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Fetal growth velocity: the NICHD fetal growth studies

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Abstract

BACKGROUND: Accurately identifying pregnancies with accelerated or diminished fetal growth is challenging and generally based on cross-sectional percentile estimates of fetal weight. Longitudinal growth velocity might improve identification of abnormally grown fetuses.

OBJECTIVE: We sought to complement fetal size standards with fetal growth velocity, develop a model to compute fetal growth velocity percentiles for any given set of gestational week intervals, and determine association between fetal growth velocity and birthweight.

STUDY DESIGN: This was a prospective cohort study with data collected at 12 US sites (2009 through 2013) from 1733 nonobese, low-risk pregnancies included in the singleton standard. Following a standardized sonogram at 10w0d–13w6d, each woman was randomized to 1 of 4 follow-up visit schedules with 5 additional study sonograms (targeted ranges: 16–22, 24–29, 30–33, 34–37, and 38–41 weeks). Study visits could occur ± 1 week from the targeted GA. Ultrasound biometric measurements included biparietal diameter, head circumference, abdominal circumference, and femur length, and estimated fetal weight was calculated. We used linear mixed

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models with cubic splines for the fixed effects and random effects to flexibly model ultrasound trajectories. We computed velocity percentiles in 2 ways: (1) difference between 2 consecutive weekly measurements (ie, weekly velocity), and (2) difference between any 2 ultrasounds at a clinically reasonable difference between 2 gestational ages (ie, velocity calculator). We compared correlation between fetal growth velocity percentiles and estimated fetal weight percentiles at 4-week intervals, with 32 (±1) weeks' gestation for illustration. Growth velocity was computed as estimated fetal growth rate (g/wk) between ultrasound at that gestational age and from prior visit [ie, for 28–32 weeks' gestational age: velocity = (estimated fetal weight 32–28)/(gestational age 32–28)]. We examined differences in birthweight by whether or not estimated fetal weight and estimated fetal weight velocity were <5th or ≥5th percentiles using $\chi 2$.

RESULTS: Fetal growth velocity was nonmonotonic, with acceleration early in pregnancy, peaking at 13, 14, 15, and 16 weeks for biparietal diameter, head circumference, femur length, and abdominal circumference, respectively. Biparietal diameter, head circumference, and abdominal circumference had a second acceleration at 19–22, 19–21, and 27–31 weeks, respectively. Estimated fetal weight velocity peaked around 35 weeks. Fetal growth velocity varied slightly by race/ethnicity although comparisons reflected differences for parameters at various gestational ages. Estimated fetal weight velocity percentiles were not highly correlated with fetal size percentiles (Pearson $r = 0.40–0.41$, $P < .001$), suggesting that these measurements reflect different aspects of fetal growth and velocity may add additional information to a single measure of estimated fetal weight. At 32 (SD ± 1) weeks, if both estimated fetal weight velocity and size were <5th percentile, mean birthweight was 2550 g; however, even when size remained <5th percentile but velocity was ≥5th percentile, birthweight increased to 2867 g, reflecting the important contribution of higher growth velocities. For estimated fetal weight ≥5th percentile, but growth velocity <5th, birthweight was smaller (3208 vs 3357 g, respectively, $P < .001$).

CONCLUSION: We provide fetal growth velocity data to complement our previous work on fetal growth size standards, and have developed a calculator to compute fetal growth velocity. Preliminary findings suggest that growth velocity adds additional information over knowing fetal size alone.

Keywords

birthweight; estimated fetal weight; fetal growth; fetal growth velocity

Introduction

Distinguishing fetal growth that is constitutionally small or large from growth that is pathologically restricted or increased presents one of the most significant challenges in obstetrics. Cross-sectional fetal measurements are typically compared to reference size-for age curves, with a range of 10th–90th percentiles considered appropriate for gestational age (GA).[1,2] Yet, a single measurement can only indicate size.[3] At least 2 measurements separated in time are needed to estimate actual fetal *growth*.[4]

Fetal growth velocity is the rate of fetal growth over a given time interval (eg, g/wk). Understanding whether fetal growth has deviated from a normal trajectory may have more clinical utility to distinguish constitutional from pathologic fetal growth abnormalities

compared to using a particular threshold of fetal size from a single time measure.[5] Yet until recently, there has been a lack of longitudinal prospective studies with diverse populations that have collected repeated ultrasound measurements. The benefits of using growth velocity to categorize fetal growth and assess its contribution to birthweight have not been empirically demonstrated.

