Reference charts and equations of fetal biometry for normal singleton pregnant women in Shaanxi, China

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Summary

Objective: To construct reference charts and equations of fetal biometry for singleton pregnant women in Shaanxi, China. *Materials and Methods:* This was a cross-sectional study involving 6,832 singleton pregnant women. One set of fetal ultrasonographic measurement data between the 16^{th} to 41^{st} gestational weeks (GW) was randomly selected from each pregnant woman, and biparietal diameter (BPD), abdominal circumference (AC), and femur length (FL) were recorded. Mean and standard deviation(SD) of BPD, AC, and FL were fitted by polynomial. Centile = Mean + Z_{α} × SD was used to calculate centiles. Differences in the 50^{th} centile of BPD, AC, and FL between Hong Kong, Korean, Italian and Shaanxi fetuses were compared. *Results:* Mean of BPD, AC, and FL were well-fitted by quadratic polynomial, SD of BPD, AC and FL were fitted by linear regression. Equations for estimating mean and SD for BPD, AC, and FL from GW were obtained. Centiles for BPD, AC, and FL were calculated. From the 21^{st} GW, the differences in BPD, AC, and FL between Hong Kong, Korean, Italian, and Shaanxi fetuses became larger. *Conclusion:* Fetal biometry reference charts and equations for estimating fetal size and GW could be used in obstetrics practice and research in Shaanxi, China.

Key words: Biparietal diameter; Abdominal circumference; Femur length; Reference charts; Shaanxi.

Introduction

Every year, at least 60% of the four million neonatal deaths that occur worldwide are associated with low birth weight (LBW), caused by intrauterine growth restriction (IUGR), preterm delivery, and genetic/chromosomal abnormalities [1]. An objective assessment of fetal growth has enormous utility in prenatal care. Ultrasound examination and measurement of fetal biometry has been proven to be a useful and accurate examination in evaluating fetal growth and developing status, estimating fetal age, and delivery date [2-4]. However, selecting appropriate reference charts is very important in defining "abnormal fetal growth".

Fetal growth and development is a continuous process. The most apt style of reference standard for fetal growth and development assessment is gestational weeks (GW) related centile charts. Although fetal biometric charts and equations for various populations using a recommended method [5] were published in the medical literatures [6-11], these centile charts may be inappropriate for other populations, because fetal biometry varies significantly by population's characteristics, such as race, geography, etc [12, 13].

In China, national reference values for biparietal diameter (BPD), head circumference (HC), abdominal circumference (AD), and femur length FL) used in clinical practice are tabled as $\bar{x} \pm SD$ according to GW, and all these references were established in the later 1980s [14]. Reference centiles for fetal biometry fitted by appropriate method are not available in daily obstetric care practice in mainland China. Shaanxi is a larger province in north-west of China, with a population of about 38.0 million. In recent five years, the birth defect rate is about 120/100,000 and ranks third among the 31 provinces or autonomous regions in mainland China, and the incidence of LBW is about ten percent, which is two times higher than that of the whole country [15]. Cross-sectional reference centile charts and equations for Shaanxi population using appropriate methods have not previously been published. The aim of this study was to construct reference charts and a prediction model using the recommended method [7] based on multiple two-dimensional (2D) ultrasound measurements of fetal BPD, AC, and FL from the 16^{th} to 41^{st} GW. The authors also wanted to compare the difference between these charts and published reference charts of other populations.

Materials and Methods

Subjects

This was a cross-sectional study conducted in obstetric departments of five maternal and child care hospitals located in different areas in Shaanxi province, China. Subjects were 6,832 Chinese women routinely scheduled for ultrasound examinations in obstetric departments between January 1^{st} to December 31^{st}, 2010.

Inclusion criteria were the following: (1) both parents ethnically are Chinese; (2) the date of the first day of the last normal menstrual period, and regular menstrual cycles (26-30 days) prior to pregnancy are remembered exactly; (3) difference in gestational age according to last menstrual period and according

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to fetal crown-rump length (CRL) measurement in the first trimester of ≤ four days [16].

