Estimation of Fetal Weight

NEED FOR ANTENATAL FETAL WEIGHT ESTIMATION

Both low birth weight and excessive fetal weight at delivery are associated with an increased risk of newborn complications during labor and the puerperium. The perinatal complications associated with low birth weight are attributable to preterm delivery, intrauterine growth restriction (IUGR), or both. For excessively large fetuses, the potential complications associated with delivery include shoulder dystocia, brachial plexus injuries, bony injuries, and intrapartum asphyxia. The maternal risks associated with the delivery of an excessively large fetus include birth canal and pelvic floor injuries and postpartum hemorrhage.

The occurrence of cephalopelvic disproportion is more prevalent with increasing fetal size and contributes to both an increased rate of operative vaginal delivery and cesarean delivery for macrosomic fetuses compared with fetuses of normal weight. Depending on many factors, the optimal range for birthweight is thought to be 3000-4000 grams.

Limiting the potential complications associated with the birth of both small and excessively large fetuses requires that accurate estimation of fetal weight occur in advance of delivery. A review of the methods that can be used for the accurate estimation of fetal weight is the focus of this article.

STANDARD FETAL GROWTH CURVES

Mean birth weight has been described as a function of gestational age. Several studies subdivide such results into those that apply to women of different races, male versus female fetuses, and primiparous versus multiparous gravidas. Standard fetal growth curves are useful for estimating the range of expected fetal weight at any particular gestational age. However, in order for the growth curves to be useful, all such tables presuppose that the gestational age of the fetus is established properly. Without adequate gestational dating, the standard fetal growth curves cannot be interpreted successfully.

The principal limitations of standard fetal growth curves that are derived from population-based studies are as follows:

- They apply only to fetuses that are of normal size for gestational age and not to those with significant (and potentially pathologic) growth abnormalities.
- The standard deviation (SD) associated with the mean birth weight estimate at any particular gestational age is wide, typically exceeding 450-500 grams.
- The gestational age of the fetus must be known with a high degree of certainty to use the growth curves with any degree of reliability.

In general, these growth curves can be expected to apply to large populations of pregnant women who have well-dated pregnancies, but the limits of their predictive accuracy make them less than ideal tools for estimating fetal weight for individual patients. The range of birth weights at any particular gestational age spans a wide array of values, with 95% confidence intervals of more than 1600 grams (3 lb 8 oz) at term. In addition, fetal growth curves are the most inaccurate at the extremes of fetal growth.
weight deviation (ie, women carrying fetuses that are either growth restricted or macrosomic).

**NORMAL RANGE FOR HUMAN BIRTH WEIGHT**

**Deviations in fetal weight**

The diagnosis of deviations in fetal weight presupposes that the reference range for fetal weight at each gestational age is established. Before a reference range for human birth weight can be established properly, the gestational age at which human births occur must first be defined. This issue is of primary importance because fetal weight increases rapidly once the second trimester of pregnancy is reached.

**Variations in fetal weight**

The reference range of gestational age for spontaneous delivery in human pregnancies is well accepted as 280 days (40 wk) from the first day of the last normal menstrual period (ie, 266 d after fertilization). Because fewer than 3% of births occur precisely at 40 weeks’ gestation and the SD for term pregnancies is 1 week, the normal range of term birth weight is typically referenced to the mean birth weight for pregnancies delivered at 38-42 weeks’ gestation (ie, mean term gestational age ±2 SD). During this 4-week period, the average fetus gains approximately 12.7 ±1.4 g/d, with a difference of ±0.3 g/d depending on the sex of the fetus. The average birth weight during this period varies significantly, depending on maternal race and ambient elevation.

**Birth weights of women from different racial groups**

When median term birth weights of newborns from women of different racial groups are compared, significant differences are apparent. In a study that compared the median birth weight for 17,347 newborns of white and black women of low socioeconomic status in the United States from 1959-1966, the median birth weight at 40 weeks’ gestation for live-born white male singletons was 3350 grams compared to 3210 grams for black male neonates (difference of 140 g). A similar difference in median birth weight was also evident among female offspring, with white female newborns at 40 weeks’ gestation having a median birth weight of 3210 grams and black females having a median birth weight of 3100 grams (difference of 110 g).

**Best method to determine the reference range for term birth weight**

Perhaps the best method of defining the reference range for term birth weight is to examine fetal weights at the two extremes of the reference range birth weight (ie, 5th-10th percentile at the lower end and 90th-95th percentile at the uppermost extent). In the United States, a recent comprehensive study of 3,134,879 live births from 1991 showed that from 38-42 weeks' gestation, the fifth percentile of birth weight was 2543-2764 grams, the 10th percentile was 2714-2935 grams, the 90th percentile was 3867-4098 grams, and the 95th percentile was 4027-4213 grams.