The primary aim of the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD) fetal growth studies– singletons, a multicenter US prospective cohort study of pregnant women, was to establish fetal growth standards, for size and velocity, for 4 self-identified race/ethnic groups: non-Hispanic white, non-Hispanic black, Hispanic, and Asian or Pacific Islander. We previously published our fetal size standards.[6,7] The objective of the present analysis were to complement the fetal size standards with fetal growth velocity for individual biometric parameters and estimated fetal weight (EFW). Understanding that clinicians see patients at unpredictably spaced time points, we developed a model to compute fetal growth velocity percentiles of a given fetus for any given set of gestational week intervals. Additionally, we investigated whether growth velocity had an independent association with birthweight over fetal size alone.

Materials and Methods

The NICHD Fetal Growth Studies–Singletons recruited women from 12 clinical sites from July 2009 through January 2013.[6] Inclusion criteria included: maternal age 18–40 years; pregravid body mass index 19.0–29.9 kg/m2 calculated from recalled prepregnancy weight and height; viable singleton pregnancy between 8w0d–13w6d with gestational dating consistent with last menstrual period dating within a prescribed range per screening sonogram; and planning to deliver at participating hospitals. Women with prior adverse pregnancy outcomes, history of chronic diseases, conception using medical drugs or assisted reproductive technology, cigarette smoking, illicit drug use, or intake of ≥1 alcoholic drinks per day were excluded as previously described.[6] Human subjects' approval was obtained from all participating sites, the NICHD, and data-coordinating center, and all women gave informed consent prior to any data collection (ClinicalTrials.gov Identifier: NCT00912132).[8]

Following a standardized sonogram at 10w0d–13w6d, each woman was randomized to 1 of 4 follow-up visit schedules with 5 additional study sonograms (targeted ranges: 16–22, 24–29, 30–33, 34–37, and 38–41 gestational weeks). Study visits could occur ± 1 week from the targeted GA.[8] Study sonographers underwent training and credentialing prior to enrollment and followed a standardized protocol. Ultrasound measurements were performed using standard operating procedures and identical equipment. Fetal biometry included head circumference (HC) and abdominal circumference (AC) using the ellipse function, and biparietal diameter (BPD), humerus length (HL), and femur length (FL) using the linear function measured at all study visits including 10w0d–13w6d. Voluson ultrasound machines were configured so that the sonographers were blinded to the measurements. EFW was computed from HC, AC, and FL using a formula of Hadlock et al.[9] Measurements and images were captured in ViewPoint (GE Healthcare) and electronically transferred to the study's imaging data-coordination center. Quality assurance was performed on 5% of the

scans, and demonstrated correlations between the site sonographers and experts >0.99 for all biometric parameters and coefficients of variation ≤3%.[10] In-person interviews were conducted at each research visit to ascertain information on lifestyle, and reproductive and medical history. Demographic data; antenatal history; and labor, delivery, and neonatal course and outcomes were abstracted from the prenatal record, labor and delivery summary, and hospital and neonatal records by trained research personnel.

Statistical analysis

Ultrasonographic biometric measurements (BPD, HC, AC, HL, FL) and EFW were log-transformed to stabilize variances across GAs and to improve normal approximations for the error structures.[11] For each biometric measurement and EFW we fit a linear mixed model with cubic splines for the fixed effects and a cubic polynomial for the random effects. Three-knot points (25th, 50th, 75th percentiles) were chosen at GAs that evenly split the distributions. The dependent variable is a log-transformed biometric measurement. From these we computed velocity percentiles in 2 ways: (1) the difference between 2 consecutive weekly measurements (ie, weekly velocity), and (2) the difference between any 2 ultrasounds at a clinically reasonable difference between 2 GAs (ie, velocity calculator).

The velocity curves were defined as the mean change in each anthropo-metric measurement per week of GA. This weekly change was obtained from the fitted models by exponentiations of the predicted log mean estimates at each week and making the appropriate subtractions. From these models we were able to obtain percentiles on the relative change over each gestational week. These velocities were determined across GA from 11–41 weeks and for each racial/ethnic group. The 50th percentile velocity curves were computed as the average relative change for the average week-specific measurement. Weekly velocity percentiles were calculated as relative change using the ratio of the difference between the first measurement and the second measurement to adjust for the log transformation and allow results to be reported in the original scale; for detailed equations see Appendix.