Exclusion criteria were the following: (1) maternal diseases, such as hypertension, pre-eclampsia, diabetes mellitus, renal disease; (2) multiple pregnancies; (3) fetuses with congenital malformation, chromosomal abnormality, or IUGR; (4) uncertain date of last menstrual period, and irregular menstrual cycles.

Measurements

In each hospital, all examinations were performed by an appointed ultrasound physician with at least five years obstetric ultrasound experience. All the five ultrasound physicians were pre-trained. Ultrasound equipment was not the same type in this study, but were routinely calibrated by the Department of Biomedical Engineering of each hospital using an American Institute of Ultrasound in Medicine standard test object at intervals not exceeding three months.

Strict criteria for the characteristics of the image and caliper placement were defined at the beginning of this study according to standard methods [3, 4] and were described as follows: to maximize the accuracy of caliper placement, all measurement data were taken from images obtained at the largest possible magnification. BPDs were obtained from a transverse axial plane of the fetal head showing a central midline echo broken in the anterior third by the cavum septum pellucidum and demonstrating the anterior and posterior horns of the lateral ventricle. BPD was measured from the outer edge of the proximal calvarial wall, both to the inner edge of the distal calvarial wall. AC was measured on a transverse circular plane of the fetal abdomen at the level where the spine, descending aorta, anterior third of the umbilical vein, and stomach bubble could be seen in the same plane. FL was measured from the greater trochanter to the lateral condyle, with both ends clearly visible and at a horizontal angle < 45°. Each ultrasound file was specially marked to ensure that data from the same pregnant woman were not entered into the study more than once. Each parameter was measured three times, and the mean was calculated and recorded on database specifically designed for this study. Last menstrual date, delivery date, ultrasound examination date, and other social-economic characteristics were also recorded in this database.

The present study was approved by the Fourth Military Medical University Ethics Committee for Human Research, and all the subjects signed an information consent form.

Statistical methods

The database was checked carefully during and after input to ensure data quality. To reduce correlation between measurements of repeated ultrasonography within a pregnancy, only one set of ultrasonography measurements was randomly selected from all the ultrasonography data during each pregnancy by using a computer program. The selected ultrasonography data were used for further analysis. The selected ultrasonography date and last menstrual date were used to calculate GW, rounding up when gestational age more than three days and down at three or less days. From the frequency table of each set of measurements, the authors found the number of validated data for BPD, AC, and FL in many GW before 16th were less than 50, so they only constructed reference charts for BPD, AC, and FL between the 16th to the 41st GW, all with a validated measurement number above 150.

Statistical analysis was performed using the Statistical Package for Social Sciences, version 16.0 (SPSS Inc., Chicago, IL, USA). In order to obtain centiles for fetal biometric measurements, a multi-step procedure based on a regression model [17] was used. The procedure began from the equation for centiles:

$$\text{Centile} = \text{Mean} + Z_{\alpha}\alpha \times SD$$

Table 1. — *Numbers of valid measurements of BPD, AC, and FL according to GW.*

GW	BPD	AC	FL
16	232	232	219
17	224	224	233
18	219	219	201
19	213	213	213
20	249	249	255
21	231	231	206
22	259	259	263
23	246	246	240
24	239	239	239
25	246	246	246
26	290	290	290
27	278	278	278
28	204	204	216
29	286	286	286
30	312	312	309
31	326	326	321
32	317	317	323
33	295	295	301
34	319	319	297
35	277	277	277
36	267	267	267
37	301	301	301
38	341	341	341
39	231	231	231
40	196	196	196
41	157	157	157
Total	6,755	6,755	6,706

where *Mean* and *SD* are respectively the mean and standard deviation of fetal measurements for each GW, Z_{α} is ± 1.88 for the 3rd and 97th centiles, ± 1.645 for the 5th and 95th centiles, ± 1.281 for the 10th and 90th centiles, and ± 0.6745 for the 25th and 75th centiles. Firstly, *mean*s were modeled by fitting a polynomial curve to the original data. Models were chosen based on the coefficient of multiple determinations (R^2) and Sum of Squares Due to Error (*SSE*). R^2 closer to 1 and *SSE* closer to 0 indicated a better fitting. Then, the *residuals*, which indicated the difference between fitted *mean* and raw *mean* of original data, were used for deriving the variability as a function of GW. After removing the algebraic signs from the *residuals*, they were regressed on GW by using a linear model. The fitted values multiplied by a corrective constant equal to $=\pi/2$ gave the GW-specific *SD* estimates. These values, together with the fitted *mean* obtained in the first step, were thus substituted in the centile equation to obtain any centiles for BPD, AC, and FL. Equations for estimating GW from BPD, AC, and FL were also obtained by fitting polynomial.

