Correlation of Fetal Age and Measurements Between 10 and 26 Weeks of Gestation

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Fetal measurements, especially fetal foot length, were correlated with fetal age—as measured by last menstrual dates—for 1800 tissue specimens obtained after dilatation and evacuation abortion. These observations were compared with Streeter's results from 1920. Fetal ages ranged from ten through 26 completed menstrual weeks. Fetal measurements including weight, knee-to-heel length, biparietal diameter, placental weight, and amniotic fluid volume were correlated with foot length. Sonographic biparietal diameter obtained by real-time imaging was correlated with tissue measurement of biparietal diameter for various fetal ages. The difficulties of establishing valid correlations are discussed, and a table of recommended values for fetal measurements by week of fetal age is provided. ***(Obstet Gynecol 63:26, 1984)***

In reading Streeter's[1] 1920 description of fetal measurements, one senses the frustration he experienced in studying this stage of human development. Most of his specimens were obtained from obstetric departments throughout the country where women had experienced spontaneous abortions. Little was known of the pregnancy histories, and the menstrual dates were frequently absent or questionable. Because the specimens were preserved in formalin, Streeter advises us that an artifactual element may have been introduced.

No similarly complete data concerning human fetal measurements have appeared in the medical literature since Streeter published his results. The present report reviews fetal measurements from the tenth through the 26th completed menstrual week of fetal age in fresh specimens obtained through dilatation and evacuation abortion in a private outpatient abortion facility. Results are compared with those obtained by Streeter.

Materials and Methods

In all cases, specimens were obtained from induced abortions performed on patients requesting this procedure in the author's private medical practice. In all patients from 14 menstrual weeks on, a serial multiple laminaria protocol was used which resulted, with few exceptions, in a cervical dilatation of 2 to 3 cm by the time the procedure was performed.[2] For patients with pregnancies of 20 menstrual weeks or more, hyperosmolar urea solution was injected intraamniotically several hours before the procedure.[3] The wide dilatation provided by the serial multiple laminaria treatment and, in the more advanced pregnancies, by urea amnioinfusion, permitted the use of large forceps to collapse the fetal calvarium before delivery. In some cases, the fetus was delivered virtually intact.

Routine tissue examination was performed in all cases to assure completion of the procedure and to identify unusual situations such as hydatidiform mole and multiple gestations. The tissue examination was performed immediately after the abortion procedure. Equipment consisted of an ordinary 500-g spring scale, a triple-beam balance scale, forceps, basins, and a clear plastic ruler. As tissue was removed from the collecting vessels, it was separated into fetal tissue and placenta. Blood was permitted to drain from the placenta to the extent possible. Total tissue weight and then fetal weight and placental weight were obtained. After the separate components were weighed, fetal foot length, knee-to-heel length, and biparietal diameter were measured.

The fetal foot was turned upward and the clear plastic ruler laid on it for measurement. Sight measurement was taken from the tip of the longest toe (almost always the second) to the tip of the heel. In measuring knee-to-heel distance, the leg was flexed and the ruler sighted from the bottom of the heel to the top of the flexed knee.

Biparietal diameter was measured in most cases by holding the inverted, collapsed fetal calvarium under a stream of water to fill it through the foramen magnum or some defect that may have been created in the base of the cranium. The ruler was placed across the surface above the specimen and the sides of the cranium were

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sighted through the ruler markings on either side. In cases where the fetus was intact, biparietal diameter was measured directly by sighting a ruler across the top of the calvarium.

Amniotic fluid was measured in two ways. First, the midtrimester abortion procedure was usually begun by rupturing membranes with forceps or a hook. This usually permitted free drainage of the amniotic fluid into a basin for direct measurement. Thereafter, almost all collected fluid represented blood lost during the procedure. In cases where blood was mixed with amniotic fluid, the clot was removed with the gloved hand and placed into a graduated beaker.

Midway through the study, ultrasound equipment became available at a nearby hospital. All middle-trimester patients were required to obtain ultrasound evaluation for an accurate preoperative diagnosis of gestational length. Results of correlations between (outside–to–outside) sonographic cephalometry and clinical measurement of obtained tissue have been reported elsewhere.[4] A total of 237 observations was made under these arrangements.

