermia or liver mass to support adequate gluconeogenesis. Assessment of fetal lung maturity by analyzing amniotic fluid is critical for the diagnosis and management of a growth-retarded fetus that is small for gestational age. With evidence of fetal lung maturity associated with a small-for-gestational-age fetus, delivery should be attempted by 38 weeks or earlier if the clinical condition deteriorates. In one study, only 30% of cases of intrauterine growth retardation were suspected clinically. Even in retrospect, 42% of the remaining 70% had absolutely no known risk factors. In the antenatally diagnosed group there was no perinatal mortality whereas mortality was 12% in the undiagnosed group.[1] An ultrasound examination establishes the diagnosis of intrauterine growth retardation and allows a perinatologist to prepare for a possible difficult delivery.

TABLE 1.—*Factors Associated With Decreased Fetal Growth**

Fetal Factors
Sex: male fetus weighs 15 grams more than female fetus
Chromosomal abnormalities
Fetal infection—cytomegalovirus, herpes, toxoplasmosis, rubella
Multiple gestation
Medical (Vascular) Complications
Acute and chronic hypertension
Preeclampsia
Renal disease
Systemic lupus erythematosus
Cyanotic heart disease
Diabetes ≥ class D
Maternal Conditions
Low pregnancy weight, low maternal weight gain
Age younger than 17 yr or older than 35 yr
Smoking
Drug or alcohol abuse
Environmental Factors
High altitude
Toxic substances
Placental Problems
Multiple infarcts
Partial abruption
Circumvallate placenta
Hemangioma

*From Smith.[8]

Ultrasonic Assessment of Fetal Gestational Development

Assessment of fetal gestational age and weight requires careful measurement of fetal dimensions, such as biparietal diameter, occipitofrontal diameter, either abdominal diameter or abdominal circumference and crown-to-rump length or femoral lengths. Tables or calculation formulas are used to estimate gestational age as well as weight and ideal weight based on these measurements (Tables 2, 3 and 4). Although examinations are readily carried out using sector and linear array scanners, we prefer sector scanners with small transducer heads. A decreased transducer head surface allows easier handling and positioning, especially during late pregnancy. This reduces scanning and examination time. The excellent resolution of newer machines visualizes fetal organs at an early stage.

Crown-Rump Length

Different measurements have been used to assess fetal gestational age. Different fetal parts are measured and show maximal accuracy at different stages of the fetal development. An ultrasonographer will, therefore, have to decide which measurements to use for the optimal assessment of the fetal gestational age.

Whereas the gestational sac of pregnancy may be visualized by high-resolution ultrasonography as early as 4½ weeks after conception, crown-rump lengths may not be measured before six weeks' gestation (Figure 1). This measurement is useful for determination of gestational age from 7 to 14 weeks and is optimal

at nine to ten weeks within ±4.7 days (±2 standard deviation [SD]).[15] Based on tabular data, a formula to calculate gestational age has been developed by polynomial regression (Tables 2 and 4).[16,17]

Femoral Length

The femur in a fetus may be identified at as early as ten weeks' gestation with real-time ultrasonography (Figure 2). Initial studies of the fetal femur were done to detect dwarfism after a relationship between fetal development and femoral length growth had been established.[18,19] Though other bones show similar growth patterns, the femur is the easiest to measure reproducibly. Linearity of femoral growth was assumed at first; however, this has since been proved not to be the case.[18,20,21] From initial results an accuracy of predicting gestational age of ±6.7 days (±2 SD) was claimed at 12 to 23 weeks and of ±5 to 6 days at 25 to 35 weeks.[22] However, subsequent studies have shown a ±9.5 days (±2 SD) accuracy between 12 and 23 weeks and a 3- to 3½-week variability from actual gestational age can be expected between 25 and 35 weeks' gestation.[18,23] For calculation purposes, the formulas in Table 2 may be used.