Perhaps the best method for establishing the reference range of term birth weight is to define the point at which newborns begin to vary significantly from the mean with respect to their overall prevalence of perinatal complications and perinatal death. Even within neonatal groupings that are well matched for gestational age, poor perinatal outcomes occur most frequently in fetuses who are born with weights at the extreme ends of the birth weight range (ie, <10th percentile and >90th percentile ranks for each gestational age). Using this approach to establish a criterion, the reference range for term birth weight can be defined as approximately 3250 grams at the lower limit to
approximately 4250 grams as an upper limit, or 3750 ±500 grams (8 lb 4 oz ±1 lb 2 oz).

Recently, a British cohort study of 3599 neonates of reference range weight during 1946 suggested that increasing term birth weight was correlated positively with cognitive ability later in life. This result persisted even after neonates of low birth weight weighing less than 2500 grams were eliminated from analysis, such that all of the remaining neonates weighed 2500-5000 grams.

DEFINITIONS OF DEVIATIONS IN FETAL GROWTH

Fetal weight categories

Fetal weight may be characterized as falling into 1 of 3 categories, as follows:

- Reference range (generally defined as between 10th and 90th percentile for gestational age)
- Small for gestational age (<10th percentile)
- Large for gestational age (>90th percentile)

Until a fetus is delivered, only those methods that can evaluate fetal size in utero are of any value in assessing into which of these 3 categories the fetus will fall. Depending on the precise nature of the patient population used for establishing the birth weight percentile ranks, these standards may be misleading if applied to other sets of gravidas. For instance, if standard birth weight curves for white women are applied inappropriately to black gravidas, a higher proportion of black women would appear to have birth weights below the 10th percentile compared to a matched group of white women.

Complications

The term low birth weight has been used to refer to different fetal weight ranges by different authors during different eras. Whereas substantially excessive neonatal morbidity and mortality was once associated with newborns weighing 2000-2500 grams, adverse neonatal outcomes attributable to low birth weight have been impacted successfully by the more modern neonatal care that has become available during the last quarter century. One classification scheme for the modern era that is based on fetal weight alone divides underweight newborns into 3 distinct categories. Using this schema, newborns can be categorized according to their risk for neonatal complications, as follows:

- Low birth weight (1501-2500 g)
- Very low birth weight (1001-1500 g)
- Extremely low birth weight (500-1000 g)

Subclassifications within these 3 weight groups are possible, according to the overall incidence of neonatal morbidity and mortality within each group and the gestational age within these different categories (especially within the very low birth weight and extremely low birth weight groups). Successfully classifying fetuses within each of these 3 broad categories with improved accuracy in advance of delivery can potentially aid in the prediction and possible avoidance of neonatal complications for underweight newborns.

Fetal macrosomia
The term fetal macrosomia denotes a fetal size that is too large. Ideally, this designation should be referenced to the mean of fetal and maternal dimensions within a given population, but, rather arbitrarily, it has been defined previously as a birth weight greater than 4000 grams, greater than 4100 grams, greater than 4500 grams, or greater than 4536 grams for all gravidas, depending on author and era. When fetal macrosomia is considered a birth weight greater than 4000 grams (8 lb 13 oz), it affects 2-15% of all gravidas, depending on the racial, ethnic, and socioeconomic composition of the population under study.

FACTORS CONTRIBUTING TO DIFFERENCES IN FETAL WEIGHT

Many factors, both endogenous and extrinsic, can influence fetal weight. These include racial, physiologic, genetic, pathologic, and environmental factors, to include the following:

- Maternal factors (eg, race, stature)
- Environmental factors (eg, altitude, availability of adequate nutrition)
- Physiologic factors (eg, altered glucose metabolism, microvascular integrity)
- Pathologic factors (eg, hypertension, uterine malformations)
- Complications of pregnancy (eg, gestational diabetes mellitus, preeclampsia)

Gestational age at delivery

Gestational age at delivery is the most significant single determinant of newborn weight. Preterm delivery constitutes the single largest cause for low birth weight in newborns. Other potential causes for low birth weight can be attributed collectively to IUGR (previously termed intrauterine growth retardation). Causes include intrauterine infections, congenital syndromes, genetic abnormalities, and chronic uteroplacental insufficiency.

Maternal race

Another major determinant of fetal weight is maternal race. Black and Asian women have smaller fetuses compared to white women when appropriately matched for gestational age. Not surprisingly, white gravidas show a significantly higher prevalence of fetal macrosomia compared with black and Asian gravidas, and nonwhite gravidas have a significantly higher prevalence of small-for-gestational-age newborns compared to white women.

Other maternal and pregnancy-specific determinants

After gestational age and maternal race, 6 other major maternal and pregnancy-specific determinants of birth weight are relevant, which include the following:

- Maternal height
- Obesity
- Pregnancy weight gain
- Age
- Parity
- Fetal sex

Taken together, these measurable demographic factors can help explain more than one third of the variance in term birth weight. By comparison, paternal factors are only minimally important in determining fetal weight. Paternal height is the only routinely
measured paternal demographic variable that has significant influence on fetal weight, but it accounts independently for less than 2% of the variance. Fetal sex is associated significantly with birth weight; female fetuses are known to be smaller than male fetuses when matched for gestational age. Although fetal sex is a significant predictor of fetal weight, it accounts independently for less than 2% of the variance.

