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Fetal Biparietal Diameter:

A Critical Re-evaluation of the Relation to Menstrual Age by Means of Real-time Ultrasound

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The relationship between fetal biparietal diameter (BPD) and menstrual age was determined by cross-sectional analysis of 533 fetuses (12 to 40 weeks) examined with a linear array real-time (dynamic image) scanner using specifically defined methodology. Mathematical modeling of the data demonstrated that the optimal fit was the linear cubic function (r^2 = 99 per cent); predicted BPD values calculated from the function were most comparable with composite data from cross-sectional studies performed with static scanners after 1974 (average difference, 0.22 mm) and least comparable with composite data from cross-sectional studies performed with static scanners before 1974 (average difference, 2.0 mm). The variability associated with predicting menstrual age from the BPD increased progressively throughout gestation; the maximal variability was noted between 36 and 42 weeks (±3.6 weeks). Comparison with our longitudinal study of BPD growth indicates that the cross-sectional data represent a valid estimate of the true longitudinal BPD growth curve of the population. (Key words: fetal biparietal diameter; fetal age, determination of; ultrasonographic cephalometry; real-time ultrasound.)

Several investigators have made comparative measurements of the fetal biparietal diameter (BPD) using real-time and static-image ultrasound scanners, and the results have indicated that the measurement differences are not statistically significant. The conclusion of these studies is that real-time determinations of the BPD may be applied to BPD/gestational age charts generated by static image equipment.[1–5]

A problem remains, however, in deciding which static-image BPD chart to use, since there are discrepancies among charts from different institutions. For example, the original data from Yale[6] differs at some points by as much as three weeks' gestation from the values reported by Sabbagha and Hughey.[7] Some investigators have attempted to solve this problem by making composite charts[7–9] using data from as many as 17 institutions. But there are problems with such charts: 1) these composite charts do not agree specifically on mean values or, more importantly, on the range of standard deviation values at various points in gestation; 2) although large numbers of measurements were used to construct each chart, there is no indication of whether there was an equal distribution of measurements made at various points in gestation; 3) the number of measurements exceeds the number of patients, indicating that some patients were measured more than once during gestation, which is known to increase the possibility of bias in cross-sectional data[10]; 4) the specific anatomy of the plane of section used for measuring the biparietal diameter of the fetal skull was not indicated in these studies; and 5) the gain settings and transducer frequency were either not indicated or not uniform in the individual studies.

The use of real-time ultrasound has greatly facilitated identification of specific planes of section in the fetal brain[11] and thus provides an ideal tool for producing a highly reproducible image for measurement of the BPD.[5,12] Johnson et al. have pointed out the need for new BPD data based on a specific anatomic plane in the fetal cranium and obtained by means of current high-resolution equipment.[13] The purpose of this investigation, therefore, was to define and analyze the BPD/gestational-age relationship determined by real-time ultrasound at a specific anatomic level in the fetal cranium. In this way we hope to provide a useful set of data for the many clinicians now performing real-time cephalometry.