Biparietal Diameter

The biparietal diameter is the mainstay for determining gestational age.[24] It is measured at the thalamic level, from leading edge to leading edge of the parietal bone (Figure 3). In one series, the biparietal diameter determination predicted 93% of deliveries within two weeks, compared with 89% by known dates and 85% with uncertain dates.[25] Still, statistical variation due to biologic factors or biparietal diameter measurement exists. Sabbagha has shown that at 17 to 26 weeks the accuracy of a single biparietal diameter measurement will be ±10 to 11 days (±2 SD), ±14 days up to 28 weeks and ±14 to 21 days at 29 to 40 weeks.[26] He has therefore suggested a system for growth-adjusted sonographic age, claiming an accuracy of ±1 to 3 days, to improve on estimates of gestational age in the second trimester.[26]

Correcting the measurement of biparietal diameter for cranial shape variations that contribute to relative biparietal diameter inaccuracy as a predictor of gestational age is an alternative to corrections of growth-adjusted sonographic age (Figure 3). The geometric relationship of a normal-shaped fetal head follows the equation[17]

TABLE 2.—*Mathematical Formulas for Calculating Gestational Age**

Measurement	*Gestational Age (weeks)*	*Confidence Level ±2 SD*
Crown-rump length (≤80 mm)	$5.3066+0.20943\times CRL-0.0021264\times CRL^2+1.1206\times 10^{-5}\times CRL^3$	± 4.7 days (at 9 to 10 wk)
Femoral length (≤37.1 mm)	$0.33437\times FEM+7.954$	± 9.5 days†
(>37.1 mm)	$0.447\times FEM+4.4$	
BPD′ (<45 mm)	$9.0067+0.07239\times BPD'+0.0039434\times BPD'^2$	±10 to 11 days (17 to 26 wk)
(≥45 mm)	$0.6047-0.16983\times BPD'+1.4334\times e^{(0.014\times BPD'+2.3626)}$	±14 days (26 to 28 wk)
		±21 days (29 to 40 wk)

Corrected BPD = BPD′ = (BPD × OFD)/1.265; if OFD is not available: BPD′ = BPD
SD = standard deviation; CRL = crown-rump length; FEM = femoral lengths; BPD = biparietal diameter; OFD = occipitofrontal diameter.

*From Greenes, 1982.[17]
†From R. A. Greenes, MD, and J. Birnholz, MD, Brigham and Women's Hospital, Harvard Medical School, Boston, written communication, December 24, 1981.

TABLE 3.—*Mathematical Formulas for Calculation of Gestational Weight (WT) and Ideal Weight (WI) for Gestational Age (GA) of 25 Weeks or Older**

Formulas	*Standard Deviation*	*Calculated Gestational Weight*
$WT=\frac{3.42928\times BPD'\times AD^2}{1{,}000}+41.218$ (grams)	±2 = ±60 grams; within 200 grams of birth weight	
$WI=-2{,}108.63+55.171\times GA+2.084\times GA^2$ (grams)	±1 = $-6{,}352.37+569.96\times GA-16.168\times GA^2+0.15478\times GA^3$	
	10th to 90th percentile limits = WI ± 1 SD × 1.28	

BPD′ = corrected biparietal diameter; AD = abdominal diameter; SD = standard deviation

*From Greenes,[17] based on tabular data by Gruenwald.[33]

TABLE 4.—*Sources for Tabular Data Relating Fetal Gestational Age With Measurements at Differing Times During Pregnancy*

Measurement Versus Gestational Age	*Time During Gestation (weeks)*	*Sources for Tabular Data*
Crown-rump length	7-14	Robinson and Fleming, 1975[15]; Hobbins and Winsberg, 1977[16]
Femoral length	12-23	Hadlock et al, 1982[18]
Biparietal diameter (BPD′)	17-term	Hobbins and Winsberg, 1977[16]; Lubchenco et al, 1972[42]
Growth-adjusted sonographic age	20-term	Sabbagha, 1978[43]
Total intrauterine volume	6-38	Gohari et al, 1977[27]

Occipitofrontal diameter (OFD) =
1.265 × biparietal diameter (BPD)

The biparietal diameter is corrected by using the formula

Corrected BPD (BPD′) = [(BPD × OFD)/1.265]½

The occipitofrontal diameter is measured at the same level as the biparietal diameter from mid echo of the frontal bone to mid echo of the occipital bone. Difficulties in measuring the occipitofrontal diameter may be encountered at the end of pregnancy due to large fetal heads and a sector scanner's limited field of view.