Later, real-time ultrasound equipment was obtained. Results of these examinations were used to provide general correlations with fetal measurements as well as correlations between the (outside–to–inside) cephalometry and measurement of biparietal diameter in the aborted specimen. Correlations between sonographic cephalometry and clinical measurement were made for 631 cases under the conditions of real-time ultrasound availability.

Dates of the last normal menstrual period (LMP) were obtained directly from forms filled out by patients at the time of the first visit. Patients with no menses subsequent to last term delivery or abortion were excluded from analysis.

Patients came from throughout the midwestern and western United States and Canada. The median age was 19. Sixty-five percent of the patients were experiencing their first pregnancy, and 86% were having their first abortion. Preoperative estimates of fetal age ranged from ten to 24 completed menstrual weeks with sonographic biparietal diameter readings from 19 to 56 mm. A cutoff of 56 mm by sonographic biparietal diameter was used as the upper limit of patients accepted for abortion.

Regression analysis and scatterplot formation of the observations were conducted including cases in which both a reliable LMP date and measurable fetal foot length were available. Fetal age was used as an independent variable, and foot length was used as a dependent variable. Fetal foot length was correlated with all other fetal measurements according to availability, with foot length as independent and other fetal measurements as dependent variables. Correlations were also made between fetal weight and biparietal diameter and between sonographic and clinical biparietal diameters.

Analysis of the Streeter data was performed by examining Tables 6 and 7 from Streeter's original paper and extracting the raw data. Streeter's observations were used only if both the foot length and actual reported menstrual age of the specimen were reported ($N = 244$). Regression analysis and scatterplot formation were also performed on these data, and results were compared with current observations.

Results

Following 2719 first- and second-trimester abortion procedures, fetal foot measurements were possible on 1800 specimens. Foot lengths ranged from 3 to 53 mm, knee–to–heel lengths from 5 to 91 mm, fetal weights from 2 to 906 g, placental weights from 7 to 366 g, biparietal diameters from 10 to 62 mm, and sonographic biparietal diameters (outside–to–inside) from 18 to 56 mm. Mean and standard deviations for each week of gestation are given in Table 1.

Scatterplot formation using fetal age as independent and foot length as dependent variables revealed a curvilinear association (Figure 1). Using foot length as the independent variable, scatterplots and regression analysis showed foot length to have a linear relationship to knee–to–heel length with a correlation of 0.985 ($N = 1418$); a curvilinear relationship to biparietal diameter, the increase in biparietal diameter decreasing with foot length ($N = 930$); a curvilinear and almost exponential relationship with fetal weight, fetal weight increasing dramatically with foot length ($N = 1182$; Figure 2); a linear relationship to placental weight, with considerable variance in placental weight ($N = 981$); and a more or less linear relationship to amniotic fluid volume ($N = 597$).

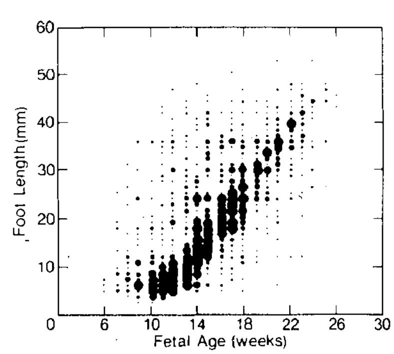

Figure 1. Scattergram of 1800 observations of foot length plotted by weeks of fetal age, six to 26 menstrual weeks.

As with the first 237 observations, correlation between sonographic biparietal diameter and clinical biparietal diameter in 631 patients evaluated by real-time ultrasound in the clinic was 0.97. Comparison of the two regression lines revealed no difference in intercepts ($P > .83$) or slopes ($P > .89$).

A scattergram of biparietal diameter and fetal weight demonstrates that small increases in biparietal diameter are accompanied by large increases in fetal weight ($N = 865$; Figure 3).

Examination of the scatterplot of the Streeter data as well as regression analysis revealed a linear relationship between fetal age and foot length (Figure 4). Predicted values from Streeter were almost identical for both linear and quadratic equations and quite different from the recommended values that he gives in his Table 4 as derived from his Table 6.[1]

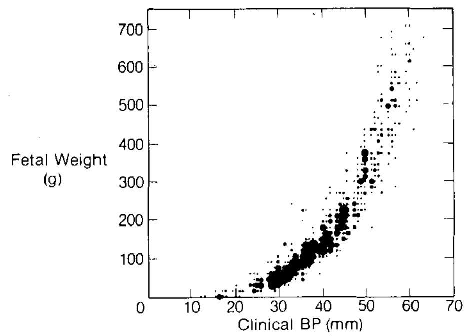

Figure 3. Scattergram of 854 observations of fetal weight plotted against clinical biparietal diameter (BP).