**Diabetes mellitus**

Uncontrolled maternal diabetes mellitus is a condition commonly associated with excessive fetal weight. Glucose is the primary substrate used by fetuses for growth. When maternal glucose levels are excessive, abnormally high rates of fetal growth can be expected. Even in women without frank diabetes mellitus, elevated glucose screening test values in pregnancy predispose to increasing birth weight. Because of the stringent glucose criteria now used to monitor and treat women with frank diabetes during pregnancy, the group of women now most at risk for fetal macrosomia are those who are unmonitored and untreated who have abnormal 1-hour glucose screening test results during pregnancy and subsequently have normal 3-hour glucose tolerance tests with a single abnormal value indicative of only mild glucose intolerance.

**Other maternal illnesses and complications of pregnancy**

Several maternal illnesses and complications of pregnancy are associated with decreased birth weight. The most common associated illnesses are chronic maternal hypertension and preeclampsia. Some intrauterine infections (eg, viral, parasitic, bacterial) are associated with small-for-gestational-age fetuses. In addition, several major environmental factors can have an adverse effect on fetal size, with the 2 chief among these being high altitude and cigarette smoking.

**Diagnosis of deviations in fetal weight**

**Techniques for estimating fetal weight**

All the currently available methods for assessing fetal weight in utero are subject to significant predictive errors. These errors are the most clinically relevant at the 2 extremes of birth weight (eg, those <2500 g who are also more likely the products of premature deliveries and those >4000 g who are at risk for the complications associated with fetal macrosomia).

**Tactile assessment of fetal size:** The oldest technique for assessing fetal weight involves the manual assessment of fetal size by the obstetrician. Worldwide, this method is used extensively because it is both convenient and virtually costless; however, it has long been known as a subjective method that is associated with significant predictive errors.

**Clinical risk factor assessment:** Quantitative assessment of clinical risk factors has previously been shown to be valuable in predicting deviations in fetal weight. In the case of fetal macrosomia, the odds ratios for the presence of 12 clinical risk factors are shown in Table 4.

Clinical Risk Factors for Fetal Weight Greater Than 4000 Grams
### Estimation of Fetal Weight

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Percent of Patients with Macrosomic Fetuses with Presence of Risk Factors</th>
<th>Odds Ratio for Presence of Risk Factors Compared with Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maternal diabetes mellitus†</td>
<td>2-30%</td>
<td>1.6-3</td>
</tr>
<tr>
<td>Abnormal 50-g GST‡ (without GDM§)</td>
<td>15-27%</td>
<td>1.8-2.1</td>
</tr>
<tr>
<td>Abnormal single 3-h GTT‖ value</td>
<td>8-34%</td>
<td>1.9-2.4</td>
</tr>
<tr>
<td>Prolonged gestation (&gt;41 wk)</td>
<td>19-35%</td>
<td>5.5-5.9</td>
</tr>
<tr>
<td>Maternal obesity</td>
<td>16-37%</td>
<td>1.7-4.4</td>
</tr>
<tr>
<td>Pregnancy weight gain &gt;35 lb</td>
<td>21-56%</td>
<td>1.5-2.2</td>
</tr>
<tr>
<td>Maternal height &gt;5 ft 3 in</td>
<td>20-24%</td>
<td>1.5-2</td>
</tr>
<tr>
<td>Maternal age &gt;35 y</td>
<td>12-21%</td>
<td>1.3-2.3</td>
</tr>
<tr>
<td>Multiparity</td>
<td>64-93%</td>
<td>1.2-1.3</td>
</tr>
<tr>
<td>Male fetal sex</td>
<td>62-69%</td>
<td>1.2-1.4</td>
</tr>
<tr>
<td>White maternal race</td>
<td>45-94%</td>
<td>1.1-2.5</td>
</tr>
</tbody>
</table>

† All classes, including gestational diabetes mellitus; the wide range of values reflects differences among studies in the following: (1) criteria used for screening and diagnosis, (2) prevalence of disease in the populations under study, and (3) success of glucose control during pregnancy.

‡ GST - One-hour 50-gram oral glucose screening test
§ GDM - Gestational diabetes mellitus
‖ GTT - Three-hour 100-gram oral glucose tolerance test

**Maternal self-estimation:** A third method for estimating fetal weight is via maternal self-estimation. Perhaps surprisingly, these maternal self-estimations of fetal weight in multiparous women show comparable accuracy in some studies to clinical palpation for predicting abnormally large fetuses.

**Obstetric ultrasonography:** The most modern method for assessing fetal weight involves the use of fetal measurements obtained via obstetric ultrasonography. The advantage of this technique is that it relies on linear and/or planar measurements of intrafetal dimensions that are definable objectively and should be reproducible. Early expectations that this method might provide an objective standard for identifying fetuses of abnormal size for gestational age were recently undermined by prospective studies that showed ultrasonographic estimates of fetal weight to be no better than clinical palpation for predicting fetal weight.

The sonographic prediction algorithms used to make fetal weight estimations in these various studies were those of Shepard, Hadlock, Sabbagha, and Warsof, in addition to the best of 8 algorithms based on various combinations of abdominal circumference (AC), femur length (FL), biparietal diameter (BPD), and head circumference (HC), both singly and in combination.

