Improved Prediction of Gestational Age from Fetal Head Measurements

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Gestational age estimation based on biparietal diameter alone was compared with three approaches to age prediction that consider head shape: area-corrected biparietal diameter, circumference-corrected biparietal diameter, and head circumference. The analysis was based on 67 fetuses (13–41 weeks) in whom age was known with a high degree of accuracy, using a crown-rump length measurement from a prior first trimester sonographic examination. The three methods that consider head shape are more precise than biparietal diameter alone ($p < 0.05$ for second trimester cases, less significantly demonstrated for third trimester cases). While the three appear to be equal to one another in accuracy, area correction may be the preferred approach based on theoretical grounds and on convenience. It is easy and can be used in conjunction with any formula (or table) now applied to biparietal diameter alone.

Accurate assessment of gestational age (*gestational age* is used synonymously with *menstrual age*) by sonography can be of great importance in management decisions during pregnancy. For example, timing of elective cesarean delivery and the decision whether to consider a fetus at risk for intrauterine growth retardation depend in part on the estimated age. In the first trimester, the crown-rump length (CRL) measurement is a reliable predictor of gestational age [1, 2]. In the second and third trimesters, the biparietal diameter (BPD) has been similarly used.

Despite the fact that a number of studies have yielded tables or formulae to predict age from BPD [3–6], none of these achieve a precision comparable to that obtained via CRL. One reason proposed for the lower reliability of the BPD as a predictor of gestational age is that it disregards head shape, which can vary considerably in utero [7]. As a result, two alternative measurements that take head shape into account have been proposed: *head circumference* [8–10] and *area-corrected BPD* [4]. Another measurement, closely related to the latter, is the *circumference-corrected BPD* (defined below). However, no reported study has directly compared, on a single set of patients, the different methods for gestational age prediction based on head measurements. Therefore, we studied a set of cases in which true gestational age was known with a high degree of certainty, to answer two questions: (1) do the methods of gestational age prediction that account for head shape offer greater accuracy than those using BPD alone? and (2) if so, which of the methods that account for head shape is best?

Materials and Methods

Case Material

During an 8½ month period the data on 4051 consecutive obstetric patients examined with sonography at Brigham and Women's Hospital were collected and stored in computer files. Data on each case included the patient's hospital identification number, the date of the examination, last menstrual period (when known), and one or more of the following measurements: CRL, BPD, and occipitofrontal diameter (OFD). (The method of obtaining the latter

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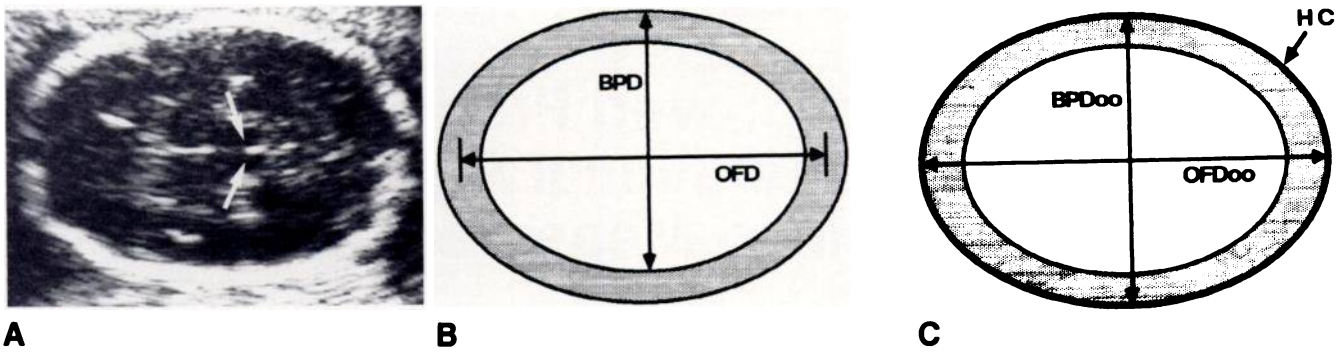

Fig. 1.—**A**, Sector sonogram in axial plane through level of thalami (*arrows*). **B**, BPD is measured from outer margin of near skull line to inner margin of far one, OFD from midskull to midskull. (Skull thickness has been exaggerated to better demonstrate endpoints of measurements.) **C**, Head circumference (HC) is measured about outer perimeter of skull or can be computed (see text) from outer-to-outer biparietal (BPDoo) and occipitofrontal (OFDoo) diameters. BPDoo is one skull thickness greater than traditional BPD, and OFDoo is one skull thickness greater than OFD.