Discussion

There have been some attempts to confirm Streeter's original results reported in the medical literature. Most have been flawed by too small a number of specimens, important sources of bias, or lack of standardized procedures.[5–10] Trolle[11] studied fetuses from 250 cases of spontaneous abortion, comparing his results with those of Scammon and Streeter. Trolle's formula for calculating either foot length or gestational length is imprecise. Birkbeck and associates[12,13] produced internal correlations of fetal measurements ($N = 200$) and correlated foot length with menstrual dates ($N = 56$). The resulting regression equation was linear and different from that obtained in the present study. Comparison of slopes and intercepts is impossible without more information.

Berger et al[14] compared biparietal diameter with crown–rump length and compared each with gestational age, and Brenner et al[15] developed a standard of fetal growth using fetal weight and length. Both series were based on large numbers of cases. Golbus and Berry[16] examined 133 fetuses, giving great attention to organ weights, but they did not give the details of a linear model describing the relationship between foot length and gestational age.

Weiner et al[17] and Sabbagha and Hughey[18] have constructed composite sonographic curves for estimating gestational age. Both groups of authors have discussed the errors and variations inherent in sonographic results; neither group of authors, however, compares their sonographic results with directly related clinical findings. The report of Weiner et al provides neither the polynomial formula from which the composite curve is derived nor the table of values that could accompany it. Difficulty in interpreting the published curve reduces its helpfulness. Sabbagha and Hughey's composite table of values is somewhat different from the results presented here, especially in the 23 to 26-week fetal age portion of the scale. It is not possible to deduce whether these variations represent truly different results, variations in the methods of observation by the contributors to the composite values, or insufficient data in the current set of observations.

The problem each investigator faces in the study of

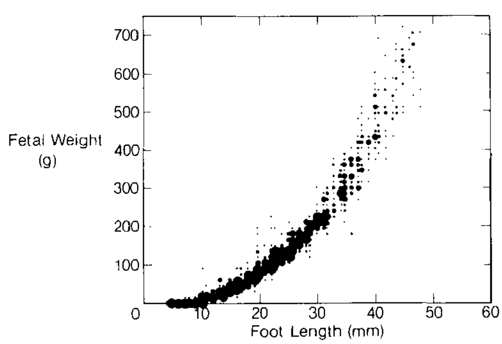

Figure 2. Scattergram of 1182 observations of fetal weight in grams plotted against foot length in millimeters.

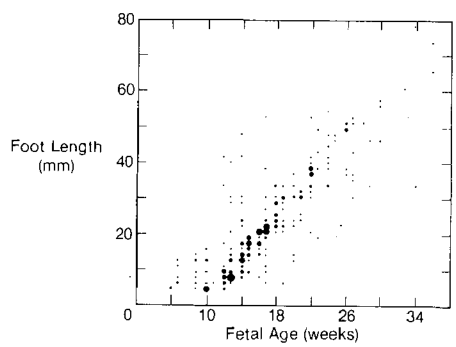

Figure 4. Scattergram of Streeter's 244 observations of foot length plotted by weeks of fetal age, six to 33 menstrual weeks. Adapted.[1]

Table 1. Frequency Tabulations,* by Week of Fetal Age (N = 1800)