The growth velocity for EFW and each individual anthropometric parameter was tested for overall differences in racial/ethnic-specific curves using a likelihood- ratio test. When the global test was significant (<.05 level), we tested for week-specific differences by race/ethnicity using Wald tests at each week of gestation. These tests were conducted on the estimated curves with adjustment for maternal characteristics: age, height and pregravid weight, parity, full-time employment/student status (yes/no), marital status (married/living as married vs not), health insurance (private/managed vs Medicaid/other), income, education, and infant sex (male/female). All covariates were treated as continuous unless otherwise stated. Annual income (<$30,000; $30,000–39,999; $40,000–49,999; $50,000–74,999; $75,000–99,999; >$100,000) and education (<high school; high school or equivalent; some college or associate degree, bachelor's degree; and master's or higher degree) were analyzed categorically. We used multiple imputation (with 20 imputations) to account for missing covariate information when performing covariate-adjusted tests for week-specific racial/ethnic differences in the fetal growth curves.[12]

EFW percentiles were computed as previously reported for singleton fetal growth.[6] We then compared fetal growth velocity percentiles and the EFW percentiles at 24, 28, 32, 36, and 40 (±1) weeks' gestation to evaluate whether these 2 measures were correlated using the Pearson correlation coefficient (r). Growth velocity was computed as the estimated fetal growth rate (g/wk) between the ultrasound at that GA and from the prior visit [ie, for 28–32 weeks GA: velocity = (EFW 32–28)/(GA 32–28)].

Understanding that clinicians see patients at unpredictably spaced time points, we developed a model so that the fetal growth velocity with corresponding percentiles can be computed for any given set of gestational weeks. Percentile distributions for this difference were constructed on the log scale using the linear mixed models that includes within and between women variation discussed above. These percentiles assessed the relative change in anthropometric measurement taken at any fixed set of 2 GA times, without having to observe all the time points in between. Thus, for any given set of 2 GA and anthropometric measurements the change percentile can be computed.

We examined whether the maternal demographics, birthweight, and composite neonatal morbidity distributions differed by whether or not EFW and EFW velocity were each <5th percentile (both <5th percentile), EFW <5th percentile but velocity not, velocity <5th percentile but EFW not, and lastly, both >5th percentile. The $\chi 2$ or t tests for categorical and continuous data, respectively, were performed with significance defined as a 2-sided $P < .05$ using 32 weeks' gestation for illustration purposes. The composite neonatal outcome included: metabolic acidosis (pH <7.1 and base deficit >12 mmol/L), neonatal intensive care unit stay >3 days, pneumonia, respiratory distress syndrome, persistent pulmonary hypertension, seizures, hyperbilirubinemia requiring exchange transfusion, intrapartum aspiration (meconium, amniotic fluid, blood), mechanical ventilation at term, necrotizing enterocolitis, hypoglycemia, hypoxic ischemic encephalopathy, periventricular leukomalacia, sepsis based on blood culture, bronchopulmonary dysplasia/chronic lung disease, retinopathy of prematurity, birth injury, or neonatal death.13–17

All analyses were implemented using SAS (Version 9.4; SAS Institute Inc, Cary, NC) or R (Version 3.4.2; http://www.R-project.org).

Results

Among the 2334 low-risk women enrolled, 169 (7%) exited the study; 356 (16%) were excluded due to pregnancy complications (eg, miscarriages, stillbirths, preterm delivery, hypertensive diseases, gestational diabetes); and 72 (4%) due to fetal or neonatal conditions (stillbirth, aneuploidy, or anomalies), resulting in 1737 pregnant women included in the standard. Four women did not have ultrasound data leaving 1733 for analysis. Of these women, 480 (28%) were non-Hispanic white, 423 (24%) were non-Hispanic black, 488 (28%) were Hispanic, and 342 (20%) were Asian or Pacific Islander. Additional demographic details are previously published.6