two measurements is described below.) From this data base, we first identified all patients who had a sonogram from which a CRL measurement was recorded and whose gestational age based on CRL was not more than 13 weeks (using the determination of age from CRL presented in [4]). From this set of patients, we then identified the subset of patients who had at least one more sonogram beyond 13 weeks from which both BPD and OFD measurements were recorded. Our analysis is based on the first of these subsequent sonograms, because they are believed to have the most certain gestational ages. The age at the time of each of these sonograms is taken to be the age from the original sonogram (based on CRL) plus the number of weeks (or fraction thereof) elapsed between the initial and current sonograms. That is, the age projected from the original CRL is assumed to be the true gestational age.

Fetal Head Measurements

All measurements were obtained from a transaxial section of the fetal head at the level of the thalami (fig. 1A) [2]. We obtained the following measurements and derived values: *BPD* (fig. 1B) is measured from leading edge to leading edge (i.e., outer margin of the near skull line to inner margin of the far one [2]). *OFD* (fig. 1B) is measured from the middle of the anterior skull to the middle of the posterior skull. *Head circumference* (fig. 1C) is measured around the outer perimeter of the head. Alternatively, it can be approximated [11] from the outer-to-outer BPD (BPDoo) and OFD (OFDoo) by: *head circumference* = $\pi/2 \times (BPDoo + OFDoo)$. In [11], $\pi/2$ is written as 1.57.

Area-corrected BPD (BPDa) is the quantity referred to simply as "corrected" BPD in [4]. It is defined as the BPD of the standard-shaped head with the same cross-sectional area as that of the fetal head examined. A standard-shaped head is one with an OFD/BPD ratio of 1.265, which is the mean value for this ratio in our laboratory [4]. (This number is very close to the reciprocal of 0.783, a value reported as the mean value of the cephalic index BPD/OFD [7].) Using the formula for the area of an ellipse ($\pi/4$ times the product of the long and short diameters of the ellipse), an equation expressing the area-corrected BPD in terms of the BPD and OFD can be derived [4]: $BPDa = \sqrt{(BPD \times OFD)}/1.265$. *Circumference-corrected BPD* (*BPDc*) is a quantity, not previously defined, that is closely related to the one above. It is the BPD of the standard-shaped head with the same circumference. It can be computed: $BPDc = (BPD + OFD)/2.265$. It should be noted that, for a standard-shaped head, both the area-corrected and the circumference-corrected BPD are exactly equal to the uncorrected BPD.

Prediction of Gestational Age from Fetal Head Measurements

Any method that uses the BPD to predict gestational age can be used with area- or circumference-corrected BPD as well. We considered four formulae (or tabular data) that relate gestational age and BPD: those of Hadlock et al. [3], Birnholz (reported in [4]), Kurtz et al. [5], and Sabbagha and Hughey [6]. Descriptions of the first two of these provide formulae expressing gestational age as a function of BPD. Analogous formulae for the weighted mean data from 17 studies of Kurtz et al. [5] and the composite mean values of Sabbagha and Hughey [6] were obtained using third-degree polynomial regression: Kurtz—$GA = 3.418 + 0.482\,BPD - 0.00457\,BPD^2 + 0.000037\,BPD^3$; $r = 0.9998$. Sabbagha—$GA = -1.459 + 0.742\,BPD - 0.00904\,BPD^2 + 0.000061\,BPD^3$; $r = 0.999$. GA = gestational age in weeks; BPD is measured in mm, r = correlation coefficient comparing the formula to the data from which it is derived.

Gestational age can be estimated from head circumference using a formula of Hadlock et al. [9] expressing age as a function of the circumference. Because our computerized data file did not list a measured head circumference, we first determined that measurement via the equation $HC = \pi/2 \times (BPD + OFD)$* and then applied the circumference formula of Hadlock et al. [9].

Assessing and Comparing the Various Methods of Predicting Age

All assessments and comparisons were carried out using the gestational age based on CRL from prior sonograms as the standard of "truth." For example, the *mean error* associated with the formula of Hadlock et al. applied to area-corrected BPD was obtained as follows. For each case, we computed the estimated age by applying the formula to the area-corrected BPD. The absolute value of the difference between this value and the true age was taken to be the error for that case, and the average over all cases represents the mean error. The standard deviation of the differences for all cases was also computed, from which 95% confidence intervals were determined (as ±1.96 SD). Both mean error and 95% confidence interval were computed separately for second and third trimester cases, as well as for the entire group of cases.