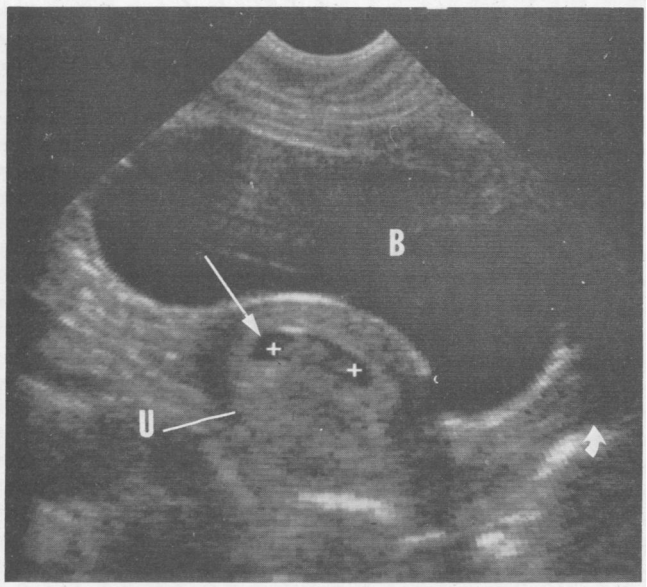

Figure 1.—Obstetrical ultrasound examination of a 26-year-old woman with positive pregnancy test. The longitudinal image through the uterus **(U)** shows a gestational sac **(arrow)** and the fetus. The crown-to-rump length (+ to +) measures 23 mm, which is compatible with a gestational age of 9 weeks 1 day. Vagina **(curved arrow)**, bladder **(B)**.

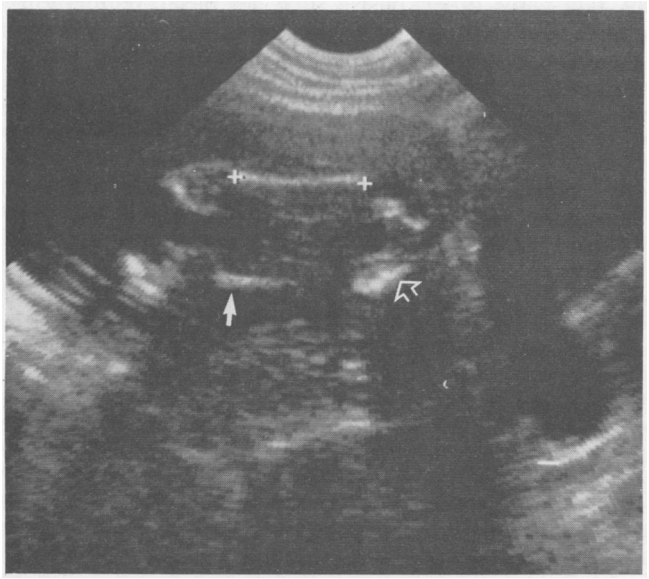

Figure 2.—Ultrasound examination of pregnancy of 20 weeks' gestation by clinical dates. Left fetal femur with measuring points (+ to +), part of right fetal femur **(arrow)** and fetal pelvis **(open arrow)** are shown. Femoral length measures 35 mm, which gives a calculated gestational age of 19.6 weeks.