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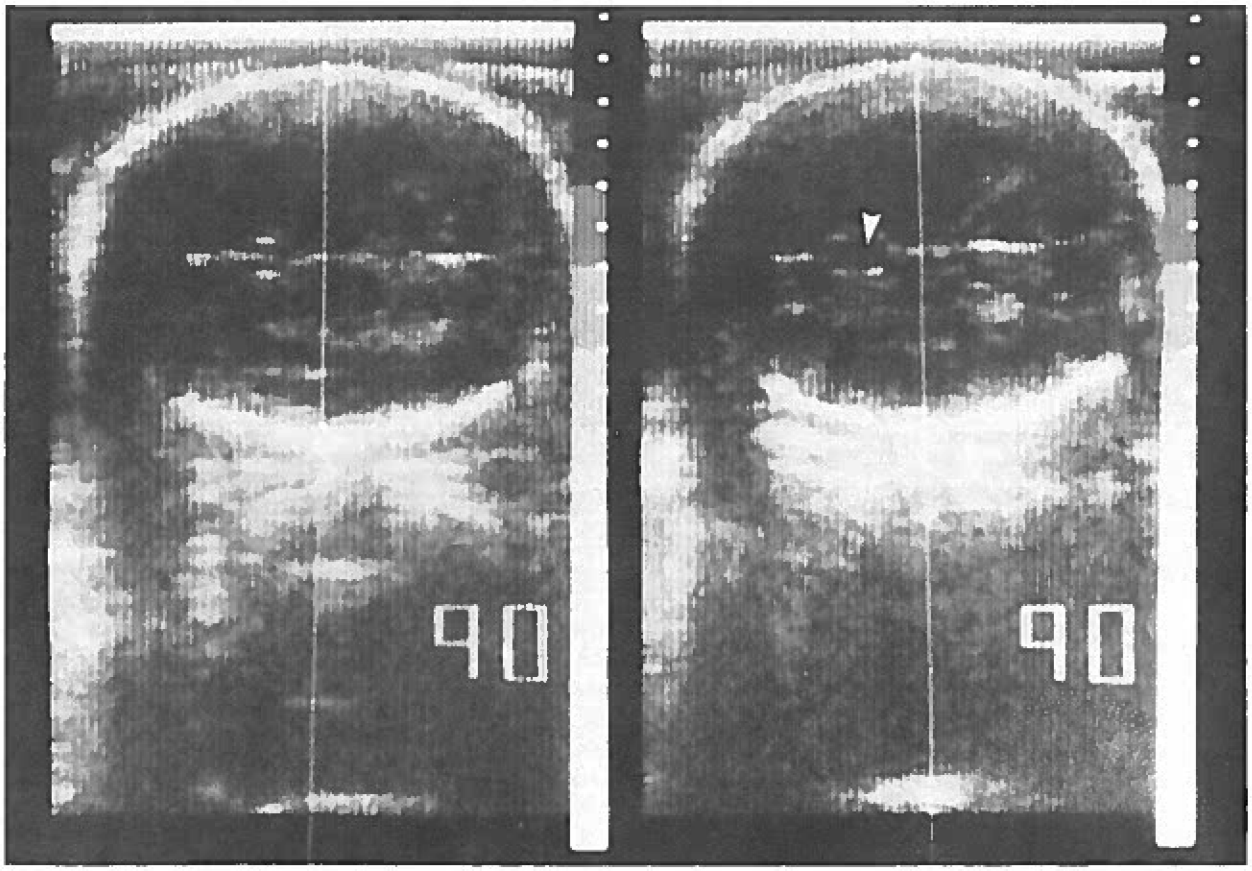

Figure 1. On the right is a real-time image of fetal BPD representative of those used in the study; the arrowhead indicates the landmark described by Campbell and Thoms[16] for identification of this section. The section shown on the left is approximately 1 cm caudal to the section shown on the right.[11] Because of the proximity of these sections relative to the width of the transducer (1.8 cm), the images of some anatomic features may overlap, particularly in younger fetuses. Our experience* indicates that the BPD measurement is the same for both sections, as illustrated in this 37-week-old fetus. A detailed description of the anatomy of these sections has been published elsewhere.[11,13]

MATERIALS AND METHODS

The study involved 533 consecutive patients (more than 95 per cent were middle-class whites) chosen for analysis on the basis of the following criteria: 1) a history of regular menses, 2) known date of the beginning of the last menstrual period, 3) a close relationship (±1 week) between the menstrual age (MA) of the fetus and the clinical evaluation, 4) ultrasonic measurements of the fetal head circumference and abdominal circumference within the normal range (SD ±2) for the stated MA,[14-15] 5) fetal head in occiput transverse position so that anatomic planes could be easily recognized,[11] 6) absence of maternal disease known to affect normal fetal growth—e.g., diabetes mellitus, and 7) absence of multiple gestation—e.g., twins—in the current pregnancy.

All examinations were performed using a commercially available linear-phased array system with a 3.5-mHz single-focus transducer.* The plane of section chosen for BPD measurements was the axial plane,[11] described by Campbell and Thomas in 1977 for measurement of the fetal fronto-occipital head circumference (FOC)[16] (fig. 1). The gain settings were adjusted so that the width of the skull table was 3 to 5 mm.[5] All measurements were made from the Polaroid image by one investigator (F.P.H.) using hand-held calipers; the measurements were made from the outer margin of the skull table closer to the transducer to the inner margin of the skull table farther from the transducer. Each fetus was measured only once in gestation.

