Standards for Fetal Abdominal Circumference and Estimated Fetal Weight in Shanghai, China

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Abstract

Introduction: While current evidence suggests that fetal skeletal parameters do not vary considerably across populations, there is uncertainty about the standards of abdominal circumference (AC) and estimated fetal weight (EFW), which are the basis of clinical guidelines for the management of fetal growth restriction. The use of different algorithms for mapping ultrasound parameters to fetal size parameters also make it difficult to make local applications of growth standards developed elsewhere. Therefore, we aimed to construct standards of AC and EFW for use in China.

Methods: This is an analysis of pregnant women who received antenatal care from 2009 to 2013 in Shanghai, China. A healthy cohort of 2529 singleton pregnancies defined by maternal, pregnancy and fetal characteristics and birth outcomes were selected for analysis. Ultrasound measurement was used to estimate gestational age and the Hadlock algorithm was used to calculate EFW.

Results: A linear increase of AC was observed from 16 to 35 weeks, after which the increase slightly flattened out. An accelerating increase of EFW was observed from 16 to 27 weeks, after which the increase became linear and then flattened out around 36 weeks. Model diagnostics showed sufficient goodness-of-fit of the standards.

Conclusion: Standards of AC and EFW are available to monitor fetal growth for pregnancy in China. Comparability with other cohorts cannot be conclusive as different analysis methods were used across studies.

Keywords: Abdominal circumference; Estimated fetal weight; Growth charts; Growth standards; Ultrasound, Chinese

Abbreviations: AC: Abdominal Circumference; APTD: Anterior-posterior Trunk Diameter; BPD: Biparietal Diameter; CI: Confidence Interval; CRL: Crown-rump Length; EFW: Estimated Fetal Weight; FGR: Fetal Growth Restriction; FL: Femur Length; GA: Gestational Age; HC: Head Circumference; SD: Standard Deviation; SGA: Small-for-gestational-age; TTD: Transverse Trunk Diameter

Introduction

Ultrasound measurement of fetal biometry is an important and commonly used tool in antenatal care. It measures biometric parameters such as biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC) and femur length (FL). Estimated fetal weight (EFW) can be calculated based on multiple biometric parameters using established formulae [1]. It is important not only to measure fetal biometric parameters accurately, but also to interpret the results appropriately. It helps to predict or diagnose fetal health problems.

Fetal growth restriction (FGR), conventionally defined as estimated fetal weight that is less than the 10th percentile for gestational age and small-for-gestational-age (SGA), conventionally defined as birth weight less than the 10th percentile for gestational age, are conditions that have been associated with increased risk of perinatal morbidity and mortality and increased metabolic and cardiovascular disease risk in later life [2-5]. The reduction of such risk depends on improved antenatal detection and careful clinical management [6]. Various studies have demonstrated that AC and EFW are preferred parameters to diagnose FGR or predict SGA [7,8]. Below 10th percentiles of AC or EFW standards has also been recommended as diagnostic criteria by recent national clinical guidelines [2,6,9].

Many fetal biometric standards are derived from Caucasian populations in Western Europe or North America. The INTERGROWTH-21 project has shown that skeletal size parameters, such as crown-rump length, fetal head circumference and newborn birth length, are similar across diverse geographical areas [10]. However, similarities across countries in AC or EFW have not been established.

There are limited numbers of fetal biometric standards derived from Chinese population. Two studies were conducted for Singaporean Chinese and another two studies for Hong Kong Chinese [11-14]. Environmental and social factors can affect pregnancy outcomes [15]. This urges the development of fetal biometric standards for the Chinese population in mainland China, where about 19% of the world’s population resides [16]. One study conducted in central-south China provided median AC using data from 1992 to 1993 [17]. However, they did not provide the 5th or 10th percentile of AC or EFW that are needed in diagnosis of FGR or prediction of SGA or the top percentiles that are useful for predicting macrosomia. In addition, their data were more than 20 years old and may not be the best evidence for current clinical practice given environmental and socio-economic changes in...
the past two decades in China. To assist clinical management of FGR and SGA in mainland China, growth standards of AC and EFW using most recent data are needed.

The aim of this study is to construct standards for AC and EFW for the Chinese population in mainland China, using ultrasound observations obtained in Shanghai, China, during 2009-2013.

**Materials and Methods**

Data for analysis were extracted from a routine clinical and ultrasound database for standard health care procedures of pregnant women who had their antenatal visits at the maternal unit of International Peace Maternity and Child Health Hospital, Shanghai, China from 2009 to 2013 [18]. Patient identifiers were removed from the dataset before analysis and ethical approval for the analysis was granted by the hospital's Institutional Review Board.