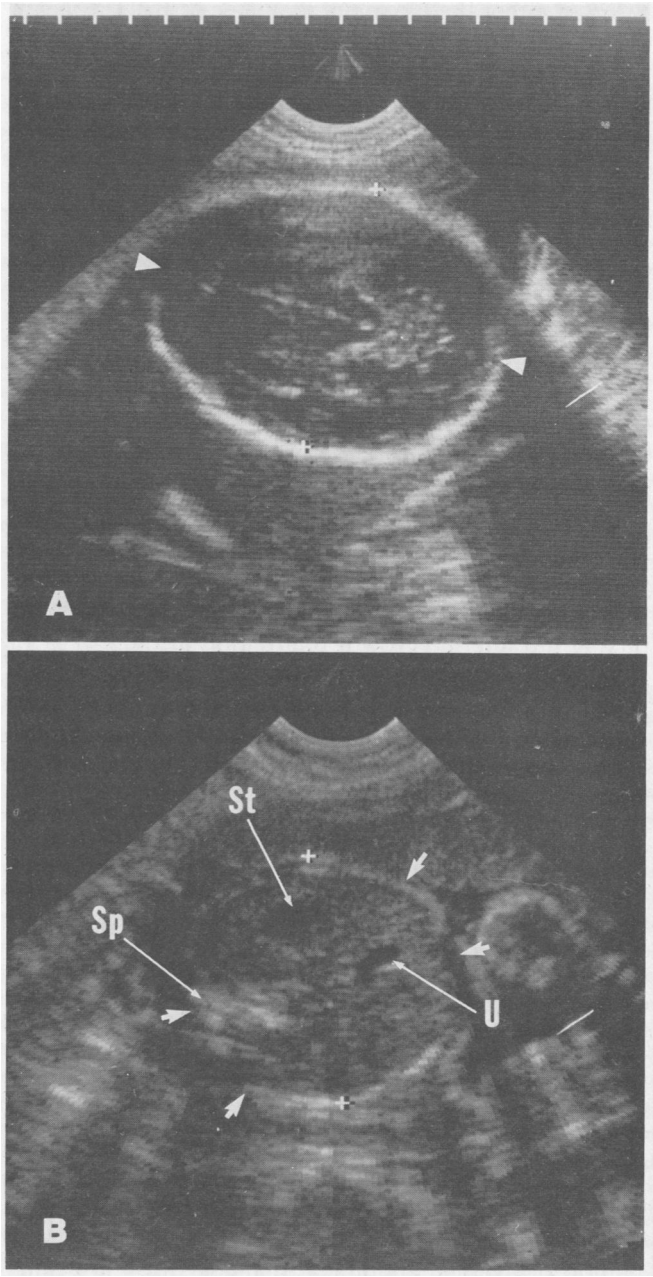

Figure 3.—**A,** Pregnancy of 36 weeks' gestation according to clinical dates. Cross-sectional image of fetal head at the level of the falx cerebri and thalamus and hypoechoic areas on each side of the falx at the level of the biparietal diameter. This diameter (+ to +) measures 82 mm and the occipitofrontal diameter (▶ to ◀) 110 mm. These measurements allow for a corrected biparietal diameter of 85 mm, which is compatible with 35 weeks' gestation. **B,** Cross-sectional image of the same fetus through the abdomen at the level of the umbilical vein **(U)** and fundus of the stomach **(St)**. The abdominal diameters (AD, + to +) with additional transverse measurements (→ to ←) for averaging purposes are shown. The abdominal diameter averages 78 mm, which allows for a calculated weight of 1,816 grams. This calculated weight is below the 25th percentile for a 35-week gestation and is highly suggestive of asymmetric retarded growth in utero.

Static scans with a larger field of view may be used to obtain the occipitofrontal diameter. In the third trimester, however, the major contributor to the imprecision of either the biparietal diameter or BPD′ appears to be the leveling off of the cranial growth curve. Determination of the gestational age by the biparietal diameter or BPD′ may be done using the tabular data by Hobbins and Winsberg[16] or calculation using formulas that are based on these tabular data (Table 2).

Total Intrauterine Volume

Fetal size can be determined by several methods. Gohari and co-workers[27] have proposed that the total intrauterine volume (TIUV) is a relatively sensitive indicator of gestational development and intrauterine growth retardation, using the following formula:

$$TIUV = 0.5233 \times L \times T \times AP$$

when L = longitudinal, T = transverse and AP = anteroposterior diameters. A high correlation between decreased amniotic fluid volume and intrauterine growth retardation was found.[28,29] Using the total intrauterine volume to identify pregnancies at risk for retarded growth in utero has, however, proved unreliable, predicting intrauterine growth retardation in only 41% of cases.[30] Inaccuracy is at least in part based on the assumption that the uterine configuration follows an ellipsoid.[31]