The mean BPD values and their standard deviations were calulated at weekly intervals using standard methods; each interval was centered on the week (e.g., a 16-week interval = 15.50 to 16.49 weeks). Mathematical modeling of the BPD/MA relationship was carried out using the linear, linear quadratic, and linear cubic models. Optimal coeffi-

* Unpublished data.

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cient estimates were obtained by the least squares method,[17] and the adequacy of each function was evaluated by measurement of the coefficient of determination (r^2)[18]. Predicted BPD values at different MAs and predicted MA values for different BPDs were calculated using the optimal model.

To evaluate the variability associated with determining MA from BPD values, the expected value of the BPD at 12, 18, 24, 30, 36, and 42 menstrual weeks was determined using the optimal model. The experimental data were then subdivided into five groups based on these BPD bounding limits; for example, group I was composed of BPD values between 1.99 and 4.03 cm (12 and 18 weeks, respectively). Regression analysis[18] of the MA/BPD relationship was carried out on each of these groups using the linear, linear quadratic, and linear cubic models, and the optimal model was determined from r^2 measurements.[18] The standard deviation of the regression (in weeks) associated with each optimal model was taken as the measure of the average variability for the group. This method of measuring variability is method I.

To assess variability further, the average standard deviation of the mean BPD values in each group was calculated from the experimental data.* The 95 per cent confidence interval in weeks was calculated by dividing twice the average standard deviation by the average difference in millimeters between mean BPD values at consecutive weeks in the group. For example, if the average standard deviation for the group was 2 mm and the average difference between BPD values at consecutive weeks in the group was 3 mm, then the 95 per cent confidence interval for predicting the MA from the BPD equals 4 mm/3 mm/week = 1.33 weeks. This method of determining variability is method II.

* Average standard deviation = $\frac{\text{sum of SDs in group}}{6}$.

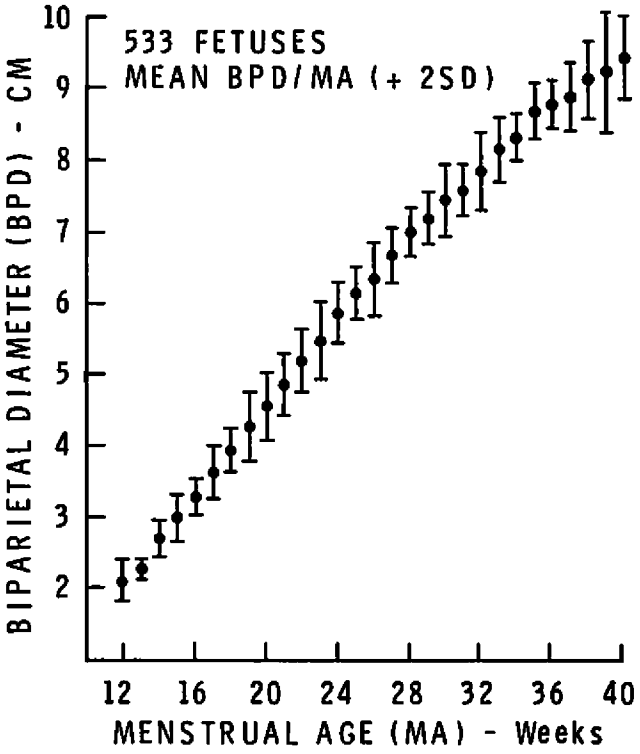

Figure 2. The distribution of the mean BPD values (SD ±2) as a function of menstrual age for the experimental data (533 fetuses, one measurement per fetus).