Taken together, these findings suggest that the prediction of fetal weight is not an exact science and requires additional refinement.
ACCURACY OF FETAL WEIGHT PREDICTION USING DIFFERENT METHODS

Accuracy of clinical palpation for estimating fetal weight

Recently, several investigations showed that the accuracy of clinical palpation for estimating fetal weight was ±278-599 grams and ±7.5-19.8%, depending on fetal weight and gestational age. The technique is best for estimating fetal weight in the reference range birth weight of 2500-4000 grams. Several studies show that the accuracy of clinical palpation for estimating fetal weight below 2500 grams deteriorates markedly, with a mean absolute percentage error of ±13.7-19.8%. Only 40-49% of birth weights below the 2500-gram threshold are estimated properly by clinical palpation to within ±10% of actual birth weight. If less than 1800 grams, the accuracy of such clinical estimates is reduced even further, with more than half of these predictions off by more than 450 grams (±25%).

One recent study shows that the sensitivity of clinical palpation for identifying birth weight of less than 2500 grams is only 17%, with an associated positive predictive value of 37%. At the upper limit of term fetal weights, 2 recent studies show that the positive predictive value of clinical palpation for predicting birth weight of greater than 4000 grams is 60-63%, with an associated sensitivity of 34-54%.

Furthermore, 2 studies previously suggested that the accuracy of this technique does not depend on the level of training of the operator, whereas another recent study suggests that resident physicians in obstetrics and gynecology are systematically better than medical students at estimating term birth weights using this technique. Using this method, the mean absolute percentage error in birth weight prediction for term fetuses greater than 37 weeks' gestation is 7.2-10.6%. For a fetus predicted to weigh more than 4000 grams, the average error in birthweight estimation routinely exceeds 300-400 grams. In one study, more than 6% of fetal weights were wrongly assessed by more than 1370 grams (3 lb).

Accuracy of obstetric ultrasonography for estimating fetal weight

Obstetric sonographic assessment for the purpose of obtaining fetal biometric measurements to predict fetal weight has been integrated into the mainstream of obstetric practice during the past quarter century. From its inception, this method has been presumed to be more accurate than clinical methods for estimating fetal weight. The reasons for this assumption vary, but the fundamental underlying presumption is that the sonographic measurements of multiple linear and planar dimensions of the fetus provide sufficient parametric information to allow for accurate algorithmic reconstruction of the 3-dimensional fetal volume of varying tissue density. Consistent with these beliefs, much effort has generated best-fit fetal biometric algorithms that can help make birth weight predictions based on obstetric ultrasonographic measurements. As such, the ultrasonographic technique represents the newest and most technologically sophisticated method of obtaining birth weight estimations.

Modern algorithms that incorporate standardly defined fetal measurements (eg, some combination of AC, FL, and either BPD or HC) are generally comparable in terms of overall accuracy in predicting birth weight. The most commonly used fetal biometric algorithms are shown in Table 6. When other sonographic fetal measurements are used to estimate fetal weight (eg, humeral soft tissue thickness, ratio of subcutaneous tissue to FL, cheek-to-cheek diameter), these nonstandard measurements do not significantly improve the ability of obstetric sonography to help predict birth weight, except in special patient subgroups (eg, mothers with diabetes).
Table . Ultrasonographic Fetal Biometric Prediction Algorithms for Calculating Estimated Fetal Weight*

<table>
<thead>
<tr>
<th>Source</th>
<th>Year</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shepard</td>
<td>1982</td>
<td>$\log_{10} BW^* = -1.7492 + 0.0166 (BPD^{†}) + 0.0046 (AC^{‡}) - 0.00002646 (AC \times BPD)$</td>
</tr>
<tr>
<td>Campbell</td>
<td>1975</td>
<td>$\ln^§ BW = -4.564 + 0.0282 (AC) - 0.0000331 (AC)^2$</td>
</tr>
<tr>
<td>Hadlock 1</td>
<td>1985</td>
<td>$\log_{10} BW = 1.326 - 0.0000326 (AC \times FL^{‖}) + 0.00107 (HC^{¶}) + 0.00438 (AC) + 0.0158 (FL)$</td>
</tr>
<tr>
<td>Hadlock 2</td>
<td>1985</td>
<td>$\log_{10} BW = 1.304 + 0.005281 (AC) + 0.01938 (FL) - 0.000004 (AC \times FL)$</td>
</tr>
<tr>
<td>Hadlock 3</td>
<td>1985</td>
<td>$\log_{10} BW = 1.335 - 0.000034 (AC \times FL) + 0.00316 (BPD) + 0.00457 (AC) + 0.01623 (FL)$</td>
</tr>
<tr>
<td>Warsof 1</td>
<td>1986</td>
<td>$\ln BW = 4.6914 + 0.00151 (FL)^2 - 0.0000119 (FL)^3$</td>
</tr>
<tr>
<td>Warsof 2</td>
<td>1986</td>
<td>$\ln BW = 2.792 + 0.108 (FL) + 0.000036 (AC)^2 - 0.00027 (FL \times AC)$</td>
</tr>
<tr>
<td>Combs</td>
<td>1993</td>
<td>$BW = [0.00023718 \times (AC)^2 \times (FL)] + 0.00003312 (HC)^3$</td>
</tr>
<tr>
<td>Ott</td>
<td>1986</td>
<td>$\log_{10} BW = 0.004355 (HC) + 0.005394 (AC) - 0.000008582 (HC \times AC) + 1.2594 (FL/AC) - 2.0661$</td>
</tr>
</tbody>
</table>