Fetal Weight

The actual weight of a fetus may be more accurately calculated from the BPD′ and average abdominal diameter, using a recently developed formula by Greenes[17] that improves on previously published figures[32] (Table 3). The abdominal diameter is measured at the level of the umbilical vein and the fundus of the stomach (Figure 3B). To account for an asymmetric shape of the abdominal diameter, several different diameters are measured and averaged. If the occipitofrontal diameter cannot be determined and the BPD′ cannot be calculated, the actual biparietal diameter may be used. If the abdominal circumference (AC) has been determined, then the average abdominal diameter is approximated by AC/3.1416. This approximation of average abdominal diameter does not differ significantly from that done by averaging pairs of abdominal diameters measured in the anteroposterior and transverse dimensions.[17] Weight is considered reliable and reported only for a gestational age of more than 25 weeks, showing an accuracy of ±60 grams (Table 4). The modified formula of Birnholz[32] predicts the weight estimates consistently within 200 grams of actual birth weight.

Ideal weight, as predicted on the basis of gestational age, is given by the formula adapted from data published by Gruenwald (Table 3).[33] This computation is considered reliable for a gestational age in the range of 25 to 44 weeks.

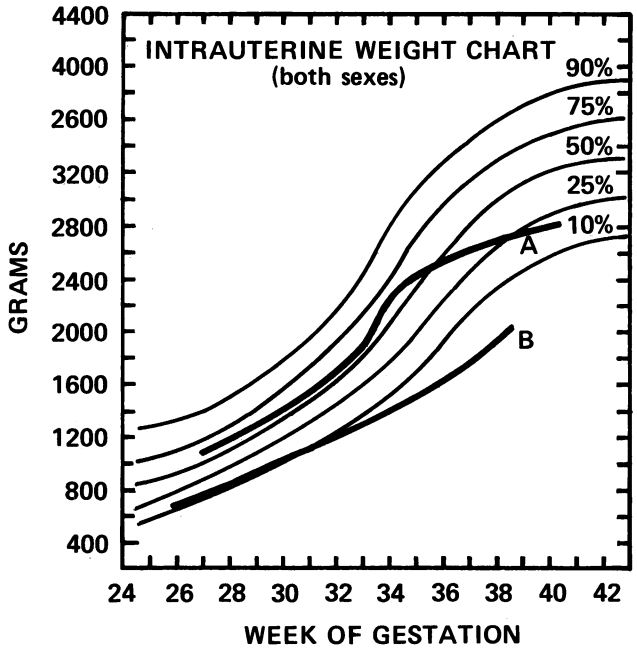

Figure 4.—Intrauterine weight development chart, based on data by Lubchenko, with growth profiles of asymmetric **(A)** and symmetric **(B)** retardation of growth in utero.

Growth Analysis and Ultrasonic Determination of Intrauterine Growth Retardation

Assessment of the appropriateness of fetal growth is based on comparison of the calculated gestational age and weight, estimated on the basis of measurements, with the predicted gestational age and ideal weight determined on the basis of the last menstrual period, the estimated date of confinement, previous ultrasound studies using crown-rump length, femoral lengths, biparietal diameter or clinical examination or, in fact, any other basis, such as basal temperature charts and the like. A physician selects the appropriate measure to use for gestational age (Table 4), from which are calculated the ideal weight for that age and the 10th and the 90th percentile limits (Figure 4). The actual weight estimated from fetal measurements is then compared with the ideal weight using formulas or by plotting on a weight-growth chart.[34] If the weight is below the 10th percentile, the possibility of retarded growth is considered. Such assessment of fetal growth is one of the most important purposes of routine obstetrical ultrasonography because, as Goldstein and Peckman[35] have shown, low-birth-weight fetuses are at the greatest risk for antenatal and neonatal mortality. Detection and optimal management of both large-for-gestational-age fetuses and especially small-for-gestational-age fetuses depend primarily on the use of ultrasound. Growth patterns of normal twin pregnancies are similar to those of single gestations at all stages. Biparietal diameter charts and formulas can, therefore, be used in both types of pregnancies. An intratwin biparietal diameter discordance of more than 5 mm suggests abnormal development. A high incidence of twin-to-twin transfusion with its associated high mor-

tality and morbidity can be expected if such a discordance is found before 30 weeks' gestation.[36]

Symmetric retardation of growth in utero is often difficult to determine, and is suggested when ultrasound dating is earlier than known or suspected dates (Figure 4). The biparietal diameter and weight should be plotted on a nomogram during follow-up examinations at frequent (two to four weeks) intervals to determine the rate of fetal growth. Serial head measurements alone (without weight determination) may not be sufficiently sensitive to detect retardation of growth. At the end of pregnancy, head growth is slow. Campbell could not detect 20% of cases of intrauterine growth retardation with serial cephalometry.[37] Some feel that the risk for growth retardation in a fetus with a biparietal diameter below the 25th percentile is 50%.