Centiles of this study and those published by Italian, Korean, and Hong Kong studies fitted by the recommended method were compared. The mean fetal measurements for Hong Kong were calculated from the published equations [18], for Korea [19], and Italy [20], referenced from the published centile tables. Because the smallest GW for Italians is the 17th week, so the 50th centile between the 17th to the 41st GW were compared to reflect the difference in fetal size between Italian, Korean, Hong Kong, and Shaanxi populations.

Results

General characteristics of the subjects

Fetal biometric measurements from 6,832 singleton preg-

Table 2. — *Centiles for BPD (cm) of Shaanxi singleton pregnancies.*

GW	3rd	5th	10th	25th	50th	75th	90th	95th	97th
16	2.4	2.5	2.6	2.9	3.1	3.4	3.7	3.8	3.9
17	2.8	2.9	3.0	3.2	3.5	3.8	4.0	4.2	4.3
18	3.1	3.2	3.4	3.6	3.9	4.1	4.4	4.5	4.6
19	3.5	3.6	3.7	4.0	4.2	4.5	4.7	4.9	5.0
20	3.8	3.9	4.0	4.3	4.6	4.8	5.1	5.2	5.3
21	4.1	4.2	4.4	4.6	4.9	5.1	5.4	5.5	5.6
22	4.5	4.5	4.7	4.9	5.2	5.4	5.7	5.8	5.9
23	4.8	4.8	5.0	5.2	5.5	5.7	6.0	6.1	6.2
24	5.0	5.1	5.3	5.5	5.8	6.0	6.3	6.4	6.5
25	5.3	5.4	5.6	5.8	6.0	6.3	6.5	6.7	6.8
26	5.6	5.7	5.8	6.0	6.3	6.6	6.8	6.9	7.0
27	5.8	5.9	6.1	6.3	6.5	6.8	7.0	7.2	7.3
28	6.1	6.2	6.3	6.5	6.8	7.0	7.3	7.4	7.5
29	6.3	6.4	6.5	6.8	7.0	7.3	7.5	7.6	7.7
30	6.5	6.6	6.8	7.0	7.2	7.5	7.7	7.8	7.9
31	6.7	6.8	7.0	7.2	7.4	7.7	7.9	8.0	8.1
32	6.9	7.0	7.1	7.4	7.6	7.9	8.1	8.2	8.3
33	7.1	7.2	7.3	7.5	7.8	8.0	8.2	8.4	8.5
34	7.3	7.4	7.5	7.7	8.0	8.2	8.4	8.5	8.6
35	7.4	7.5	7.7	7.9	8.1	8.3	8.6	8.7	8.8
36	7.6	7.7	7.8	8.0	8.2	8.5	8.7	8.8	8.9
37	7.7	7.8	7.9	8.1	8.4	8.6	8.8	9.0	9.0
38	7.8	7.9	8.0	8.3	8.5	8.7	8.9	9.1	9.1
39	8.0	8.0	8.2	8.4	8.6	8.8	9.0	9.2	9.2
40	8.0	8.1	8.3	8.5	8.7	8.9	9.1	9.3	9.3
41	8.1	8.2	8.3	8.5	8.8	9.0	9.2	9.3	9.4