*BW - Estimated fetal weight (g)  
†BPD - Fetal biparietal diameter (mm)  
‡AC - Fetal abdominal circumference (mm)  
§ln – Natural logarithm  
‖FL - Fetal femur length (mm)  
¶HC - Fetal head circumference (mm)

In a recent study of 1034 patients, the mean absolute percentage error associated with the calculation of estimated fetal weights based on fetal measurements of BPD, AC, and FL (according to a widely used equation of Hadlock) was 10.0-11.3%, depending on the gestational age of the fetus (ie, after a crude stratification of fetal size). When the mean absolute percentage error of the method is assessed for 3 different clinically significant ranges of fetal weight (ie, <2500 g, 2500-4000 g, >4000 g), the mean absolute percentage error of the technique typically is lowest (±7.1-10.5%) for the mid...
range (2500-4000 g) and higher values of fetal weight (>4000 g) and slightly greater for fetuses weighing less than 2500 grams (±8-11%).

When another commonly used measure of accuracy is used (the percentage of fetuses with weight accurately estimated to within ±10% of actual birth weight), 56% were predicted accurately to within these limits for fetuses weighing less than 2500 grams, 58% for fetuses weighing 2500-4000 grams, and 62% for fetuses with actual birth weights greater than 4000 grams.

When the accuracy of the detection of clinically relevant deviations in term birth weight is assessed using the sonographic technique (ie, ability of the sonographic method to help accurately identify term fetuses weighing <2500 g, >4000 g, and >4500 g), the positive predictive value is 44-55%, with associated sensitivities of 58-71%. For preterm fetuses delivered at less than 37 weeks' gestation, the one-way accuracy of such sonographic fetal biometric classifications of clinically significant birth weight deviations (ie, low birth weight) is better; the positive predictive value of a sonographic estimate of fetal weight less than 2500 grams is 87% for preterm fetuses, with an associated sensitivity of 90%, and the positive predictive value for a sonographic estimate of fetal weight less than 1500 grams is 86%, with an associated sensitivity of 93%.

The notion that multiple obstetric sonographic fetal biometric evaluations might prove superior to a single examination for predicting fetal weights has been examined. One recent study evaluated the advantage of multiple ultrasonographic examinations compared with a single examination for the purpose of estimating fetal weight. The accuracy of birth weight percentile predictions was similar whether one or multiple such examinations were performed during the third trimester. In this study, which used the ultrasonic algorithm of Shepard, 38% of the fetuses had their weight accurately estimated to within ±10% after a single ultrasonographic assessment of fetal dimensions and 42% had such predictions correct to within ±10% after multiple sonographic examinations were performed. No statistically significant difference occurred in accuracy between these 2 approaches.

The sensitivity, specificity, positive predictive value, and negative predictive value for the prediction of both small-for-gestational-age and large-for-gestational-age fetuses using these sonographically derived estimated fetal weights, which are obtained from one or more sonographic examinations, are shown in Table below.

Table. Accuracy of Single Versus Multiple Sonographic Fetal Biometric Examinations for Detecting Clinically Relevant Deviations in Fetal Weight
### Actual Birth Weight

<table>
<thead>
<tr>
<th>Actual Birth Weight</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive Predictive Value</th>
<th>Negative Predictive Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small for gestational age (&lt;10th percentile)†</td>
<td>100%</td>
<td>76%</td>
<td>25%</td>
<td>100%</td>
</tr>
<tr>
<td>Single examination</td>
<td>100%</td>
<td>75%</td>
<td>25%</td>
<td>100%</td>
</tr>
<tr>
<td>Multiple examinations</td>
<td>48%</td>
<td>94%</td>
<td>63%</td>
<td>89%</td>
</tr>
<tr>
<td>Large for gestational age (&gt;90th percentile)†</td>
<td>62%</td>
<td>100%</td>
<td>100%</td>
<td>92%</td>
</tr>
</tbody>
</table>

*Adapted from Hedriana et al

†Prevalence of small-for-gestational-age fetuses in the series was 7.2% (19 of 264 patients), and the prevalence of large-for-gestational-age fetuses was 17.4% (46 of 264 patients).

Another question is the potential difference in the predictive accuracy of fetal weight estimates made using fetal biometric measurements obtained by professional sonographers in a controlled setting compared with hospital-based resident physicians performing studies in a labor and delivery unit. Although the interobserver variation in ultrasonic fetal biometric measurements has been shown to be small, these differences may still introduce unacceptable variability into the parameters employed for fetal weight estimation by fetal biometric algorithms.