Women were advised to have ultrasound scans at gestational ages of 16th week, 24th week, 34th week and 38th week according to standard schedule of antenatal care at Shanghai, China. Crown-rump length (CRL), biparietal diameter (BPD), femur length (FL), anterior-posterior trunk diameter (APTD) and transverse trunk diameter (TTD) were measured in the antenatal ultrasound scans according to a protocol widely used in China [19]. Briefly, CRL was measured based on frozen image taken on stretched body at first antenatal visit for gestational age estimation. The maximum distance between crown and rump were recorded. AC was based on measurements of APTD and TTD and computed by the formula (APTD+TTD)*1.57 [20]. Head circumference was measured using the ellipse facility on the outer border of the skull. Femur length was measured using a longitudinal view of the fetal thigh closest to the probe and with the femur as close as possible to the horizontal plane. Fetal ultrasonography was performed using a GE Voluson E8 color Doppler ultrasonic diagnostic apparatus (GE Ultrasound, USA), equipped with a 3.5 MHz transabdominal transducer.

For the purpose of developing growth standards, a ‘healthy’ cohort of women with singleton pregnancy who conceived naturally was selected for analysis. Mothers or pregnancies with the following characteristics were excluded: Maternal age <18 or >35 years, self-reported pre-pregnancy BMI<17.0 or >27.0, delivery before 37.0 weeks or after 42.0 weeks, still birth, fetal death and/ or eclampsia, pregnancy-induced hypertension, diabetes and gestational age <37 weeks as intended. Huber–white robust standard error estimator was used in the analyses to adjust for correlated data (multiple ultrasound scans per woman). Statistical analyses were performed using the R 3.1.2.

**Results**

Out of a total of 11463 women with singleton pregnancies in the database, 2529 women qualified for the healthy cohort for the purpose of the analysis. Excluding the ultrasound data from the GA dating visit, there were 6837 and 6832 ultrasound measurements of AC and EFW for the development of the standards, respectively. Five criteria that for the development of the standards, respectively. Five criteria that were used for the development of the standards were independent of gestational ages as intended. Huber–white robust standard error estimator was used in the analyses to adjust for correlated data (multiple ultrasound scans per woman). Statistical analyses were performed using the R 3.1.2.

**Statistical modelling of repeated measurements**

The Box-Cox transformation gave estimates of power transformation parameter $\lambda = 0.46$ (95% CI: 0.37 to 0.56) for AC and $\lambda = 0.13$ (95% CI: 0.096, 0.17) for EFW, respectively. Thus we used AC$^{0.46}$ and EFW$^{0.13}$ in the analysis after rounding to one significant digit.

The nonlinear relation between AC$^{0.46}$ and GA can be described by a second-degree fractional polynomial model with powers 1 and 2. The estimated linearizing function

$$
\log(\text{EFW}) = 1.335 \times 0.0034 \left( \frac{\text{AC}}{10} \right)^{0.1} + 0.0316 \left( \frac{\text{FL}}{10} \right)^{0.057} + 0.1623 \left( \frac{\text{AC}}{10} \right)^{0.057} \left( \frac{\text{FL}}{10} \right)^{0.1}\ [11].
$$

Ultrasound biometric data from the first antenatal visits were used only for GA estimation, not for estimation of fetal growth trajectories.
0.7396 × GA\(^1\) − 0.007095 × GA\(^2\) = 0.7396 \times f(GA), \text{where} 
\[ f(GA) = \frac{GA^1 - 0.007095}{0.7396} \times GA^2, \]
provided an approximately linear relationship between AC\(^{0.5}\) and f(GA). The estimated regression coefficients were: \(AC^{0.5} = 0.05597 + 0.7374 \times f(GA)\). The non-linear relation between EFW\(^{0.1}\) and GA can be described by a second-degree fractional polynomial model with powers 1 and 3. The estimated linearizing function \(0.04281 \times GA^1 - 6.8997 \times 10^4 \times GA^2 = 0.04281 \times f(GA)\), where

\[ f(GA) = \frac{GA^1 - 6.8997 \times 10^4}{0.04281} \times GA^2, \]
provided an approximately linear relationship between EFW\(^{0.1}\) and f(GA). The estimated regression coefficients were: \(EFW^{0.1} = 0.9734 + 0.04263 \times f(GA)\) (Table 1).