Fetal age (wk)	Foot length (mm)	Knee–heel length (mm)	Fetal weight (g)	Placental weight (g)	Biparietal diameter (mm)	Sonographic biparietal diameter (mm)	Amniotic fluid volume (ml)
10	$\bar{X}$ = 8	$\bar{X}$ = 14	$\bar{X}$ = 54				
	SD = 5	SD = 12	SD = 103				
11	$\bar{X}$ = 9	$\bar{X}$ = 14	$\bar{X}$ = 78				
	SD = 7	SD = 8	SD = 144				
12	$\bar{X}$ = 11	$\bar{X}$ = 18	$\bar{X}$ = 70	$\bar{X}$ = 90	$\bar{X}$ = 32	$\bar{X}$ = 31	$\bar{X}$ = 180
	SD = 8	SD = 13	SD = 118	SD = 75	SD = 13	SD = 12	SD = 150
13	$\bar{X}$ = 14	$\bar{X}$ = 24	$\bar{X}$ = 91	$\bar{X}$ = 94	$\bar{X}$ = 33	$\bar{X}$ = 29	$\bar{X}$ = 159
	SD = 9	SD = 15	SD = 131	SD = 62	SD = 12	SD = 9	SD = 148
14	$\bar{X}$ = 17	$\bar{X}$ = 28	$\bar{X}$ = 84	$\bar{X}$ = 96	$\bar{X}$ = 32	$\bar{X}$ = 31	$\bar{X}$ = 141
	SD = 8	SD = 13	SD = 100	SD = 50	SD = 9	SD = 9	SD = 120
15	$\bar{X}$ = 21	$\bar{X}$ = 36	$\bar{X}$ = 128	$\bar{X}$ = 116	$\bar{X}$ = 34	$\bar{X}$ = 36	$\bar{X}$ = 164
	SD = 8	SD = 15	SD = 131	SD = 61	SD = 9	SD = 9	SD = 123
16	$\bar{X}$ = 22	$\bar{X}$ = 37	$\bar{X}$ = 133	$\bar{X}$ = 120	$\bar{X}$ = 36	$\bar{X}$ = 36	$\bar{X}$ = 197
	SD = 7	SD = 12	SD = 96	SD = 41	SD = 8	SD = 8	SD = 130
17	$\bar{X}$ = 24	$\bar{X}$ = 42	$\bar{X}$ = 162	$\bar{X}$ = 129	$\bar{X}$ = 38	$\bar{X}$ = 39	$\bar{X}$ = 230
	SD = 7	SD = 12	SD = 108	SD = 49	SD = 9	SD = 6	SD = 130
18	$\bar{X}$ = 26	$\bar{X}$ = 43	$\bar{X}$ = 185	$\bar{X}$ = 138	$\bar{X}$ = 39	$\bar{X}$ = 39	$\bar{X}$ = 265
	SD = 8	SD = 12	SD = 127	SD = 61	SD = 10	SD = 7	SD = 187
19	$\bar{X}$ = 29	$\bar{X}$ = 49	$\bar{X}$ = 227	$\bar{X}$ = 155	$\bar{X}$ = 42	$\bar{X}$ = 43	$\bar{X}$ = 355
	SD = 6	SD = 11	SD = 116	SD = 53	SD = 10	SD = 7	SD = 187
20	$\bar{X}$ = 32	$\bar{X}$ = 53	$\bar{X}$ = 280	$\bar{X}$ = 171	$\bar{X}$ = 47	$\bar{X}$ = 46	$\bar{X}$ = 368
	SD = 6	SD = 9	SD = 122	SD = 56	SD = 6	SD = 6	SD = 159
21	$\bar{X}$ = 34	$\bar{X}$ = 57	$\bar{X}$ = 344	$\bar{X}$ = 195	$\bar{X}$ = 48	$\bar{X}$ = 47	$\bar{X}$ = 360
	SD = 8	SD = 13	SD = 145	SD = 57	SD = 7	SD = 6	SD = 184
22	$\bar{X}$ = 37	$\bar{X}$ = 61	$\bar{X}$ = 433	$\bar{X}$ = 219	$\bar{X}$ = 52	$\bar{X}$ = 49	$\bar{X}$ = 408
	SD = 7	SD = 12	SD = 182	SD = 66	SD = 6	SD = 7	SD = 243
23	$\bar{X}$ = 38	$\bar{X}$ = 64	$\bar{X}$ = 423	$\bar{X}$ = 215	$\bar{X}$ = 53	$\bar{X}$ = 51	
	SD = 8	SD = 10	SD = 160	SD = 68	SD = 6	SD = 5	
24	$\bar{X}$ = 39	$\bar{X}$ = 66	$\bar{X}$ = 449	$\bar{X}$ = 219	$\bar{X}$ = 53	$\bar{X}$ = 51	
	SD = 8	SD = 10	SD = 211	SD = 96	SD = 6	SD = 5	
25	$\bar{X}$ = 41	$\bar{X}$ = 67	$\bar{X}$ = 493	$\bar{X}$ = 227	$\bar{X}$ = 53	$\bar{X}$ = 50	
	SD = 8	SD = 12	SD = 164	SD = 93	SD = 10	SD = 9	