* An adjustment had to be applied to BPD and OFD because each is one calvarial thickness less than BPDoo and OFDoo (see fig. 1). This thickness is not constant throughout pregnancy. We have derived, from published data [3, 9] and regression analysis, a formula expressing calvarial thickness (t) in mm as a function of BPD in mm: $t = 1.31 - 0.119\,BPD + 0.00472\,BPD^2 - 0.00003627\,BPD^3$. Details of the derivation are available from the authors on request.

TABLE 1: **Comparison of Gestational Age Computed from Corrected and Uncorrected Biparietal Diameters**

Trimester: Statistical Standard	Gestational Ages Estimated on the Basis of Formula or Table from Ref.: [3]	[4]	[5]	[6]
Second trimester (n = 52):				
95% confidence range (in weeks) using:				
BPD	±1.99	±2.12	±1.91	±2.16
BPDa	±1.72	±1.87	±1.61	±1.85
BPDc	±1.67	±1.81	±1.55	±1.81
Mean error (weeks) using:*				
BPD	0.82	0.90	0.77	0.86
BPDa	0.72	0.80	0.68	0.76
BPDc	0.71	0.79	0.68	0.76
No. of cases in which:				
BPDa outperforms BPD } †	24	24	24	23
BPD outperforms BPDa } †	6	7	5	5
BPDc outperforms BPD } †	23	23	23	23
BPD outperforms BPDc } †	6	9	6	7
BPDa outperforms BPDc } ‡	2	3	3	3
BPDc outperforms BPDa } ‡	4	4	3	3
Third trimester (n = 15):				
95% confidence range (in weeks) using:				
BPD	±3.37	±3.66	±3.09	±3.10
BPDa	±3.07	±3.13	±2.95	±3.22
BPDc	±3.25	±3.35	±3.14	±3.39
Mean error (weeks) using:				
BPD	1.46	1.57	1.26	1.16
BPDa	1.26	1.28	1.16	1.22
BPDc	1.31	1.33	1.21	1.27
No. of cases in which:				
BPDa outperforms BPD	7	7	8	6
BPD outperforms BPDa	5	4	5	7
BPDc outperforms BPD	7	7	8	6
BPD outperforms BPDc	5	4	5	7
BPDa outperforms BPDc	2	2	2	2
BPDc outperforms BPDa	1	1	1	1

Note.—BPD = biparietal diameter; BPDa = area-corrected BPD; BPDc = circumference-corrected BPD.

* For each column, the difference between BPD and BPDa is statistically significant ($p < 0.05$, paired Student t-test), as is the difference between BPD and BPDc; the difference between BPDa and BPDc is not significant.

† For each column, the comparison of BPD vs. BPDa is statistically significant ($p < 0.05$, sign test), as is the comparison of BPD vs. BPDc.

‡ Each pair of values is not significant.

Results

Sixty-seven sonograms met the criteria for inclusion in our study. Fifty-two involved second trimester pregnancies (13–26 weeks), 15 third trimester. The results of comparing gestational age estimation by corrected and uncorrected BPDs are presented in table 1. We will explain the entries in table 1 by considering the first column in detail for second trimester cases. This column carries out the comparison of corrected and uncorrected BPDs using the formula of Hadlock et al. [3]. The 95% confidence range of the age estimate was narrower with area-corrected BPD (±1.72 weeks) and circumference-corrected BPD (±1.67 weeks) than with uncorrected BPD (±1.99 weeks). The mean error (i.e., discrepancy between estimated and true gestational age) was less using area- and circumference-corrected diameters (0.72 and 0.71 weeks, respectively) than without correction (0.82 weeks). The difference in mean errors between using either correction method and using no correction was statistically significant, but there was no significant difference between the two correction methods themselves. Area correction outperformed the uncorrected BPD (i.e., yielded an age estimate at least 1 day closer to the actual age) in 24 of the 52 cases and was outperformed in only six, a statistically significant difference. (In the other 22 cases, the two were within 1 day of each other.) Using the same performance measure, circumference correction also bettered noncorrection; furthermore, there was no significant difference between the two correction methods.

Reviewing the other columns of table 1 reveals that the same conclusion holds for the other three formulae as well, when applied to second trimester cases. Whether compared in terms of mean error or on the basis of case-by-case performance, either correction method yields a more accurate estimate of gestational age, on average, than does uncorrected BPD. No significant difference between the two correction methods was found.