Table 1. Calculated BPD Values (Mean ± SD) at Menstrual Ages from 12 to 40 Weeks

Menstrual Age (weeks)	Calculated BPD (cm)
12 (n = 2)	2.10 ± 0.13
13 (n = 3)	2.27 ± 0.06
14 (n = 4)	2.70 ± 0.14
15 (n = 12)	2.98 ± 0.16
16 (n = 32)	3.30 ± 0.13
17 (n = 36)	3.63 ± 0.18
18 (n = 24)	3.95 ± 0.15
19 (n = 23)	4.28 ± 0.24
20 (n = 19)	4.56 ± 0.24
21 (n = 27)	4.84 ± 0.21
22 (n = 27)	5.21 ± 0.22
23 (n = 21)	5.48 ± 0.27
24 (n = 24)	5.86 ± 0.21
25 (n = 16)	6.15 ± 0.17
26 (n = 22)	6.35 ± 0.25
27 (n = 17)	6.69 ± 0.19
28 (n = 17)	7.01 ± 0.16
29 (n = 11)	7.20 ± 0.17
30 (n = 17)	7.45 ± 0.25
31 (n = 20)	7.59 ± 0.19
32 (n = 10)	7.86 ± 0.26
33 (n = 22)	8.16 ± 0.23
34 (n = 22)	8.33 ± 0.16
35 (n = 7)	8.69 ± 0.21
36 (n = 19)	8.79 ± 0.17
37 (n = 8)	8.90 ± 0.24
38 (n = 15)	9.14 ± 0.27
39 (n = 36)	9.26 ± 0.43
40 (n = 20)	9.44 ± 0.30

RESULTS

Preliminary data based on studies of the initial 283 fetuses using the linear quadratic function are published elsewhere.[19] The distribution of the mean BPD data (SD ±2) as a function of MA for the entire group of 533 fetuses is shown in figure 2; the mean BPD value and its standard deviation for each week in gestation is shown in table 1.

The optimal model was the linear cubic function (r^2 = 99 per cent); the r^2 for the linear function and the linear quadratic function were 98.1 per cent and 98.9 per cent, respectively. The predicted BPD values for given MAs, based on the linear cubic func-

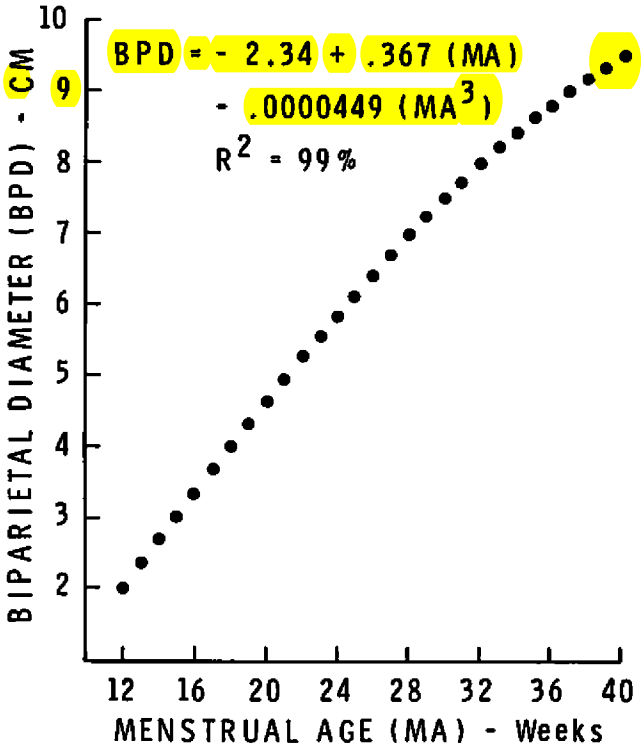

Figure 3. The distribution of the predicted BPD values at various points in gestation, based on the linear cubic function.

tion, are shown in figure 3; the predicted BPD value for each week in gestation is compared with predicted mean values from the composite BPD growth curves of Sabbagha and Hughey[7] and Kurtz et al.[9] in table 2. The predicted MAs for given BPD values are shown in table 3.

In the evaluation of BPD variability by method I, similar r^2 values were obtained for groups I to V using the linear quadratic and linear cubic functions; the r^2 value for the linear function was similar for group I, but its values were consistently lower than those of the other two functions in groups II through V. The variability associated with predicting MA (SD ±2) from BPD values is shown in table IV for both methods I and II.