Asymmetrically retarded growth in utero is more common and is rare before 32 weeks.[38] When head-body disproportion is recognizable (a biparietal diameter of 70 mm at 28 weeks), the abdominal diameter will begin to exceed the biparietal diameter (Figure 3). The technique for detection involves simple plotting of weight and gestational age against ideal weight (Figure 4). Because a fetus should normally remain within a rough percentile group during development, flattening of a growth curve is also highly suggestive of intrauterine growth retardation. Actual weight gain will be less than expected for a normal fetus. Follow-up examinations are important; intervals of examination should vary according to the clinical situation. If a fetus appears marginally small, reexamination in two to three weeks is recommended. Later, during the third trimester or if there is a bona fide intrauterine retardation of growth, examinations every two weeks are necessary.

Ratios of head to abdominal measurements have been used to distinguish asymmetric from symmetric growth retardation.[39,40] However, these studies are difficult to reconcile with one another because head measurement is based on circumferences, abdominal measurements on ratios of areas. Even when appropriate corrections are made, the measurements do not appear consistent. In addition, the mean normal head-to-abdomen ratios given by these studies do not appear to correspond well with those that were actually found in fetuses whose estimated weights by Birnholz's formula are close to the ideal weights for their gestational ages.[17] Schmidt found a 42% accuracy in biparietal-to-abdominal diameter ratio in detecting retarded intrauterine growth and 72% accuracy using head-to-thorax circumference ratio. He reports on a preselected patient population, however, and does not use a double-blind scheme.[41] Therefore, the following alternative approach has been recommended to assess the nature of intrauterine growth retardation when a small-for-gestational-age fetus is detected: if the weight is within normal range for the ideal weight when the gestational age is based on the BPD′, then the symmetric form of intrauterine growth retardation is presumed; otherwise, the asymmetric form is presumed.[17]

In the past, the biparietal diameter was simply measured and the gestational age was read from a table. This approach is often insufficient to evaluate symmetric or asymmetric retardation of growth in utero.[17,26] Studies using a simple quotient between head and thoracoabdominal measurements show slightly better results but are less accurate and reproducible. Calculation of gestational age and weight from BPD′, biparietal, occipitofrontal and abdominal diameters has proved to be much more accurate and helpful.[32] A routine ultrasonic report should contain certain statements regarding the calculated gestational age and weight, including a statement of their appropriateness according to clinical date—that is, relative to growth retardation. When in doubt or in the case of abnormal findings, a repeat examination is indicated. The collected data may best be sequentially plotted on intrauterine head growth and intrauterine weight-growth charts, as developed by Lubchenco and colleagues.[34,42]

Calculations are conveniently done with a small programmable calculator. A computer reporting system has recently been developed that does all the calculations based on the above formulas or whichever formulas a physician decides to use. This computer system can also generate a complete report including statements regarding fetal number and position, activity, anatomic survey, heartbeat, amniotic volume and placental position and appearance. Interpretation of measurements and observations regarding fetal status are preprogrammed.[17]

Conclusion

All obstetric ultrasound examinations should be done with the most advanced equipment—that is, high-resolution real-time ultrasound—to allow detailed anatomic observations and measurements of different biometric factors important for the assessment of fetal gestational age and growth rate. In early pregnancy, the crown-rump length should be measured, which shows the highest accuracy around nine to ten weeks' gestation. Between 12 and 23 weeks' gestation femoral measurement best predicts gestational age. Thereafter, the biparietal diameter, in conjunction with the occipitofrontal diameter, expressed in BPD′, appears to be a reliable indicator of the gestational age during the second and the beginning of the third terms. About a three-week inaccuracy has to be accepted during the third trimester. The weight is reliably calculated within 60 to 200 grams during the second and third trimesters. Besides gestational age, weight should be determined and reported in each examination done after 25 weeks' gestation. It represents the most reliable method for determination of retardation of growth in utero. In case of normal development, an important baseline measurement for later examinations will be established. Identification of intrauterine growth retardation will help to significantly reduce mortality in small-for-gestational-age newborns.