Table 3. — *Centiles for AC (cm) of Shaanxi singleton pregnancies.*

GW	3rd	5th	10th	25th	50th	75th	90th	95th	97th
16	8.8	9.0	9.3	9.8	11.5	11.0	11.5	11.9	12.1
17	9.8	10.0	10.4	10.9	10.6	12.2	12.8	13.1	13.3
18	10.8	11.1	11.4	12.0	12.5	13.3	13.9	14.3	14.5
19	11.8	12.1	12.4	13.1	12.9	14.5	15.1	15.5	15.7
20	12.8	13.1	13.5	14.1	15.5	15.6	16.3	16.6	16.9
21	13.8	14.0	14.4	15.1	15.6	16.7	17.4	17.8	18.1
22	14.7	15.0	15.4	16.1	16.5	17.7	18.5	18.9	19.2
23	15.7	15.9	16.4	17.1	19.0	18.8	19.5	20.0	20.3
24	16.6	16.9	17.3	18.1	19.5	19.8	20.6	21.0	21.3
25	17.5	17.8	18.3	19.1	19.8	20.8	21.6	22.1	22.4
26	18.4	18.7	19.2	20.0	20.3	21.8	22.6	23.1	23.4
27	19.3	19.6	20.1	20.9	21.7	22.8	23.6	24.1	24.4
28	20.2	20.5	21.0	21.8	22.8	23.7	24.5	25.0	25.4
29	21.0	21.3	21.9	22.7	23.9	24.6	25.5	26.0	26.3
30	21.9	22.2	22.7	23.6	24.9	25.5	26.4	26.9	27.2
31	22.7	23.0	23.5	24.4	26.2	26.4	27.3	27.8	28.1
32	23.5	23.8	24.4	25.3	26.3	27.2	28.1	28.6	29.0
33	24.3	24.6	25.2	26.1	27.0	28.1	28.9	29.5	29.8
34	25.1	25.4	26.0	26.9	26.7	28.9	29.8	30.3	30.6
35	25.9	26.2	26.8	27.7	28.2	29.7	30.6	31.1	31.4
36	26.6	27.0	27.5	28.4	29.5	30.4	31.3	31.9	32.2
37	27.4	27.7	28.3	29.2	29.6	31.2	32.1	32.6	32.9
38	28.1	28.5	29.0	29.9	31.3	31.9	32.8	33.3	33.7
39	28.8	29.2	29.7	30.6	32.1	32.6	33.5	34.0	34.4
40	29.5	29.9	30.4	31.3	32.1	33.3	34.1	34.7	35.0
41	30.2	30.6	31.1	32.0	33.1	33.9	34.8	35.3	35.7

nancies were analyzed. Among all the fetuses, males occupied 51.2%, the first delivery occupied 80.4%, from urban areas occupied 47.3%, and the mean age of the subjects was

Table 4. — *Centiles for FL (cm) of Shaanxi singleton pregnancies.*

GW	3rd	5th	10th	25th	50th	75th	90th	95th	97th
16	1.0	1.1	1.3	1.6	1.8	2.1	2.4	2.5	2.6
17	1.3	1.4	1.6	1.9	2.1	2.4	2.7	2.8	2.9
18	1.6	1.7	1.9	2.1	2.4	2.7	3.0	3.1	3.2
19	1.9	2.0	2.2	2.4	2.7	3.0	3.3	3.4	3.5
20	2.2	2.3	2.4	2.7	3.0	3.3	3.6	3.7	3.8
21	2.4	2.5	2.7	3.0	3.3	3.6	3.8	4.0	4.1
22	2.7	2.8	3.0	3.2	3.5	3.8	4.1	4.3	4.4
23	2.9	3.1	3.2	3.5	3.8	4.1	4.4	4.5	4.6
24	3.2	3.3	3.5	3.7	4.0	4.3	4.6	4.8	4.9
25	3.4	3.5	3.7	4.0	4.3	4.6	4.8	5.0	5.1
26	3.6	3.8	3.9	4.2	4.5	4.8	5.1	5.2	5.3
27	3.9	4.0	4.1	4.4	4.7	5.0	5.3	5.5	5.6
28	4.1	4.2	4.3	4.6	4.9	5.2	5.5	5.7	5.8
29	4.3	4.4	4.6	4.8	5.1	5.5	5.7	5.9	6.0
30	4.5	4.6	4.7	5.0	5.3	5.7	5.9	6.1	6.2
31	4.7	4.8	4.9	5.2	5.5	5.8	6.1	6.3	6.4
32	4.8	4.9	5.1	5.4	5.7	6.0	6.3	6.5	6.6
33	5.0	5.1	5.3	5.6	5.9	6.2	6.5	6.7	6.8
34	5.2	5.3	5.4	5.7	6.1	6.4	6.7	6.8	6.9
35	5.3	5.4	5.6	5.9	6.2	6.5	6.8	7.0	7.1
36	5.5	5.6	5.7	6.0	6.4	6.7	7.0	7.1	7.3
37	5.6	5.7	5.9	6.2	6.5	6.8	7.1	7.3	7.4
38	5.7	5.8	6.0	6.3	6.6	7.0	7.3	7.4	7.5
39	5.8	6.0	6.1	6.4	6.8	7.1	7.4	7.6	7.7
40	6.0	6.1	6.3	6.6	6.9	7.2	7.5	7.7	7.8
41	6.1	6.2	6.4	6.7	7.0	7.3	7.6	7.8	7.9