DISCUSSION

Comparison with Other Cross-sectional BPD Growth Curves. The relationship between the BPD and gestational age has been the subject of many investigations throughout the world, and there are at least 25 BPD charts from which the newcomers to the field can choose.[9] Unfortunately, most of these charts were compiled from studies done with static-image equipment before the advent of static scanners of today's resolution capabilities, and the methodologies used in these studies were not uniform. For example, different investigators used different ultrasonic modes for measurement—e.g., A mode, B mode, or a combination of A and B modes, and the transducer frequency and gain settings were either not uniform or not indicated in most studies. In addition, in most studies no assurance was given that the distribution of the sampling data was uniform throughout gestation (14 to 42 weeks), and the precise anatomy of the measured plane of section was not indicated. The technique employed in most studies to produce the BPD image was that of Campbell,[20] but as Christie notes,[21] this technique is more complex than Campbell's report would appear to indicate. It should not be surprising, then, that some charted values differ by as much as three weeks at some points in gestation[6-7] or that some charted values obtained by measuring BPD from outer to outer margins are lower than those obtained by measuring it from outer to inner margins.[9] In addition, most studies have not included mathematical analyses of the data, making comparisons between data sets even more difficult.

Unlike prior investigations, our study is a true cross-sectional one (i.e., one data point per fetus), and it contains an even distribution of data points throughout gestation (14 to 40 weeks). All studies were performed with linear-array real-time instrumentation at medium gain, which has been shown to produce the most accurate and reproducible BPD measurements.[5,12] All BPD images were measured at a specific anatomic plane in the fetal cranium;[11] this section was chosen because it contains the maximal transverse fetal head diameter, is easily identified by ultrasound, and allows simultaneous measurement of the FOC and cephalic index.[11,13-14,16,22] Normal values for ultrasonic measurement of the fetal head circumference and abdominal circumference were used to ensure that the fetus was normal at the time of the study,[14-15] rather than fetal birth weight above the tenth percentile at term, which does not ensure that the fetus was normal at the time of the study. Spontaneous delivery within ±14 days of the expected date of confinement based on the last menstrual period was not used as a criterion, since its use could be expected to exclude up to 22 per cent of normal pregnancies.[23]

The mathematical analysis indicated very high coefficients of determination for both the linear quadratic (r^2 = 98.9 per cent) and linear cubic (r^2 = 99 per cent) models, and the predicted values were essentially the same throughout gestation. Expanding the sample size from 283 to 533 fetuses did not significantly alter the mean values (average difference, 0.296 mm), which indicates that the sample size was adequate. Our data cannot be compared with those of Wiener et al.[8] because their values were not reported in tabular form and no mathematical functions were provided. Our values (table 2) are consistently smaller than the mean values in the Sabbagha and Hughey composite[7] (average difference, 2.2 mm; range, 1 to 3 mm); our values are also less than those reported in the Kurtz et al. com-

TABLE 2. Comparison of Predicted BPD Mean Values at Menstrual Ages from 14 to 40 Weeks

Menstrual Age (weeks)	BPD Mean Values (cm)				
	Composite Sabbagha and Hughey[7]	Composite Kurtz et al.[9]	Kurtz et al.[9] <1974	Kurtz et al.[9] >1974	This Study (Linear Cubic Function)
14	2.8	2.7	2.8	2.6	2.7
15	3.2	3.1	3.1	2.9	3.0
16	3.6	3.4	3.5	3.3	3.3
17	3.9	3.8	3.9	3.6	3.7
18	4.2	4.1	4.2	4.0	4.0
19	4.5	4.5	4.6	4.3	4.3
20	4.8	4.8	4.9	4.6	4.6
21	5.1	5.1	5.2	5.0	5.0
22	5.4	5.4	5.5	5.3	5.3
23	5.8	5.7	5.8	5.6	5.6
24	6.1	6.0	6.1	5.9	5.8
25	6.4	6.3	6.4	6.1	6.1
26	6.7	6.6	6.7	6.4	6.4
27	7.0	6.9	6.9	6.7	6.7
28	7.2	7.1	7.2	7.0	7.0
29	7.5	7.4	7.5	7.2	7.2
30	7.8	7.6	7.7	7.5	7.5
31	8.0	7.9	7.9	7.7	7.7
32	8.2	8.1	8.1	7.9	7.9
33	8.5	8.3	8.3	8.2	8.2
34	8.7	8.5	8.5	8.4	8.4
35	8.8	8.7	8.7	8.6	8.6
36	9.0	8.9	8.9	8.8	8.8
37	9.2	9.1	9.1	9.0	9.0
38	9.3	9.2	9.2	9.2	9.1
39	9.4	9.4	9.4	9.4	9.3
40	9.5	9.5	9.5	9.5	9.5