REFERENCES

1. Mann L, Tejani N, Weiss R: Antenatal diagnosis and management of the small-for-gestational-age fetus. Am J Obstet Gynecol 1974 Dec; 120:995-1004

2. Sozoki K: Fetal growth and intrauterine environment, *In* Notake Y, Suzuki S (Eds): Biologic and Clinical Aspects of the Fetus. Baltimore, University Park Press, 1977, pp 18-64

3. Thomson AM, Billewicz WZ, Hytten FE: The weight of the placenta in relation to birthweight. J Obstet Gynaecol Br Comm 1969 Oct; 76:865-872

4. Winick M: Cellular growth of the placenta as an indicator of abnormal growth, chap 5, *In* Adamson K (Ed): Diagnosis and Treatment of Fetal Disorders. New York, Springer Verlag, 1969, pp 83-101

5. Miller HC, Merritt TA: Abnormal factors affecting fetal growth, chap 3, Fetal Growth in Humans. Chicago, Year Book Publishers, 1979, pp 25-30

6. Battaglia FC: Intrauterine growth retardation. Am J Obstet Gynecol 1970 Mar; 106:1103-1116

7. Clifford SH: Postmaturity with placental dysfunction. J Pediatr 1954 Jan; 44:1-13

8. Smith LA: Effects of maternal undernutrition upon newborn infants in Holland (1944-45). J Pediatr 1947 Mar; 30:229-243

9. Gruenwald P, Funakawa H, Mitani S, et al: Influence of environmental factors on foetal growth in man. Lancet 1967 May; 1:1026-1031

10. Dayton D: Cellular changes in the placentas of undernourished mothers in Guatemala. Pediatr Proc 1969; 28:488-504

11. DeVore G, Hobbins JC: Fetal growth and development: The diagnosis of intrauterine growth retardation, chap 7, *In* Hobbins JC (Ed): Diagnostic Ultrasound in Obstetrics. New York, Churchill Livingstone, 1979, pp 81-94

12. Barker DJP: Low intelligence—Its relation to length of gestation and rate of fetal growth. Br J Prev Soc Med 1966 May; 20:58-66

13. Assali NS, Brinkman CR: The role of circulatory buffers in fetal tolerance to stress. Am J Obstet Gynecol 1973 Nov; 117:643-653

14. Naeye RL: Abnormalities in infants of mothers with toxemia of pregnancy. Am J Obstet Gynecol 1966 Mar; 95:276-283

15. Robinson HP, Fleming JE: A critical evaluation of sonar crown-rump lengths measurements. Br J Obstet Gynaecol 1975 Sep; 82:702-710

16. Hobbins JC, Winsberg F: Ultrasonography in Obstetrics and Gynecology. Baltimore, Williams & Wilkins, 1977, pp 159-171

17. Greenes RA: OBUS: A microcomputer system for measurement, calculation, reporting, and retrieval of obstetric ultrasound examinations. Radiology 1982 Sep; 144:879-883

18. Hadlock FP, Harrist RB, Deter RL, et al: Fetal femur length as a predictor of menstrual age: Sonographically measured. AJR 1982 May; 138:875-878

19. Jeanty PH, Kirkpatrick C, Dramaix-Wilmet M, et al: Ultrasonic evaluation of fetal limb growth. Radiology 1981 Jul; 140:165-168

20. Queenan JT, O'Brien GD, Campbell S: Ultrasound measurement of fetal limb bones. Am J Obstet Gynecol 1980 Oct; 138:297-301

21. O'Brien GD, Queenan JT, Campbell S: Assessment of gestational age in the second trimester by realtime ultrasound measurement of the femur length. Am J Obstet Gynecol 1981 Mar; 139:540-545