In a recent study designed to address this clinically important question, the mean absolute percentage error associated with ultrasonographic estimates of fetal weight by house staff physicians in a labor and delivery suite (±9.3%) was comparable to that reported by professional ultrasonographers in a controlled setting. Thus, no clinically important systematic bias is introduced into such results based on differences in operator training or diagnostic setting.

Several technical limitations of the sonographic technique for estimating fetal weight are well known. Among these are maternal obesity, anterior placentation, and oligohydramnios.

Recently, several studies challenged the overall accuracy of sonographic birth weight estimations. More than a dozen investigations concluded that ultrasonography may be no more accurate for predicting birth weight than clinical palpation or even maternal self-estimations of fetal weight. Two of these studies also suggested that quantitative assessment of maternal characteristics may be as accurate as obstetric ultrasonography for the purpose of predicting the occurrence of fetal macrosomia.

#### Maternal self-estimations of fetal weight

Recently, 3 studies examined the accuracy of patient self-estimations of fetal weight by parous women. The mean absolute percentage errors for these birth weight predictions was 8.7-9.5% for term fetuses, with mean absolute birth weight errors of 305-350 grams. In a small study that reported the sensitivity for macrosomia greater than
4000 grams, it was 56%. These results seem comparable to those reported for both clinical palpation and obstetric ultrasonography.

**Predicting fetal weight using an algorithm derived from maternal and pregnancy-specific characteristics**

Recently, a new, theoretically defensible equation that can predict individual birth weights prospectively from maternal characteristics was developed. To do this, the predictive efficacy of 59 scientifically justifiable terms was evaluated simultaneously, obviating any confounding covariation and determining which of the predictors could account for variations in birth weight that others could not. Aside from maternal race, only 6 maternal and pregnancy-specific variables were important in the prediction of birth weight for otherwise normal gravidas. Only one additional paternal factor was found to be independently predictive of birth weight (ie, paternal height), but it accounts separately for less than 2% of the variance.

Using these routinely recorded variables, an equation based on maternal demographic and pregnancy-related characteristics alone was developed to help predict birth weight based on the following:

- Maternal height
- Maternal weight at 26 weeks' gestation
- Maternal weight gain rate during the third trimester
- Parity
- Fetal sex
- Gestational age at delivery

These prospectively measurable variables can explain 36% of the variance in term birth weight and can help predict birth weight accurately to within ±267 grams (±7.6% of individual birth weights). In addition, 75% of newborn weights can be estimated properly to within ±10% of actual birth weight using this technique.

Equation 1, the equation generated for this purpose, is as follows:

\[
\text{Birth weight (g)} = \text{gestational age (d)} \times [9.36 + 0.262 \times \text{fetal sex} + 0.000237 \times \text{maternal height (cm)} \times \text{maternal weight at 26 wk (kg)} + 4.81 \times \text{maternal weight gain rate (kg/d)} \times (\text{parity} + 1)],
\]

where fetal sex is equal to +1 for males, -1 for females, and 0 for unknown sex and gestational age is equal to days since onset of last normal menses, which equals the conception age (d) + 14.

**Which of the methods for predicting fetal weight is the most accurate?**

The accuracy of the different methods of predicting fetal weight depends on the gestational age and range of birth weights under study. Again, for this purpose, dividing fetuses into 3 birth weight categories of less than 2500 grams, 2500-4000 grams, and greater than 4000 grams is useful. For the clinically significant birth weight ranges of less than 2500 grams and greater than 4000 grams, the accuracy of sonographic fetal biometry appears to be superior to clinical palpation for predicting the occurrence of low birth weight fetuses weighing less than 2500 grams, whereas the 2 techniques appear to be comparable in predictive accuracy for fetuses weighing 2500 grams or more.

A recent study directly comparing the 4 different methods of fetal weight prediction in 44 normal term pregnancies found no difference between the accuracy of the clinical methods (eg, clinical palpation, birth weight prediction equation, maternal self-
Estimation of Fetal Weight

Eight different ultrasonic fetal biometric algorithms were assessed for this purpose. The mean birth weight for newborns in this study was 3445 ±458 grams, with a birth weight range of 2485-4790 grams. No systematic advantage was found with the ultrasonic technique for predicting term birth weight over the clinical methods.

Seven other recent studies directly compared the accuracy of clinical palpation to ultrasonographic fetal biometry using the same gravidas, and 3 compared clinical palpation to parous patients' self-estimates of fetal weight after 37 completed weeks' gestation.

One study compared clinical palpation to both ultrasonographic fetal biometry and parous patients' self-estimations of fetal weight. All of the methods have significant predictive errors in birth weight estimations for term fetuses that range from 290-560 grams, and no consistent or clear superiority of ultrasonographic fetal biometry over the other techniques of fetal weight estimation was found.