posite,[9] but the average difference (1.26 mm; range, 0 to 2 mm) is considerably smaller, even though the Sabbagha and Hughey data account for approximately 25 per cent of the Kurtz et al. data. Interestingly, our data correlates best with the values calculated from the linear quadratic function reported by Kurtz et al. for studies done after 1974 (average difference, 0.2 mm; range 0 to 1 mm), rather than with the expected values from the linear quadratic function reported by Kurtz et al. for studies done before 1974 (average difference, 1.9 mm; range, 0 to 3 mm). It is difficult to know exactly why there are systematic differences between our data and the composite data of Sabbagha and Hughey[7] and Kurtz et al.,[9] since there are so many variables in the individual studies from which the composite data were derived. It is evident, however, that there is a difference between data collected prior to 1974 and data collected from 1974 to the present.[9] One possible explanation, which we cannot prove conclusively, is that this difference is related to the significant improvements in ultrasound scanners since 1974. In any case, it is unlikely that these differences represent different populations of fetuses, since the vast majority of fetuses in all the studies were white and since the average growth rate of the fetal BPD is so similar among the studies (Kurtz et al.: 2.62 mm/week; Sabbagha and Hughey: 2.58 mm/week; this study: 2.62 mm/week) for the entire period of gestation (12 to 40 weeks).

Our range of standard deviation values (applicable to 95 per cent of fetuses) are comparable for methods I and II (table 4) except for group V (36 to 42 weeks); we feel the values for method II in this group are more reliable, since in a subsequent analysis of 100 fetuses* (36 to 42 weeks) the fetal age predicted from the BPD was more than three weeks greater than the MA in 7 per cent of cases. Our normal range (SD ±2) is in agreement with the values of Kurtz et al.,[9] Sabbagha and Hughey,[7] and Sabbagha et al.[25-26] (applicable to 90 per cent of fetuses) for fetuses less than 26 weeks old (±1 to 1.5 weeks). It also agrees with the values reported by Campbell[24] for fetuses between 20 and 30 weeks of age (SD 2 = 1.2 weeks) and with values reported by Sabbagha et al.[25] for fetuses between 20 and 29 weeks of age (SD 2 = 1.6 weeks). Sabbagha and

* Unpublished data

TABLE 3. Predicted Menstrual Ages for BPD Values from 2.0 to 10.0 cm

BPD (cm)	Menstrual Age (weeks)	BPD (cm)	Menstrual Age (weeks)
2.0	12.2	6.1	25.0
2.1	12.5	6.2	25.3
2.2	12.8	6.3	25.7
2.3	13.1	6.4	26.1
2.4	13.3	6.5	26.4
2.5	13.6	6.6	26.8
2.6	13.9	6.7	27.2
2.7	14.2	6.8	27.6
2.8	14.5	6.9	28.0
2.9	14.7	7.0	28.3
3.0	15.0	7.1	28.7
3.1	15.3	7.2	29.1
3.2	15.6	7.3	29.5
3.3	15.9	7.4	29.9
3.4	16.2	7.5	30.4
3.5	16.5	7.6	30.8
3.6	16.8	7.7	31.2
3.7	17.1	7.8	31.6
3.8	17.4	7.9	32.0
3.9	17.7	8.0	32.5
4.0	18.0	8.1	32.9
4.1	18.3	8.2	33.3
4.2	18.6	8.3	33.8
4.3	18.9	8.4	34.2
4.4	19.2	8.5	34.7
4.5	19.5	8.6	35.1
4.6	19.9	8.7	35.6
4.7	20.2	8.8	36.1
4.8	20.5	8.9	36.5
4.9	20.8	9.0	37.0
5.0	21.2	9.1	37.5
5.1	21.5	9.2	38.0
5.2	21.8	9.3	38.5
5.3	22.2	9.4	38.9
5.4	22.5	9.5	39.4
5.5	22.8	9.6	39.9
5.6	23.2	9.7	40.5
5.7	23.5	9.8	41.0
5.8	23.9	9.9	41.5
5.9	24.2	10.0	42.0
6.0	24.6		