Average EFW growth velocity increased across gestation from 29 g/wk at 16 weeks, to 59 g/wk at 20 weeks, to 175 g/wk at 30 weeks, and 215 g/wk at 35 weeks, at which point it

peaked. The 50th percentiles for weekly fetal growth velocity varied slightly by race/ethnicity for EFW (Figure 1) (global test $P < .001$) and BPD, HC, AC, FL, and HL (Figure 2) (global test $P < .001$ for all), although comparisons reflected differences for parameters at various GAs. Data for weekly growth velocity percentiles (5th, 10th, 50th, 90th, 95th) are presented in Table 1 with pairwise comparisons between racial/ethnic groups presented in Table 2. In general, the AC growth velocity increased in the first half of pregnancy until peaking on average around 16 weeks of gestation, with a second acceleration from 27–31 weeks, followed by steadily decreasing growth velocity for the remainder of pregnancy. Figure 2 illustrates the largest differences in fetal growth velocity by race/ethnicity was for the AC (Figure 2). The BPD and HC average growth velocities increased early in pregnancy peaking at approximately 13 and 14 weeks, respectively, with a second slight acceleration occurring from 19–22 weeks for BPD and 19–21 weeks for HC, followed by a decrease in growth velocity as pregnancy advanced. The long bone average growth velocities also increased in the first half of pregnancy, peaking at approximately 15 weeks for both the HL and FL, then steadily decreased over the rest of gestation. It is important to note that weekly fetal growth velocity was negative (reflecting measurement error) for the 5th and 10th percentiles for some of the anthropometric measurements at various gestational weeks. These findings were corroborated in simulations (data not presented) based on a previous approach.[18]

In clinical practice, patients may be seen at unpredictably spaced time intervals. Therefore, we created a calculator for any given set of 2 GAs and anthropometric measurements, where the EFW growth velocity with corresponding percentiles for a given fetus can be computed (Appendix). Table 3 presents an example for different scenarios for 2 ultrasounds obtained at 28–32 weeks, respectively, by self-reported maternal race/ethnicity. The results demonstrate that a fetus could have arrived at a given EFW at 32 weeks from different EFW growth velocities. If the change percentile is very small (eg, <5%) it is interpreted as no change in the measurement is unlikely in a healthy population, suggesting that this degree of fetal growth velocity may be problematic.

To determine whether EFW growth velocity might provide information beyond cross-sectional measures, the correlation of growth velocity percentile with EFW percentile was assessed at 32 (±1) weeks of gestation for illustration (Figure 3). If the 2 measures were completely correlated, the points would line up in a 45-degree line on the figure. For all racial/ethnic groups, EFW growth velocity percentiles were not highly correlated with EFW size percentiles (Pearson $r = 0.40—0.41$, $P < .001$). Results were similar at 24, 28, 36, and 40 (± 1) weeks' gestation indicating that this low correlation persisted across gestation (data not shown). These findings suggest that these measurements reflect different aspects of fetal growth, so we investigated whether velocity could add additional information compared to a single measure of EFW in the ascertainment of abnormal growth. We also compared whether maternal demographics, birthweight, and a composite neonatal morbidity differed by whether or not EFW and velocity separately were below or above their prospective 5th percentile using 32 weeks of gestation (SD 1.5) for illustrative purposes, a time when an obstetrical ultrasound might be obtained to evaluate fetal growth in clinical practice (Table 4). Maternal height was slightly higher when EFW was ≥5th compared to <5th percentile, an association that did not vary much by whether fetal growth velocity was <5th percentile or

≥5th percentile ($P = .044$). Maternal body mass index was slightly lower if either EFW or velocity alone were <5th percentile (22.8 and 22.6, respectively) compared to when they were concordantly <5th percentile or ≥5th percentile (23.7 and 23.5, respectively). Birthweight was lightest when both EFW and growth velocity were <5th percentile (2550 g) followed by when EFW was <5th percentile and velocity was ≥5th percentile (2867 g). This observation suggests that lighter birthweight is associated with both EFW <5th percentile and a slower growth velocity. Still for EFW >5th percentile, birthweight was lighter when velocity was <5th percentile compared to ≥5th percentile (3208 vs 3357 g, respectively, $P < .001$) underscoring that slower growth velocity will negatively impact birthweight. Composite neonatal outcomes did not statistically differ by the groups, although the numbers were small (Table 4).