Table 5. — *Sum of squares due to error (cm^2) of each centile for BPD, AC, and FL.*

Centile	BPD	AC	FL
3rd	0.11	0.09	0.09
5th	0.06	0.10	0.07
10th	0.07	0.02	0.06
25th	0.04	0.09	0.04
50th	0.02	0.07	0.03
75th	0.09	0.03	0.03
90th	0.04	0.05	0.04
95th	0.07	0.06	0.06
97th	0.09	0.11	0.09

27.4 ± 4.8 years. Not all the three measurements were obtained in some fetuses. The numbers of valid measurements for BPD, AC, and FL at each GW are shown in Table 1.

Equations for estimating mean and SD of BPD, AC and FL from GW

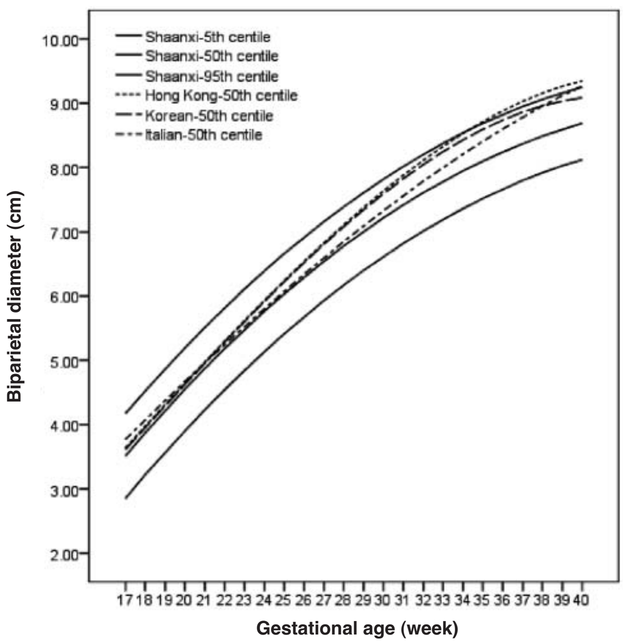
Mean BPD, AC, and FL were all well-fitted by quadratic polynomial. The residual for BPD, AC, and FL were fitted by straight line. Regression equations (mean BPD, AC or FL as dependent variable respectively, GW as independent variable) represented the relationship between fetal biometry and GW. The equations and corresponding R^2 are shown as follows: the equations for estimating the *SD* of BPD, AC, or FL from GW are also presented:

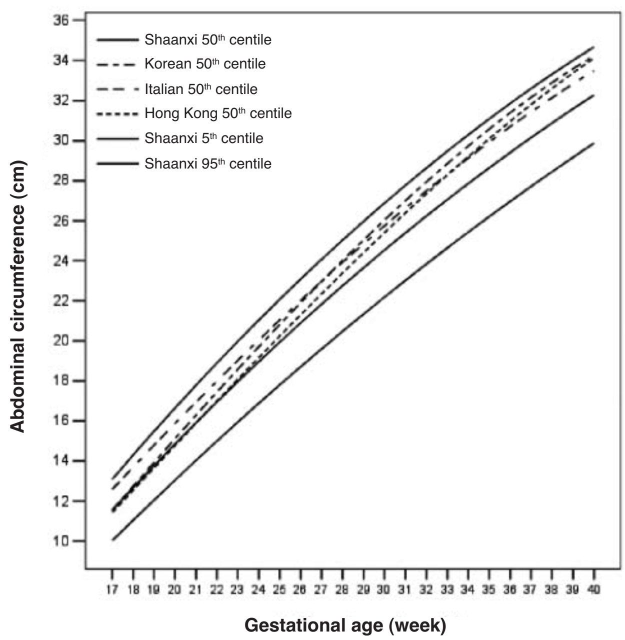
$$\text{BPD} = -4.393 + 0.567 \times \text{GW} - 0.006 \times \text{GW}^2 \; (R^2 = 0.947)$$