*Menstrual age = 6.8954 + 2.6345(BPD) + 0.008771 (BPD)^3 [r^2 = 98.7 per cent].

Hughey[7] report a normal range of ±3 weeks between 29 and 40 weeks, and our normal values during this period, calculated by method II, are comparable (±2.5 weeks): however, grouping all fetuses more than 28 weeks old together masks the considerable increase in variability that occurs after 36 weeks, when the BPD growth curve begins to flatten. Our values for fetuses older than 28 weeks are greater than the values reported by Kurtz et al.[9] (table 4); their normal range, however, is based on the 90 per cent confidence interval for the mean values of 17 different studies, and thus is not necessarily a reflection of the individual variability of values among the large number of fetuses included in the study.[27–28]

Certain disease states (hydrocephalus, microcephaly, growth retardation) will account for a small portion of the 5 per cent of values falling outside our reported normal range, but the clinical data and other sonographic findings (dilated ventricles, HC/AC disproportion, serial BPDs) should help identify the fetuses to whom these values apply. A greater portion of the 5 per cent falling outside the normal range simply reflect genetic variation in normal head size or variations in the follicular phase[29] of the menstrual cycle of the mother. The rest correspond to variations in head shape (e.g., dolichocephaly, brachycephaly). In our experience,[22] the head circumference is a more useful indicator of fetal age in such cases, especially when it is used in conjunction with the abdominal circumference, femur length, and mother's menstrual dates.

Comparison with Longitudinal BPD Growth Curves. Several authors have questioned whether cross-sectional BPD growth curves such as the one presented accurately reflect individual fetal growth.[30–31] The major criticism is that one must accept the unproven assumption that there is a common growth pattern subject only to random variation. Without this assumption the data obtained cannot be considered a valid estimate of the average population growth curve.

This problem is eliminated if the growth of individual fetuses is followed by means of serial ultrasound examinations. The data obtained in such studies permit determination of individual growth curves, which can then be averaged to provide an estimate of the true average population growth curve. Deter et al.[31] have recently reported the results of such a study, based on evaluation of 20 fetuses with known dates of conception; all fetuses in their study were born to middle-class white women in the middle child-bearing years, and all BPDs were measured from outer to inner margins on real-time Polaroid images of the fetal skull at the FOC level. In order to make our data directly comparable to theirs, we converted the MAs in our study to conceptual ages, using the standard value of two weeks for the length of the follicular phase of the normal menstrual cycle[32]; i.e., conceptual age equals MA minus two weeks. Figure 4 demonstrates that the curves are remarkably similar. Table 5 compares the predicted BPD values for given conceptual ages from the linear cubic function of each study; the cross-section values are consistently larger than the longitudinal data, but the difference is small (average difference, 1.24 mm; range, 0 to 2 mm). The standard deviation values in the longitudinal study (mean SD, 0.31 cm; range, 0.24 to 0.36 cm) are larger, on the average, than those in the

Table 4. Estimated Variability Associated with Three Methods of Determining Menstrual Age from BPD Values

Group (Menstrual Age)	This Study*		Kurtz et al.[9]†
	Method I	Method II	
I (12–18 weeks)	± 0.85 weeks (r^2 = 90.4%)	± 0.80 weeks	± 0.80 weeks
II (18–24 weeks)	± 1.29 weeks (r^2 = 87.6%)	± 1.39 weeks	± 1.70 weeks
III (24–30 weeks)	± 1.40 weeks (r^2 = 89.1%)	± 1.34 weeks	± 1.34 weeks
IV (30–36 weeks)	± 1.96 weeks (r^2 = 76.5%)	± 2.0 weeks	± 1.42 weeks
V (36–42 weeks)	± 2.06 weeks (r^2 = 25.6%)	± 3.6 weeks	± 1.23 weeks