$\bar{X}$ = arithmetic mean; SD = standard deviation.
* Complete frequency tabulation data available from author.

this subject is epistemologic: How do we know what we know? The clinician must go beyond questioning whether recommended values are based on accurate measurements. It is a question of validity rather than of precision or reliability.[19] For example, the question of precision in measuring biparietal diameter by filling an inverted and empty calvarium with water is not as important as whether this method closely approximates the true contour and that it is measured the same way each time. Use of a highly precise instrument would not overcome the problems of trying to approximate the natural shape. The methodologic antidotes are reliability (measuring the same way each time) and a large number of observations. These objectives are enhanced by the use of simple techniques and easily obtained instruments.

By the same token, use of the fetal foot length is chosen for developing a point of internal validity because it is usually available in tissue specimens. The number that can be observed is large and approximates the total number of specimens. It can be measured quite accurately the same way each time with simple

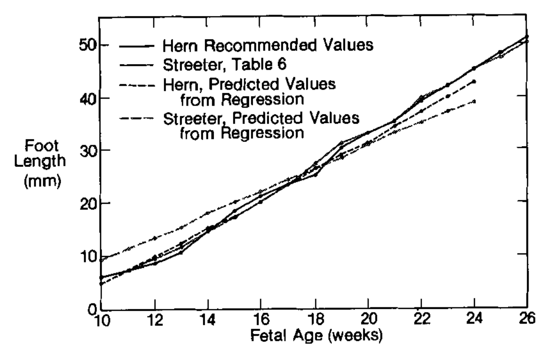

Figure 5. Plot comparing Streeter's recommended values from his Table 6; predicted values from Streeter's raw observations; predicted values from regression, current observations; and recommended values given in Table 3; foot length plotted against fetal age in weeks, ten to 26 menstrual weeks gestation.

Table 2. Predicted Values of Foot Length by Week of Fetal Age From Linear Regression Formula*

Fetal age (wk)	Predicted foot length (mm)	95% confidence interval (mm)
12	9.2	9.0–9.4
13	12.0	11.8–12.2
14	14.9	14.6–15.1
15	17.7	17.4–17.9
16	20.5	20.2–20.7
17	23.3	23.1–23.6
18	26.1	25.9–26.4
19	28.9	28.6–29.2
20	31.8	31.5–32.0
21	34.6	34.3–34.9
22	37.4	37.1–37.7
23	40.2	39.9–40.5
24	43.0	42.7–43.4

* Adjusted data (2 SD from raw median); 95% confidence interval; where foot length = −18.96 +2.82 (fetal age).

instruments, and that fact reduces the uncertainty of observations to one side of the equation, date of the last menstrual period. Because we know that there is a considerable variation in the accuracy of the reported LMPs, the methodologic antidote to the question of validity is a large number of observations. No assumptions can be made that other kinds of observations such as preoperative sonograms are more likely to yield a certain estimate of fetal age. The assumptions of the sonographic estimates of fetal age may themselves be wrong. The only way to develop a valid starting point is to use an imperfect but generally accurate independent variable not influenced by the observer's errors (LMP date) and compare that with a highly available and easily measurable dependent variable (foot length). Otherwise, sonographic and clinical biparietal correlations unrelated to internally valid indices of fetal age remain just that—correlations. They are descriptive but not diagnostic.

Table 3. Table of Recommended Values for Fetal Measurements, by Completed Menstrual Week of Fetal Age

Fetal age (wk)	Foot length (mm)	Knee–heel length (mm)	Fetal weight (g)	Placental weight (g)	Amniotic fluid volume (ml)	Clinical biparietal diameter (mm)	Sonographic biparietal diameter (mm)
10	6 (5–6)	8					
11	7	11					
12	8 (8–9)	13	14	26		18	18
13	10 (10–12)	17	18	38	50	23	23
14	14 (13–16)	24	36	63	100	26	25
15	18 (17–19)	31	66	87	125	31	30
16	21 (20–22)	36	97	105	175	35	34
17	23 (23,24)	40	122	117	200	37	35
18	25 (25–27)	43	150	130	250	40	38
19	30 (28–31)	51	234	160	300	45	43
20	33 (32,33)	56	294	178	350	48	46
21	35 (34–36)	60	338	191	400	50	47
22	39 (37–40)	66	434	215		53	50
23	42 (41–43)	72	517	233		55	52
24	45 (44–46)	77	606	252		58	55
25	48 (47–49)	82	702	270		60	57
26	51 (50,51)	87	805	288		61	58