$$SD \text{ for BPD} = 1.253 \times (0.353 - 0.002 \times \text{GW})$$

$$\text{AC} = -10.389 + 1.457 \times \text{GW} - 0.01 \times \text{GW}^2 \; (R^2 = 0.993)$$

$$SD \text{ for AC} = -0.660 + 0.023 \times \text{GW}$$





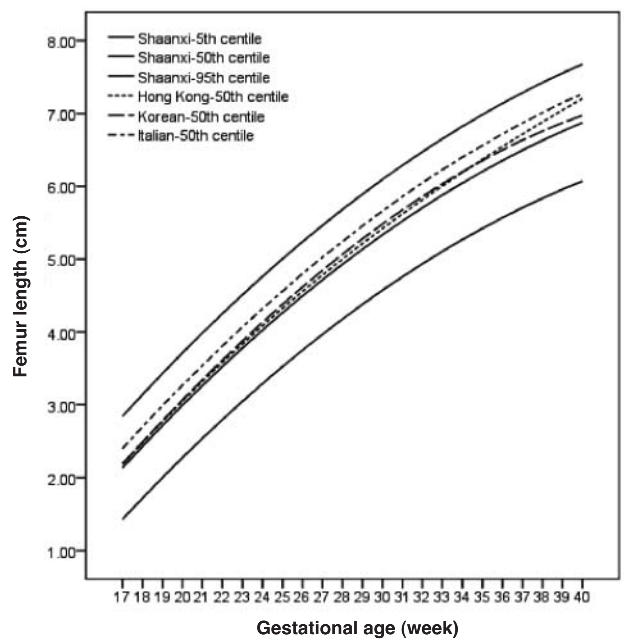


Figure 1. — Comparison of the 50th centile for BPD (cm) between Hong Kong, Korean, Italian, and Shaanxi fetuses.

Figure 2. — Comparison of the 50th centile for AC between Hong Kong, Korean, Italian, and Shaanxi fetuses.

Figure 3. — Comparison of the 50th centile for FL between Hong Kong, Korean, Italian, and Shaanxi fetuses.

$$FL = - 4.086 + 0.434 \times GW - 0.004 \times GW^2 \ (R^2 = 0.982)$$

$$SD \text{ for } FL = 1.253 \times (0.309 + 0.002 \times GW).$$

Using these equations, any centiles for BPD, AC, and FL could be calculated for each GW. *Mean* and the 3rd, 5th, 10th, 25th, 75th, 90th, 95th and 97th centiles for BPD, AC, and FL are shown in Tables 2 to 4. *SSE* between fitted centiles and raw centiles for BPD, AC, and FL are shown in Table 5, and all the *SSE* were close to zero, indicating all the models were well-fitted.

Equations for estimating GW from BPD, AC and FL

For estimation of GW, all the data were satisfactorily fitted by a quadratic polynomial model. The equations for estimating GW from BPD,AC or FL are as follows:

$$GW = 10.171 + 1.16 \times BPD + 0.2 \times BPD^2 \ (R^2 = 0.992)$$

$$GW = 9.652 + 0.492 \times AC + 0.014 \times AC^2 \ (R^2 = 0.993)$$

$$GW = 7.317 + 4.278 \times FL - 0.009 \times FL^2 \ (R^2 = 0.986)$$

Comparison of the 50th centile for BPD, AC, and FL between Shaanxi and other populations