* 95 per cent confidence interval.
† 90 per cent confidence interval (of mean values) calculated from Table 4.*

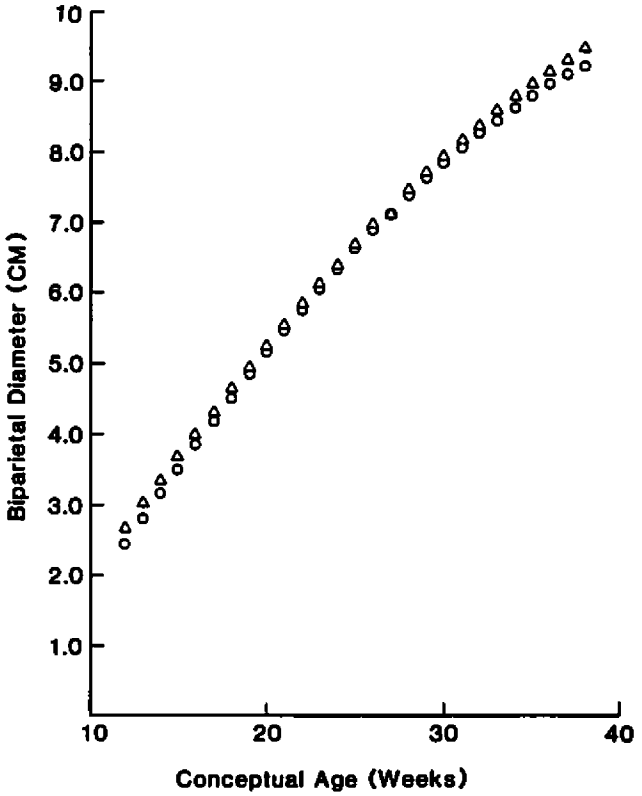

Figure 4. The similarity in curve shapes of the predicted mean BPD values as a function of conceptual age for the longitudinal[31] and cross-sectional studies. (Δ: cross-sectional data. O: longitudinal data.)

Table 5. Comparison of Predicted BPD Mean Values at Conceptual Ages from 13 to 37 Weeks

Conceptual Age (weeks)	BPD Mean Values (cm)	
	Deter et al.[31]* (Linear Cubic Function)	This Study† (Linear Cubic Function)
13	2.8	3.0
14	3.2	3.3
15	3.5	3.7
16	3.8	4.0
17	4.2	4.3
18	4.5	4.6
19	4.8	5.0
20	5.2	5.3
21	5.5	5.6
22	5.8	5.8
23	6.1	6.1
24	6.3	6.4
25	6.6	6.7
26	6.9	7.0
27	7.1	7.2
28	7.4	7.5
29	7.6	7.7
30	7.8	7.9
31	8.1	8.2
32	8.3	8.4
33	8.4	8.6
34	8.6	8.8
35	8.8	9.0
36	9.0	9.1
37	9.1	9.3

* BPD = $-2.05 + 0.384(CA) - (6.06 \times 10^{-5}[CA^3])$, where CA is the conceptual age. r^2 = 99.4% (SD ± 0.4%).
† BPD = $-1.56 + 0.360(CA) - (4.85 \times 10^{-5}[CA^3])$, where CA is the conceptual age. r^2 = 99.0%.

cross-sectional data (mean SD, 0.21 cm; range, 0.06 to 0.43 cm); this is probably related to the smaller sample size in the longitudinal study.

Theoretically, questions concerning the validity of both cross-sectional and average longitudinal BPD growth curves can be eliminated if both types of studies give the same results. Since the nature of potential errors is so different, it is extremely unlikely that these errors would affect each curve in precisely the manner needed to produce the same wrong curve. The alternative hypothesis—namely, that the potential errors are not significant and that both methods are providing valid estimates of the same population growth curve—is considered much more probable.

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