When the above analysis was applied to the 15 third trimester cases (table 1), the results tended to favor correction over noncorrection, but there were too few cases for the results to be statistically significant. For all 67 patients considered as a single group, correction methods were again found to be statistically significantly superior to noncorrection for all four formulae.

Comparison of head circumference with uncorrected BPD yielded the same conclusions: The former was superior, whether measured in terms of mean error or case-by-case performance.

There was little difference between head circumference and either of the two BPD correction methods as predictors of gestational age. When the head circumference formula of Hadlock et al. [9] was applied to the second trimester cases, the 95% confidence range was ±1.7 weeks and the mean error was 0.75 weeks. These are very close to the values listed in table 1 for the biparietal diameter formula of Hadlock et al. [3] applied to area- and circumference-corrected BPD. Case-by-case comparison also revealed no important difference; for example, head circumference outperformed circumference-corrected BPD in 15 cases and was outperformed in 17 cases.

Discussion

We compared four approaches to estimation of gestational age on a single set of obstetrical sonograms. Three of these—area correction of BPD, circumference correction of BPD, and head circumference—consider head shape; the fourth approach, BPD alone, does not. Our results confirm by direct comparison what had been suggested previously: Variation in head shape adversely affects the accuracy of age prediction using BPD alone, and better results can be achieved by accounting for head shape. Furthermore, the three methods that account for head shape appear to be equally accurate.

Because no statistically significant difference in accuracy was demonstrated among the three methods that account for head shape, we cannot advocate one over the others on the basis of precision. On other grounds, however, area correction may be the preferred approach. It has two advantages over head circumference: (1) it uses the leading edge-to-leading edge measure of BPD, which is more familiar to sonographers and often more easily measured (when the trailing edge of the side of the skull distal to the transducer is not sharply defined); and (2) the area-corrected BPD can be used in conjunction with any formula (or table) now applied to BPD alone. Area correction also has a theoretic advantage over circumference correction in that the former is based on a mathematically precise formula for the area of an ellipse. Because there is no algebraic formula for the circumference of an ellipse, circumference correction is based on an approximate formula ($\pi/2$ times the sum of the long and short diameters).

On the basis of table 1, one might assume that the actual magnitude of improved accuracy using area correction (or either of the other two methods that correct for head shape) as compared with uncorrected BPD is clinically unimportant, even though statistically significant. However, these values are deceptive, because many of the cases have standard- (or near-standard-) shaped heads, which are not affected by either area or circumference correction. Thus, the beneficial effect of head-shape correction in nonstandard (brachycephalic or dolichocephalic) heads—those cases for which correction is meant to be of assistance—is diluted in table 1, which presents the average results in the entire group. For heads in which the BPD/OFD ratio is far from 1.265, head correction can lead to an improvement of 1 or even 2 weeks, as was seen in several cases in our series.

One aspect of our analysis that requires justification is the use of the CRL-based gestational age as the "truth" against which all other estimates are compared. The CRL has been shown to be an extremely accurate means of determining age, with a 95% confidence range of ±4.7 days in the first trimester [1]. More importantly in the present context, it provides an objective predictor of fetal age that is independent of the four approaches being compared. Therefore, the discrepancies in the CRL-based age from the actual age will not only tend to cancel out over all cases, but will introduce no bias toward or against any of the approaches under consideration. The alternative of using dating based on last menstrual period as the measure of truth was not believed to be as reliable or unbiased a predictor of true gestational age.

We now illustrate, via the case in figure 1, how area correction is used in everyday practice. The BPD is 55.1 mm and the OFD 81.2 mm. The area-corrected BPD is therefore $\sqrt{55.1 \times 81.2/1.265}$, or 59.5 mm. Instead of basing the age on the BPD of 55.1 mm, as would be done conventionally, the value of 59.5 mm is used. For example, in a laboratory that uses the table (or formula) published by Hadlock et al. [3] for age estimation, the predicted age based on area-corrected BPD would be 24.4 weeks. (Note that, using BPD alone, predicted age would be 22.9 weeks.) As can be seen, a laboratory can use area correction with only minor alteration in its current pattern of practice: An additional measurement (the OFD) must be obtained and a simple computation of area-corrected BPD (easily done by a calculator) must be performed. There is no need to modify the table (or formula) already in use to determine age from BPD. In those cases in which an OFD cannot be obtained—which occurs infrequently in our laboratory, especially in the second trimester—the BPD alone is used.