Comment

We present fetal growth velocity for BPD, HC, AC, FL, HL, and EFW by maternal race/ethnicity to complement previously published fetal size standards.[6,7] Fetal growth velocity was nonmonotonic, with an acceleration early in pregnancy peaking at 13 weeks of gestation for BPD, 14 weeks for HC, 15 weeks for FL and HL, and 16 weeks for AC. The BPD and HC had a second acceleration in midpregnancy (19–22 and 19–21 weeks, respectively) and AC in the early third trimester (27–31 weeks). Conversely, long bone velocity (FL and HL) continued to slow. EFW velocity continued to accelerate peaking at approximately 35 weeks of gestation. A model to compute fetal growth velocity percentiles for any given set of gestational week intervals was also developed, since weekly velocity charts may not be that clinically useful. While an EFW size <5th percentile at 32 weeks' gestation was associated with smaller birthweight, birthweight was additionally influenced by the EFW velocity prior to that visit. Birthweight was lighter if the fetal growth velocity was <5th compared to ≥5th percentile. Furthermore, EFW growth velocity percentiles were not highly correlated with EFW size percentiles, indicating that these measurements reflect different aspects of fetal growth.

The finding that BPD and HC velocity first peaked in our study at 13 and 14 weeks of gestation, respectively, was similar to the BPD velocity peak at 13–16 weeks reported by Guihard- Costa et al[19] in a study that included mixed (mostly cross-sectional and 25% with some longitudinal) measures. Similarly, they also found a second growth velocity acceleration for BPD. Our findings were somewhat different from the peak BPD velocity of 15–16 weeks of gestation reported in a longitudinal study by Fescina et al[20] of 30 fetuses and from the peak BPD and HC velocity at 17–18 weeks reported in another study by Bertino et al[21] of 238 low-risk, uncomplicated pregnancies delivering at term. Our finding that AC growth velocity increased in the first half of pregnancy until it peaked on average around 16 weeks of gestation, with a second acceleration from 27–31 weeks, was somewhat similar to the study by Guihard-Costa et al[19] where abdominal transverse diameter peaked at 13–16 weeks, and again around 25–28 weeks of gestation. However, our findings differ from the peak AC velocity at 22 weeks of gestation reported by Bertino et al[21] and 32–34 weeks reported by Fescina et al.[20] The pattern of the long bone growth velocities increasing in the first half of pregnancy, peaking on average at 15 weeks of gestation, then steadily decreasing over the rest of gestation is also similar to the study by Bertino et al,[21] although they found

FL growth velocity peaked later around 20 weeks, and somewhat similar to the study by Guihard-Costa et al[19] where FL growth velocity accelerated until 13–16 weeks of gestation, steadily decreased until 28 weeks, followed by an irregular decrease and then a rapid decrease >37 weeks. The differences in these results may be explained, in part, by differences in study populations. Modern ultrasound machines also have a narrower beam width accuracy resulting in shorter linear measurements, although it is unclear how this difference might affect velocity.[22] We also used modern statistics that were flexible enough to demonstrate accelerations and decelerations in fetal growth velocity based on an approach from Cheon et al[18] that differed from prior publications.

The direction of our findings on EFW are also generally consistent with a prior study in a single hospital in Scotland where EFW growth velocity peaked around 35 weeks of gestation, but the magnitudes were different.[23] EFW growth velocity in our study was higher than reported in their investigation; for example at 35 weeks of gestation the EFW growth velocity was 230 g/wk in our non-Hispanic white group compared to 188 g/wk in the Scottish sample. These differences might be due to the inclusion of women with risk factors for fetal growth restriction in the Scottish sample, such as maternal smoking and pregnancy complications such as pre-term delivery, while our study included only women with uncomplicated pregnancies and optimal outcomes. In addition, our findings regarding the low correlation of EFW size with EFW growth velocity are somewhat similar, although their conclusions were based on comparing the difference (velocity) to the average of the 2 measurements. We also compared the 2 measures in a slightly different manner using the EFW measurement vs velocity from the previous visit.

The finding that fetal growth velocity was negative (representing measurement error) for the 5th and 10th percentiles for some of the anthropo-metric measurements at various gestational weeks suggests that assessing average weekly fetal growth velocity might be difficult in clinical practice. In light of these drawbacks, we have developed a calculator to compute fetal growth velocity with corresponding percentiles for a given fetus at any given set of gestational weeks, designed to enhance our assessment of fetal growth velocity. The calculator takes measurement error into account in a way by estimating the probability of how unusual fetal growth velocity is over a time period based on the NICHD fetal growth population. For very short intervals, detecting clinically meaningful changes is not possible since the measurement error in the measurements is larger than any reasonable change. For a larger interval, the clinically meaningful change would be larger and can more easily be separated from measurement error. Choosing the optimal interval is complicated and reflects the time of the measurements as well as the particular biometric measurement used. In particular cases, the calculator may be useful in making this decision.