Table 4. Predicted Values of Biparietal Diameter From Sonographic Biparietal Diameter,* Including Recommended Range by Week of Fetal Age

Fetal age (wk)	Observed sonographic biparietal diameter (mm)	Predicted biparietal diameter (mm)	Recommended range, sonographic biparietal diameter (mm)
≤11			≤16
12	18	18	17–21
13	23	23	22–24
14	25	26	25–28
15	30	31	29–31
16	34	35	32–34
17	35	37	35–36
18	38	40	37–39
19	43	45	40–43
20	46	48	44–46
21	47	50	47–48
22	50	53	49–50
23	52	55	51–53
24	55	58	54–56
25	57	60	57–58
26	58	61	58+

* Outside–to–inside diameter.

Central tendencies in the progressive comparison of fetal measurements and imputed fetal ages, however, can be deceptive because of bias introduced by inaccurate reported menstrual dates. Therefore, a mathematic study (regression analysis) must inform the interpretation by disclosing the general relationship of values.

The scatterplot of 1800 observations (Figure 1) indicates a curvilinear association between fetal age and foot length, for example. The linear regression equation was a fair predictor of fetal foot values by comparison with central tendencies shown in the frequency tabulations, but the quadratic regression predicted slightly more variance. A comparison with Streeter's data showed the Streeter values to be similar to the present linear values.

Examination of Figure 1, however, reveals many instances of suspected second-trimester foot lengths in the early weeks (ten to 14 menstrual weeks fetal age). These observations are probably due to inaccuracy in reported last menstrual dates among second-trimester patients. This source of bias adversely affects the description of a true regression line for the early cases.[20] At the lower part of the curve, all the erroneous observations are, and must necessarily be, on the upper side of the line. This problem is confirmed by examination of the frequency tabulations, which show large accumulations of observations around small modal and median numbers for foot length in the early weeks with a large upward scatter at each week of fetal age. The veracity of a curvilinear association is brought into question. At the upper part of the curve, many observations may be missing, having been placed elsewhere due to reporting bias. The upper values derived from the regression line may be in error as a result; in a linear analysis, they would tend to be on the low side.

To compensate for this source of error, observations were restricted to those falling within two standard deviations on either side of the raw median. The resulting linear association (Table 2) appears to provide a more accurate description of the relationship of true values from 12 to 24 weeks fetal age than the use of the raw regression line influenced by distorted values (eg, a 40-mm foot length associated with a reported menstrual age of 10 to 12 weeks).

At the low end of the scale (12 menstrual weeks fetal age or less), the modal and median tendencies in the raw data do not follow the regression line; those adjusted central tendencies, along with regression relationships, serve as a guide for plotted values and recommended values. At the upper end, plotted values tend to be lower, as expected, than clinical observations indicate are the likely values. Figure 5 shows a combined plot of Streeter's calculated (linear) values from his raw data, Streeter's recommended values from arbitrary assignment, calculated values from the current (linear) regression equation, and current recommended values based on both adjusted central tendencies and regression relationships. Table 3 is a summary table of recommended values based on these procedures. Table 4 gives predicted values of biparietal diameter from real-time (outside–inside) sonographic biparietal diameter, along with recommended ranges of values, for fetal ages from 12 through 26 menstrual weeks.

These procedures appear to be better than either accepting an obviously inaccurate regression equation or using the central tendency values for each week of menstrual age. The recommended values are similar, but not quite the same, as those recommended by Streeter. The more recent values are recommended because they are based on a larger number of observations on fresh specimens obtained under highly controlled conditions, and they are not obtained by interpolation of a relatively small number of widely spaced values, as Streeter found necessary.

One combination of observations that appears to have considerable clinical significance is the apparent relationship between biparietal diameter and fetal weight from the 20th week of fetal age on. As fetal age increases and foot length increases, biparietal expansion slows and fetal weight increases rapidly, at least at the upper end of the growth curve observed in this series. A very small increase in biparietal diameter is associated with a dramatic increase in fetal weight, and therefore in fetal viability.[21]

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