In summary, methods of gestational age estimation that take head shape into account are more accurate than methods using BPD alone in the second trimester. Our data suggest that this is true in the third trimester as well, but studies with more third trimester cases would be needed to confirm this. While the three methods considered appear to be equally accurate, area correction—based on convenience and theoretical considerations—may be the preferred approach. It is easy to apply and can be used in conjunction with any formula now applied to BPD alone.

REFERENCES

1. Robinson HP, Fleming JEE. A critical evaluation of sonar "crown-rump length" measurements. *Br J Obstet Gynaecol* **1975**; 82:702–710
2. Bowie JD, Andreotti RF. Estimating gestational age in utero. In: Callen PW, ed. *Ultrasonography in obstetrics and gynecology*. Philadelphia: Saunders, **1983**:21–39
3. Hadlock FP, Deter RL, Harrist RB, Park SK. Fetal biparietal diameter: a critical re-evaluation of the relation to menstrual age by means of real-time ultrasound. *J Ultrasound Med* **1982**;1:97–104
4. Greenes RA. OBUS: a microcomputer system for measurement, calculation, reporting, and retrieval of obstetric ultrasound data. *Radiology* **1982**;144:879–883
5. Kurtz AB, Wapner RJ, Kurtz RJ, et al. Analysis of biparietal diameter as an accurate indicator of gestational age. *JCU* **1980**;8:319–326
6. Sabbagha RE, Hughey M. Standardization of sonar cephalometry and gestational age. *Obstet Gynecol* **1978**;52:402–406
7. Hadlock FP, Deter RL, Carpenter RJ, Park SK. Estimating fetal age: effect of head shape on BPD. *AJR* **1981**;137:83–85
8. Metreweli C. *Practical abdominal ultrasound*. Chicago: Heinemann, **1978**:114
9. Hadlock FP, Deter RL, Harrist RB, Park SK. Fetal head circumference: relation to menstrual age. *AJR* **1982**;138:649–653
10. Law RG, MacRae KD. Head circumference as an index of fetal age. *J Ultrasound Med* **1982**;1:281–288
11. Hadlock FP, Kent WR, Loyd JL, Harrist RP, Deter RL, Park SK. An evaluation of two methods for measuring fetal head and body circumferences. *J Ultrasound Med* **1982**;1:359–360

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2. J. M. Cohen, J. A. Hutcheon, M. S. Kramer, K. S. Joseph, H. Abenhaim, R. W. Platt. 2010. Influence of ultrasound-to-delivery interval and maternal-fetal characteristics on validity of estimated fetal weight. *Ultrasound in Obstetrics and Gynecology* **35**:10.1002/uog.v35:4, 434-441. [CrossRef]
3. Henry L. Galan, Santosh Pandipati, Roy A. FillyULTRASOUND EVALUATION OF FETAL BIOMETRY AND NORMAL AND ABNORMAL FETAL GROWTH 225-265. [CrossRef]
4. Kuan-Jiin Lyu, Tsang-Ming Ko. 2000. Prenatal diagnosis of Apert syndrome with widely separated cranial sutures. *Prenatal Diagnosis* **20**:10.1002/(SICI)1097-0223(200003)20:3<>1.0.CO;2-4, 254-256. [CrossRef]
5. Alfred B. Kurtz, Laurence Needleman. 1998. American college of radiology standards: Obstetrical measurements. *Seminars in Roentgenology* **33**, 309-332. [CrossRef]
6. Scott D. Harrison, Dale R. Cyr, Randall M. Patten, Laurence A. Mack. 1993. Twin growth problems: Causes and sonographic analysis. *Seminars in Ultrasound, CT and MRI* **14**, 56-67. [CrossRef]
7. Levon N. Nazarian, Alfred B. Kurtz. 1993. Routine ultrasound surveillance of the pregnant uterus. *Seminars in Ultrasound, CT and MRI* **14**, 3-22. [CrossRef]
8. Richard J. Sherwood, Haynes B. Robinson, Richard L. May, Richard S. Meindl. 1992. Standardized residuals as a means for detection of growth alteration in the pathologic human fetus. *Teratology* **46**:10.1002/tera.v46:5, 419-427. [CrossRef]
9. Lorna Blum, Alfred B. Kurtz. 1990. Gestational age: What to measure and when. *Seminars in Roentgenology* **25**, 299-308. [CrossRef]
10. Carol B. Benson, Peter M. Doubilet, Daniel H. Saltzman. 1987. Sonographic determination of fetal weights in diabetic pregnancies. *American Journal of Obstetrics and Gynecology* **156**, 441-444. [CrossRef]