For example, if we wanted to calculate what time interval is needed to identify delayed growth based on no change in EFW, we can use the calculator with different start and end times with no change in EFW over the interval. The percentile for change will decrease as the length of the interval is increased. When this change percentile is very small (for example <5%) it is interpreted as no change in the measurement is unlikely in a healthy population, suggesting that this degree of delay may be problematic. Future work is needed to determine the optimal time intervals for clinical management.

Some evidence suggests that growth velocity might be able to distinguish constitutionally small-for-GA fetuses from pathologic fetal growth restriction <10th percentile for EFW. In a prospective cohort study of 4512 women in the United Kingdom with research ultrasounds at 20, 28, and 32 weeks of gestation, for an EFW <10th percentile, neonatal morbidity (metabolic acidosis, 5-minute Apgar <7, or intensive neonatal care unit admission) was increased only if the fetal AC growth velocity was in the lowest decile compared to normal fetal growth velocity.[5] Our findings also suggest that EFW growth velocity adds additional information over knowing fetal size alone and future work is needed to determine whether velocity can improve prediction of birthweight and neonatal outcomes over isolated fetal size estimates.

Limitations of our study reflect the observational design, including potential bias from the cohort selection or residual confounding. Also, we never observed the individual changes in growth per week, so the differences in size per week are extrapolated; however, the linear mixed models with cubic splines for the fixed effects and a cubic polynomial for the random effects are flexible enough to allow a robust calculation of growth at any point in gestation despite the fact that the percentage change in fetal weight differs at each gestational week and the time of the ultrasound examinations may be different in each patient. Further, model diagnostics demonstrated that major model assumptions such as the normality of the random effects and error distribution were met. The major strength of our study was the prospective collection of serial ultrasounds allowing the ability to assess fetal growth velocity in a racially/ethnically diverse obstetric cohort.

In summary, we provide fetal growth velocity data to complement our previous work on fetal growth size standards and have developed a calculator to compute fetal growth velocity with corresponding percentiles for a given fetus at any given set of gestational weeks. Preliminary findings suggest that EFW growth velocity adds additional information over knowing fetal size alone. Additional research is needed to determine whether an abnormal fetal growth velocity percentile identifies fetuses and neonates at increased risk for morbidity and mortality, particularly in the setting of an otherwise appropriate-for-GA EFW size.

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Appendix

For a single longitudinal ultrasound measurement, we built a random effect model with cubic spline based on 3-knot points for fixed effects and cubic function for random effects as follow:

$$Y_{ij}^{*} = \theta_0 + \theta_1 t_{ij} + \theta_2 t_{ij}^2 + \theta_3 t_{ij}^3 + \theta_4 (t_{ij} - \delta_1)_+^3 + \theta_5 (t_{ij} - \delta_2)_+^3 + \theta_6 (t_{ij} - \delta_3)_+^3 + b_{i0} + b_{i1} t_{ij} + b_{i2} t_{ij}^2 + b_{i3} t_{ij}^3 + \varepsilon_{ij}, \quad (1)$$

where Y_{ij}^{*} denotes log-transformed ultrasound measurement, t_{ij} is the jth gestational age for ith women, $(t_{ij} - \delta_k)_+^3 = max\left(0, (t_{ij} - \delta_k)^3\right)$ is the knot sequence with $\delta_1 < \delta_2 < \delta_3$, $\left(1, t_{ij}, t_{ij}^2, t_{ij}^3, (t_{ij} - \delta_1)_+^3, (t_{ij} - \delta_2)_+^3, (t_{ij} - \delta_3)_+^3\right)'$ is a truncated polynomial basis functions of degree 3, $\{\theta_0, \theta_1, \theta_2, \#_3, \theta_4, \theta_5, \theta_6)$' is a corresponding vector of parameters and describes the overall fetal growth with a cubic spline function, and $\boldsymbol{b_i} = \{b_{io}, b_{i1}, b_{i2}, b_{i3})'$ denotes the random effects, where $j = 1, 2, \ldots, n_i$, $i = 1, 2, \ldots, I$, n_i denotes the number of repeated time points for ith women, and I denotes the number of women. Further, we assume that the residual errors ε_{ij} are distributed with independent normal distributions with mean 0 and variance σ_ε^2. The random effects are assumed to have mean 0 and be correlated with each other. The random effects are interpreted as individual departures in an individual's growth curve relative to the average fetal growth curve in the population. Further, the use of the model in (1) allows us to compute the ratio and velocity of 2 ultrasound measurements as follows:

$$r_{i,jj'} = \exp\left(\widehat{Y_{ij'}^{*}} - \widehat{Y_{ij}^{*}}\right) \text{and}$$

$$v_{i,jj'} = \left(r_{i,jj'} - 1\right) Y_{ij} / \left(t_{ij'} - t_{ij}\right),$$

where Y_{ij} is an original scaled ultrasound measurement at time $\widehat{Y_{ij'}^{*}}$ is an estimated log-transformed ultrasound measurement at time t_{ij}, $r_{i,jj'}$ is a ratio of 2 ultrasound measurements, and $v_{i,jj'}$ is a velocity of 2 ultrasound measurements.

References

1. Battaglia FC, Lubchenco LO. A practical classification of newborn infants by weight and gestational age. J Pediatr 1967;71:159–63. [PubMed: 6029463]
2. ACOG. Fetal growth restriction. Practice bulletin no. 134. Obstet Gynecol 2013;121:1122–33. [PubMed: 23635765]
3. Deter RL. Evaluation of intrauterine growth retardation in the fetus and neonate: are simpleminded methods good enough? Ultrasound Obstet Gynecol 1995;6:161–3. [PubMed: 8521062]
4. Altman DG, Hytten FE. Intrauterine growth retardation: let's be clear about it. Br J Obstet Gynaecol 1989;96:1127–32. [PubMed: 2590650]
5. Sovio U, White IR, Dacey A, Pasupathy D, Smith GC. Screening for fetal growth restriction with universal third trimester ultra-sonography in nulliparous women in the Pregnancy Outcome

Prediction (POP) study: a prospective cohort study. Lancet 2015;386:2089–97. [PubMed: 26360240]

6. Buck Louis GM, Grewal J, Albert PS, et al. Racial/ethnic standards for fetal growth: the NICHD fetal growth studies. Am J Obstet Gynecol 2015;213:449.e1–41. [PubMed: 26410205]
7. Buck Louis GM, Grewal J. Clarification of estimating fetal weight between 10–14 weeks gestation, NICHD fetal growth studies. Am J Obstet Gynecol 2017;217:96–101. [PubMed: 28389223]
8. Grewal J, Grantz KL, Zhang C, et al. Cohort profile: NICHD fetal growth studies–singletons and twins. Int J Epidemiol 2018;47:25–25l. [PubMed: 29025016]
9. Hadlock FP, Harrist RB, Sharman RS, Deter RL, Park SK. Estimation of fetal weight with the use of head, body, and femur measurements–a prospective study. Am J Obstet Gynecol 1985;151:333–7. [PubMed: 3881966]
10. Hediger ML, Fuchs KM, Grantz KL, et al. Ultrasound quality assurance for singletons in the National Institute of Child Health and Human Development fetal growth studies. J Ultrasound Med 2016;35:1725–33. [PubMed: 27353072]
11. Pinheiro JC, Bates DM. Mixed-effects models in S and S-plus. New York (NY): Springer Science–Business Media New York.
12. Sterne JA, White IR, Carlin JB, et al. Multiple imputation for missing data in epidemiological and clinical research: potential and pitfalls. BMJ 2009;338:b2393. [PubMed: 19564179]
13. Longo S, Bollani L, Decembrino L, Di Comite A, Angelini M, Stronati M. Short-term and long-term sequelae in intrauterine growth retardation (IUGR). J Matern Fetal Neonatal Med 2013;26:222–5. [PubMed: 23030765]
14. Rosenberg A The IUGR newborn. Semin Perinatol 2008;32:219–24. [PubMed: 18482625]
15. Giapros V, Drougia A, Krallis N, Theocharis P, Andronikou S. Morbidity and mortality patterns in small-for-gestational age infants born preterm. J Matern Fetal Neonatal Med 2012;25:153–7. [PubMed: 21463210]
16. McIntire DD, Bloom SL, Casey BM, Leveno KJ. Birth weight in relation to morbidity and mortality among newborn infants. N Engl J Med 1999;340:1234–8. [PubMed: 10210706]
17. King JR, Korst LM, Miller DA, Ouzounian JG. Increased composite maternal and neonatal morbidity associated with ultrasonographically suspected fetal macrosomia. J Matern Fetal Neonatal Med 2012;25:1953–9. [PubMed: 22439605]
18. Cheon K, Albert PS, Zhang Z. The impact of random-effect misspecification on percentile estimation for longitudinal growth data. Stat Med 2012;31:3708–18. [PubMed: 22786788]
19. Guihard-Costa AM, Droulle P, Larroche JC. Growth velocity of the biparietal diameter, abdominal transverse diameter and femur length in the fetal period. Early Hum Dev 1991;27:93–102. [PubMed: 1802668]
20. Fescina RH, Ucieda FJ, Cordano MC, Nieto F, Tenzer SM, Lopez R. Ultrasonic patterns of intrauterine fetal growth in a Latin American country. Early Hum Dev 1982;6: 239–48. [PubMed: 7128505]
21. Bertino E, Di Battista E, Bossi A, et al. Fetal growth velocity: kinetic, clinical, and biological aspects. Arch Dis Child Fetal Neonatal Ed 1996;74:F10–5. [PubMed: 8653429]
22. Okland I, Bjastad TG, Johansen TF, Gjessing HK, Grottum P, Eik-Nes SH. Narrowed beam width in newer ultrasound machines shortens measurements in the lateral direction: fetal measurement charts may be obsolete. Ultrasound Obstet Gynecol 2011;38:82–7. [PubMed: 21308840]
23. Owen P, Donnet ML, Ogston SA, Christie AD, Howie PW, Patel NB. Standards for ultrasound fetal growth velocity. Br J Obstet Gynaecol 1996;103:60–9. [PubMed: 8608100]