### Diagnosing Significant Deviations in Fetal Weight and Management Options

#### Developing a consensus of indicators

All currently available techniques for estimating fetal weight have significant degrees of inaccuracy. Wikstrom et al demonstrated that by combining clinical and ultrasonographic data about fetal size, an improved accuracy in fetal weight estimations can be obtained. Based on this finding, a reasonable strategy for arriving at estimated fetal weight is to use multiple estimates based on different sources of clinical and sonographic information. If such a strategy is accepted, then a practical and semiquantitative schema for making an accurate antenatal diagnosis of fetal weight in the clinical setting can be suggested, as follows:

- **First**, assess maternal risk factors for predispositions to fetal growth deviations at the initial prenatal visit and again at the start of the third trimester. Any gravida who has one or more of the following conditions should be considered at high risk for abnormal fetal growth and should undergo further assessment via other techniques to estimate their fetal weight:
  - Poorly controlled diabetes mellitus (any class, including gestational diabetes)
  - Abnormal 1-hour glucose screening test result (>135 mg/dL)
  - Single abnormal value on 3-hour oral glucose tolerance testing
  - Obesity
  - Abnormally tall or short stature
  - Excessive or inadequate pregnancy weight gain
  - High parity
  - Preterm gestation
  - Postdate pregnancy
  - Chronic hypertension
  - Preeclampsia (including pregnancy-induced hypertension, HELLP syndrome [hemolysis, elevated liver enzymes, and low platelet count])
  - Microvascular disease
  - Cigarette smoking
  - Residence at high altitude
- **Once a gravida is thought to be at risk for either excessive fetal growth or IUGR**, employ all applicable test modalities to determine which of the different methods (if any) suggest that the fetus has a weight outside of the reference range for its gestational age.
The standard fetal weight for comparison can be obtained from the 50th percentile rank of published fetal growth curves that are derived from patient populations that are well matched to the particular patient under consideration.

Clinical palpation and ultrasonographic fetal biometry can always be used to obtain an estimate of fetal size, regardless of gestational age.

Additionally, the current version of the birth weight prediction equation can be used to estimate the upper fetal weight limit for pregnancies in normal gravidas of all races at or near term.

If any 2 modalities suggest that the fetal weight is abnormal for gestational age (ie, >2 SD from the expected mean or 50th percentile rank value), then presume that the fetus is growing at an abnormal rate.

If so, then institute serial assessments of fetal growth to determine the velocity of ongoing fetal weight gain.

If both fetal weight for gestational age and the velocity of fetal weight gain are abnormal, the evidence for a significant abnormality in fetal growth becomes more compelling. Under such circumstances, manage the pregnancy accordingly, with the presumption that the fetal size is outside the reference range of expected values.

**Option for suppression of labor in women carrying undersized fetuses**

In general, the case can be made to attempt labor suppression in women carrying preterm fetuses weighing less than 2000-2500 grams. As stressed previously, most low weight fetuses are associated with preterm gestations. However, any recommendation in this circumstance regarding tocolysis presupposes the following: (1) no immediate fetal or maternal indications mitigate toward the timely delivery of the undersized fetus and (2) the undersized fetus will continue to grow along an acceptable growth curve if the gestation is allowed to continue. In many cases, both of these assumptions are invalid. For instance, many women who deliver preterm neonates are allowed to do so because of compelling fetal or maternal medical conditions that warrant timely delivery (eg, intrauterine infection, severe uteroplacental insufficiency, severe preeclampsia). If fetal infection or IUGR is present, the preterm delivery of an underweight fetus may be indicated.

The increased risk of perinatal complications associated with the delivery of an underweight fetus in these circumstances may be outweighed entirely by the increased risk of morbidity and mortality for both the fetus and mother with allowing the pregnancy to continue. Additionally, in some circumstances, the inadequate velocity of fetal growth might mandate a decision for delivery. In such cases, the presumption is that extraterine growth and development in the neonatal nursery would be superior to that achieved in utero. Clinical judgment under such circumstances is of paramount importance in deciding when to effect delivery and when to attempt labor suppression. More detailed considerations for aiding in this decision are beyond the scope of this article.

**Option for labor induction in women carrying oversized fetuses**

For fetuses delivered before 37 weeks’ gestation, fetal macrosomia is a rarity; more than 99% of macrosomic fetuses are the product of term gestations. In general, nearly 95% of fetuses gain 12.7 ±2.8 g/d from 37-42 weeks’ gestation, indicating that an
average fetus gains an additional 445 ±98 grams (1 lb ±3 oz) during this period. If a patient is thought to have a term fetus weighing more than 4000 grams and is willing to undergo labor induction, effecting vaginal delivery in these gravidas sooner, rather than awaiting the onset of spontaneous labor and a higher average birth weight at delivery, is often reasonable.

In studies that have attempted to examine this question, labor induction has not been demonstrated conclusively to decrease the fetal and maternal risks of intrapartum complications, and the cesarean delivery rate has been suggested to increase in several studies, whereas it has been purported to be unchanged in others. The difficulty in interpreting these results is that significant differences have been found among the predicted and actual birth weights for patients included for investigation and the power of the studies conducted to date has been insufficient to conclusively demonstrate statistically significant differences in adverse fetal outcomes among different study groups.