Figure 1 shows that the 50th centile for BPD of Hong Kong and Italian fetuses were very close to that of Shaanxi before the 21st GW, whereas those of Hong Kong and Italy increased quickly. Upon the 31st GW, Hong Kong exceeded the 95th centile curve of Shaanxi, and increased continuously; Italy closed to the 95th centile curve of Shaanxi gradually. Before the 28th GW, the mean BPD of Korean fetuses was close to that of Shaanxi; after this time, it increased quickly and closed to the 95th centile curve of Shaanxi by the end of pregnancy. Figure 2 shows that the 50th centile for AC of the Italian fetuses was greater than that of Shaanxi, and that of Shaanxi was very close to that of Hong Kong and Korea before 24th GW and 20th GW, respectively. After this time, the 50th centile of Hong Kong and Korean fetuses increased faster than that of Shaanxi. Figure 3 shows that the 50th centile for FL of Hong Kong was always greater than that of Shaanxi, the difference became much larger at the end of pregnancy. The 50th centile for FL of Korean and Italian fetuses were very close to that of Shaanxi before the 23rd GW. After that, the two increased rather quickly and the difference between Italian and Shaanxi fetuses became larger as GW increased. After the 36th GW, the difference between Korean and Shaanxi fetuses became gradually smaller as GW increased. The three fetal biometrics of the three countries or region were all larger than those of Shaanxi by the end of pregnancy.

Discussion

In this study, centiles for BPD, AC, and FL of Shaanxi singleton pregnant women between the 16th to 41st GW were calculated using a recommended method [5, 17]. Equations for estimating BPD, AC, and FL from GW, and for estimating GW from BPD, AC, and FL were obtained by fitting polynomial. These equations were all well-fitted. Using these equations, centile charts (including the 3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 97th centiles) for BPD, AC, and FL were constructed. There were significant differences in the three fetal biometric measurements between Hong Kong, Korea, Italy, and Shaanxi.

Several studies have demonstrated racial variations in fetal growth [11-13, 21]. It was reported that fetuses of Turkish and Moroccan women had a shorter FL, smaller AC than those of Belgian women, and in Africa, AC and BPD of Nigerian fetuses were smaller than those of British fetuses [12]. The present results showed that there might be some differences in fetal size among pregnant women of Italy [20], Korea [19], Hong Kong [18], and Shaanxi. The 50th centiles for BPD of Shaanxi were significantly lower than that of the other three areas and the 50th centiles of AC and FL of Shaanxi were close to that of Hong Kong before 21st GW, and from 21st GW, the difference became larger. These differences could be explained by the different ethnic origin of the four studies in some extent. However, the larger difference between Hong Kong and Shaanxi, Korea, and Shaanxi might be explained as the larger difference in economic developing levels of the three study areas, because the three populations are all east-Asians, especially, Shaanxi and Hong Kong, are all Chinese.

Although there are many fetal biometric reference centile charts for different populations available, but most of them have some shortcomings [5-10], for example, data obtained from one hospital perhaps do not represent the whole characteristics of pregnant women in the country or region, sample size in many GW are too small to assure the precise of centiles, repeated measurements on the same fetus, formation of 'super normal' datasets by inappropriate exclusion of complicated pregnancies, and statistical methods used to fit centiles without considering the variability of measurements with gestational age [22]. All these shortcomings contribute to the fact that these reference centiles could not reflect realistically and objectively pregnant women to some extent. Appropriate methods have been published [5] and fetal biometry charts and equations for various populations using the correct method are now available in medical literatures [6-11, 18-20].

In order to make the present results more easily compared with Hong Kong, Koreans, and Italians, the design and statistical methods were the same as those of the three countries or regions [18-20]. The authors selected a cross-sectional design using only one set of ultrasonic fetal biometrics for each fetus, and centiles were fitted by using a multi-step procedure based on regression model. These measures can ensure the variability of measurements with GW [5].

Conclusion

The authors have constructed equations for estimating fetal BPD, AC, and FL based on a large sample of cross-sectional measurements of Shaanxi singleton pregnant women using a recommended method. According to these equations, any centiles for BPD, AC, and FL could be calculated based on GW and GW could be estimated based on BPD, AC, and FL, as well as the uncertainty in days. The reference charts were different from those of Hong Kong, Korea, and Italy. The authors believe that the reference charts and equations were well-fitted, and are ready for clinical use and research among Shaanxi pregnant women.

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