22. Yeh HN, Barron B, Bracero L: Ultrasound measurement of the femur length as an index of fetal growth and development. Proceedings of the 26th Annual Meeting of the American Institute of Ultrasound in Medicine. Oklahoma City, American Institute of Ultrasound in Medicine, 1981, pp 35-62

23. Hohler CW, Quetel TA: Fetal femur length: Equations for computer calculation of gestational age from ultrasound measurements. Am J Obstet Gynecol 1982 Jun; 143:479-481

24. Hadlock FP, Deter RL, Harrist RB, et al: Fetal biparietal diameter: Rational choice of plane of section for sonographic measurement. AJR 1982 May; 138:871-874

25. Campbell S, Beard RW, Nathanielsz PW: Fetal growth, chap 15, *In* Beard RW, Nathanielsz PW (Eds): Fetal Physiology and Medicine. Philadelphia, WB Saunders, 1976, pp 271-301

26. Sabbagha RE: Fetal age, chap 4, Ultrasound in High-Risk Obstetrics. Philadelphia, Lea & Febiger, 1979, pp 29-45

27. Gohari P, Berkowitz KL, Hobbins JC: Prediction of intrauterine growth retardation by determination of total intrauterine volume. Am J Obstet Gynecol 1977 Feb; 127:255-263

28. Carroll B: Ultrasonic features of pre-eclampsia. J Clin Ultrasound 1980 Dec; 8:483-488

29. Manning PA, Hill LM, Platt LD: Qualitative amniotic fluid determination by ultrasound—Antepartum detection of intrauterine growth retardation. Am J Obstet Gynecol 1981 Feb; 139:254-258

30. Chinn DH, Filly RA, Callen PW: Prediction of intrauterine growth retardation by sonographic estimation of total intrauterine volume. J Clin Ultrasound 1981 Apr; 9:178-179

31. Jones TB, Price RR, Gibbs SJ: Volumetric determination of placental and uterine growth relationship from B-mode ultrasound by serial area-volume determinations. Invest Radiol 1981 Mar-Apr; 16:101-106

32. Birnholz JC: Ultrasound characterization of fetal growth. Ultrasonic Imaging 1980 Sep; 2:135-149

33. Gruenwald P: Intrauterine growth, chap 1, *In* Stave U (Ed): Perinatal Physiology. New York, Plenum Medical Book, 1978, pp 1-18

34. Lubchenco LO, Hanmann C, Boyd E: Intrauterine growth in length and head circumference as estimated from live births at gestational ages from 26-42 weeks. Pediatrics 1966 Mar; 37:403-408

35. Goldstein H, Peckham C: Birthweight, gestation, neonatal mortality and fetal development, *In* Roberts DF, Thomson AM (Eds): The Biology of Human Fetal Growth. London, Taylor and Francis, Ltd, and New York, Halsted Press, 1976, pp 80-107

36. Crane JP, Tomich PG, Kopta M: Ultrasonic growth patterns in normal and discordant twins. Obstet Gynecol 1980 Jun; 55:678-683

37. Campbell S, Dewhurst CJ: Diagnosis of the small-for-dates fetus by serial ultrasonic cephalometry. Lancet 1971 Nov; 2:1002-1006

38. Gruenwald P: Chronic fetal distress and placental insufficiency. Biol Neonate 1963 May; 5:215-265

39. Campbell S, Thomas A: Ultrasound measurement of the fetal head to abdomen circumference ratio in the assessment of growth retardation. Br J Obstet Gynaecol 1977 Mar; 84:165-174

40. Varina TR, Taylor H, Bridges C: Ultrasound assessment of fetal growth. Br J Obstet Gynaecol 1979 Aug; 86:623-632

41. Schmidt W, Hendrik HJ, Gauwerky J, et al: Diagnose der intrauterinen Wachstumsretardierung durch die erweiterte Ultraschallbiometrie. Geburtshilfe Fraunheilkd 1982 Jul; 42:543-548

42. Lubchenco LO, Searls DT, Brazie JV: Neonatal mortality rate: Relationship to birth weight and gestational age. J Pediatr 1972 Oct; 81:814-822

43. Sabbagha RE, Hughey M, Depp R: Growth adjusted sonographic age—A simplified method. Obstet Gynecol 1978 Mar; 51:383-386