As with the case of preterm delivery of underweight fetuses, many considerations, including the size of the maternal pelvis and the weight of previously delivered fetuses, should be taken into consideration. Clinical judgment in these circumstances is of paramount importance in deciding whether or not labor induction is indicated in an attempt to minimize excessive fetal weight at delivery.

Conclusions

Both low birth weight (<2500 g) and high birth weight (>4000 g) are fetal conditions that are associated with increased risks of peripartum morbidity and mortality. Although the absolute risk that fetuses with birth weights of 2000-2500 grams and 4000-4500 grams will have major peripartum complications is not overwhelming, the risk of such complications increases substantially with both decreasing and increasing birth weight relative to these lower and upper limits. Thus, birth weight and gestational age are both important determinants of peripartum outcome. From this standpoint, the optimal range of newborn weight generally is thought to be 3000-4000 grams (6 lb 10 oz to 8 lb 13 oz). As always, the problem is knowing the fetal weight with sufficient accuracy in advance of delivery.

Many factors that impact directly upon birth weight are not modifiable. These include maternal race, height, parity, paternal height, and fetal sex. However, what can be influenced with potentially significant effects upon birth weight are the following:

- Prepregnancy weight
- Pregnancy weight gain
- Glucose control in patients with diabetes or glucose intolerance of pregnancy
- Gestational age at delivery

All of these factors can have significant impacts on fetal weight at delivery. Whereas permitting the delivery of fetuses that weigh 2000-2499 grams typically is not associated with an overwhelming increase in neonatal complications compared with normal-weight neonates, those fetuses weighing less than 2000 grams at birth are at increased risk for perinatal complications in a manner that is commensurate with their weight.

Similarly, whereas allowing a trial of a vaginal delivery for a fetus estimated to weigh 4000-4499 grams may be reasonable in many circumstances, many sources suggest that fetuses with estimated weights of 4500 grams or greater should be delivered by cesarean birth in order to avoid the increased intrapartum risks associated with the vaginal delivery of a macrosomic fetus. This is especially true when gestational diabetes is involved and the fetal conformation may be altered to reflect a larger...
shoulder girdle or head circumference ratio compared with the offspring of mothers without diabetes.

In the case of macrosomic fetuses, attempts to predict birth weight from fetal measurements obtained via ultrasonography have proven unsuccessful from the standpoint of improving clinical outcomes. Many studies conclude that ultrasonographic fetal biometric assessments are no more predictive of fetal macrosomia than clinical assessments of fetal size by simple external abdominal palpation. Both ultrasonography and manual assessment of fetal size have sensitivities of less than 60% for the prediction of fetal macrosomia, with false-positivity rates greater than 40%. Likewise, for small fetuses less than 1800 grams, ultrasonic fetal weight estimates are often in error by as much as 25%.

By using a birth weight prediction equation that is based on maternal and pregnancy-specific characteristics alone, fetal weight at and near term can be predicted with a high degree of accuracy (±7.6%). This approach appears to be at least as reliable for predicting fetal macrosomia in healthy gravidas as both clinical palpation and ultrasonographic fetal biometry, neither of which can be used with any degree of certainty in advance of the date of delivery. Such a quantitative assessment of maternal characteristics serves to objectively quantify the majority of previously recognized clinical variables that have long been employed in subjective clinical assessments and that are thought to be predictive of fetal weight.

By contrast, clinical palpation is a subjective methodology that must be employed at or near the date of delivery, and it is both patient- and clinician-dependent for its success (ie, less accurate for obese than nonobese gravidas, significant for interobserver variation in birth weight predictions even among experienced clinicians).

The disadvantages of ultrasonographic fetal biometry are that the method is both complicated and labor-intensive, potentially being limited by suboptimal visualization of fetal structures. It also requires costly sonographic equipment and specially trained personnel. Although such expensive imaging equipment is widely available in the United States and other industrialized countries, this is generally not the case in developing nations, where medical resources are often scarce.

In the future, combining the different methods of fetal weight prediction to improve their overall accuracy may be possible. Wikstrom et al suggested that by combining the independent information about fetal size obtained from the 3 different approaches (ie, clinical examination, quantitative assessment of maternal characteristics, ultrasonographic fetal biometry), the predictive value of fetal weight estimations can be improved dramatically. In the case of excessive fetal size, combining these methodologies may result in an 80% positive predictive value for the identification of fetal macrosomia, with a sensitivity of 63% and specificity of 95%.

Recently, a quantitative combination of maternal demographic information (of the type incorporated in Equation 1) with the independent information obtained by ultrasonic fetal biometry (AC) has been demonstrated to improve birth weight prediction substantially, with the area under the receiver operating characteristic curve increasing to 0.92. The mean absolute percentage error in birth weight predictions that can be attained using this new combinatorial method is ±5.4%.

With the advent of 3-dimensional fetal imaging, optimism that these new technologies can provide even better fetal weight estimations may be justified, but the advantages of estimating fetal weight using these newer techniques have not yet been demonstrated. Using these new approaches, further improvements in the accuracy of fetal weight prediction in the future will permit prospective obstetric intervention to be
undertaken more confidently by practicing obstetricians, with the aim of minimizing intrapartum and peripartum risks for both fetuses and mothers.