**Fetal growth charts**

The standards for AC and EFW are shown in Figures 1 and 2 in terms of percentiles. For AC, an approximately linear increase was observed

\[
\text{Table 1: Results of mixed-effect regression models of transformed AC and EFW in relation to gestational age.}
\]

<table>
<thead>
<tr>
<th>Step</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC(^{0.5})</td>
<td>(\rho_1)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(\rho_2)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>(a_1)</td>
<td>0.7396</td>
</tr>
<tr>
<td></td>
<td>(a_2)</td>
<td>-0.007095</td>
</tr>
<tr>
<td></td>
<td>(b_1)</td>
<td>0.05597</td>
</tr>
<tr>
<td></td>
<td>(b_2)</td>
<td>0.7374</td>
</tr>
<tr>
<td></td>
<td>(\text{var}(\beta_{\rho}))</td>
<td>0.1950</td>
</tr>
<tr>
<td></td>
<td>(\text{var}(\beta_a))</td>
<td>0.0006903</td>
</tr>
<tr>
<td></td>
<td>(\text{cov}(\beta_{\rho}, \beta_a))</td>
<td>-0.01049</td>
</tr>
<tr>
<td></td>
<td>(\text{var}(\epsilon))</td>
<td>0.09094</td>
</tr>
<tr>
<td>EFW(^{0.1})</td>
<td>(\rho_1)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(\rho_2)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>(a_1)</td>
<td>0.04281</td>
</tr>
<tr>
<td></td>
<td>(a_2)</td>
<td>-6.8997 \times 10^4</td>
</tr>
<tr>
<td></td>
<td>(b_1)</td>
<td>0.9734</td>
</tr>
<tr>
<td></td>
<td>(b_2)</td>
<td>0.04263</td>
</tr>
<tr>
<td></td>
<td>(\text{var}(\beta_{\rho}))</td>
<td>3.2231 \times 10^4</td>
</tr>
<tr>
<td></td>
<td>(\text{var}(\beta_a))</td>
<td>6.7377 \times 10^{-7}</td>
</tr>
<tr>
<td></td>
<td>(\text{cov}(\beta_{\rho}, \beta_a))</td>
<td>-1.0360 \times 10^{-5}</td>
</tr>
<tr>
<td></td>
<td>(\text{var}(\epsilon))</td>
<td>2.7308 \times 10^{-4}</td>
</tr>
</tbody>
</table>

*Solid line: 50\(^{th}\) percentile, dotted and dashed line: 25\(^{th}\) and 75\(^{th}\) percentiles, dotted lines: 10\(^{th}\) and 90\(^{th}\) percentiles, dashed lines: 5\(^{th}\) and 95\(^{th}\) percentiles

**Figure 1:** Standards for abdominal circumference.
from 16 to 35 weeks, after which the increase slightly decelerated. Differences between percentiles of AC increased slowly over time. At 20th, 24th, 36th, and 40th weeks, median AC was around 114 mm, 188 mm, 303 mm and 332 mm respectively. For EFW, an accelerating increase was observed from 16 to 27 weeks, after which the rate of increase became approximately constant and it slowed down around 36 weeks. Differences between percentiles of EFW increased rapidly over time. At 20th, 24th, 36th and 40th weeks, median EFW was around 308 g, 619 g, 2511 g and 3167 g, respectively (Figures 1 and 2).

Model diagnostics

Detrended Q-Q plots for standard of AC showed that most of the data were around the horizontal line and within the 95% CI, indicating approximate normal distribution of the z-scores. The proportions of observed AC classified below the 10th percentile or above the 90th percentiles of the standard were 10.7% (95% CI: 9.8 to 11.6%) and 10.0% (95% CI: 9.1 to 10.8%) as intended, respectively. Logistic regression assessing the association between GA and the classification of AC below the 10th percentile gave p-value of 0.658. That between GA and AC above the 90th percentile was 0.041. Despite the statistically significant association between GA and AC above the 90th percentile, the odds ratio was only 0.987 per week increase in GA and it induced practically little deviation from the targeted 10% coverage (Figure 3).

Detrended Q-Q plots for standard of EFW showed that most of the data points were around the horizontal line and within the 95% CI, except in one of the 16 GA intervals. The z-scores mostly were normally distributed. The proportions of observed EFW classified below the 10th percentile or above the 90th percentiles of the standard were 10.2% (95% CI: 9.3 to 11.2%) and 9.2% (95% CI: 8.4 to 10.0%), respectively. Logistic regression assessing the association between GA and the classifications of EFW below the 10th percentile and above the 90th percentile gave p-values of 0.987 and 0.723, respectively (Figure 4).

Comparison with other growth standards

Tables 2 and 3 compare the median AC and EFW at different gestational weeks between our study and others. In terms of AC, the previous study conducted in central-south China and the Singaporean Chinese study published in 1995 used the same algorithm as our study to derive AC from APTD and TTD [11,17]. Throughout 20th to 40th weeks, both studies had medians similar to ours. The recently published Singapore Chinese study and a Caucasian study in London, UK used

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**Table 2:** Comparison of median AC at different gestational weeks.

<table>
<thead>
<tr>
<th>Study site</th>
<th>AC algorithm</th>
<th>Median AC (mm) at Gestational Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20th week 24th week 36th week 40th week</td>
<td></td>
</tr>
<tr>
<td>Shanghai</td>
<td>Estimated by APTD and TTD</td>
<td>144 188 303 332</td>
</tr>
<tr>
<td>Singapore</td>
<td>Estimated by APTD and TTD</td>
<td>145 188 303 334</td>
</tr>
<tr>
<td>Central-south China</td>
<td>Estimated by APTD and TTD</td>
<td>150 188 301 325</td>
</tr>
<tr>
<td>Singapore</td>
<td>Measured directly</td>
<td>146 197 317 Not reported</td>
</tr>
<tr>
<td>UK</td>
<td>Measured directly</td>
<td>153 187 320 355</td>
</tr>
</tbody>
</table>

**Table 3:** Comparison of median EFW at different gestational weeks.

<table>
<thead>
<tr>
<th>Study site</th>
<th>EFW algorithm</th>
<th>Median EFW (g) at Gestational Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20th week 24th week 36th week 40th week</td>
<td></td>
</tr>
<tr>
<td>Shanghai</td>
<td>Hadlock (I)</td>
<td>308 619 2511 3167</td>
</tr>
<tr>
<td>Singapore</td>
<td>Hadlock (II)</td>
<td>312 606 2644 Not reported</td>
</tr>
<tr>
<td>Congo</td>
<td>Hadlock (II)</td>
<td>315 635 2646 3403</td>
</tr>
<tr>
<td>UK</td>
<td>Hadlock (II)</td>
<td>344 697 2880 3633</td>
</tr>
</tbody>
</table>
direct AC measurements and they shared similar medians [12,28]. The medians in our study tended to be lower than theirs (Table 2).

In terms of EFW (Table 3), our study used the Hadlock (I) formula that only involves AC, FL and BPD to derive EFW, as HC was not measured in our study [1]. A Congolian study, the Singapore Chinese study and a UK study used the Hadlock formula involving AC, FL, BPD and HC (Hadlock (II)) instead [12,28,29]. Esinler et al. compared different EFW algorithms and suggested that Hadlock (I) and Hadlock (II) had good and similar degree of accuracy [30]. Our study, the
Singapore Chinese study and the Congolian study showed similar EFW at 20 and 24 weeks, but at 36 weeks our study showed lower EFW. The UK study showed higher median of EFW throughout 20th to 40th weeks. The previously mentioned central-south Chinese study and Singapore Chinese study who shared similar medians of AC with our study did not provide standards for EFW, so we were unable to compare EFW with these two Chinese studies.

Discussion

We have developed standards for both AC and EFW for singleton pregnancies in Shanghai, China. By using only data from a 'healthy cohort', the standards describe the growth trajectories for healthy pregnancy and birth outcomes. Model diagnostics show sufficient goodness-of-fit. Caution is urged, as the AC could be underestimated in the previously published AC EFW algorithms. HC was not measured in this study. Therefore, we did not use the Hadlock formula involving HC which was applied in the studies in Congo, Singapore, and UK. It may be that the algorithm used in our study underestimated EFW or the algorithm used in other study overestimated EFW in the third trimester. This is a speculation and further studies need to be done before any firm conclusion is made.

A strength of our study is that, even after stringent selection to define a healthy cohort for the purpose of developing fetal growth standards, there was still a sufficient sample size of 2529 pregnancies/fetuses included in our statistical analysis. The pregnancies/fetuses included were not supposed to represent the excluded pregnancies/fetuses. Instead, they were chosen to represent a healthy pregnancy cohort, which is commonly used in the development of growth standards. The large sample size offers sufficient precision for the development of the standards.

Conclusion

In summary, we have developed growth standards for clinical use to monitor fetal AC and EFW for Chinese population in China. Compared to standards developed elsewhere, our standards indicate that Chinese fetus in Shanghai, China, had similar AC compared to other Singapore and Chinese cohorts. Variation in EFW across populations cannot be conclusively determined due to differences in EFW estimation algorithms.

Acknowledgement

YZ, LW and QH collected the data. YW, WY and YBC conceived and conducted this analysis. YW, WY and YBC drafted the first version of the article. All authors participated in the critical review and revision of the article. All authors approved the submission. This work is supported by National Natural Science Foundation of China, Grant No. 81273168 and the 2nd Shanghai new-one Hundred Person Project, Grant No. XBR2013101.

References