AJOG at a Glance

Why was this study conducted?

Identifying pregnancies with accelerated or diminished fetal growth is challenging and generally based on cross-sectional percentile estimates of fetal weight. Longitudinal growth velocity might improve identification of abnormally grown fetuses.

Key findings

We provide fetal growth velocity data to complement our fetal growth size standards and developed a calculator to compute fetal growth velocity. Estimated fetal weight growth velocity percentiles were not highly correlated with estimated fetal weight size percentiles, indicating that these measurements reflect different aspects of fetal growth. Preliminary findings suggest that growth velocity adds additional information over knowing fetal size alone.

What does this add to what is known?

Until recently, there has been a lack of prospective studies with diverse populations and repeated ultrasound measurements to calculate fetal growth velocity. A calculator to compute fetal growth velocity percentiles for any given set of gestational week intervals may be clinically useful.

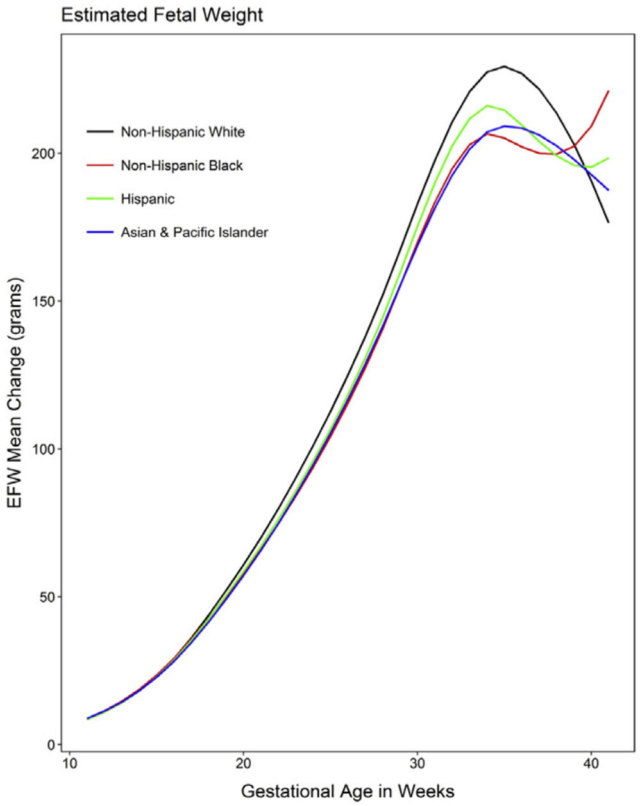

FIGURE 1:

Estimated fetal weight (EFW) velocity (g/wk) by race/ethnicity and gestation, *Eunice Kennedy Shriver* National Institute of Child Health and Human Development fetal growth studies–singletons

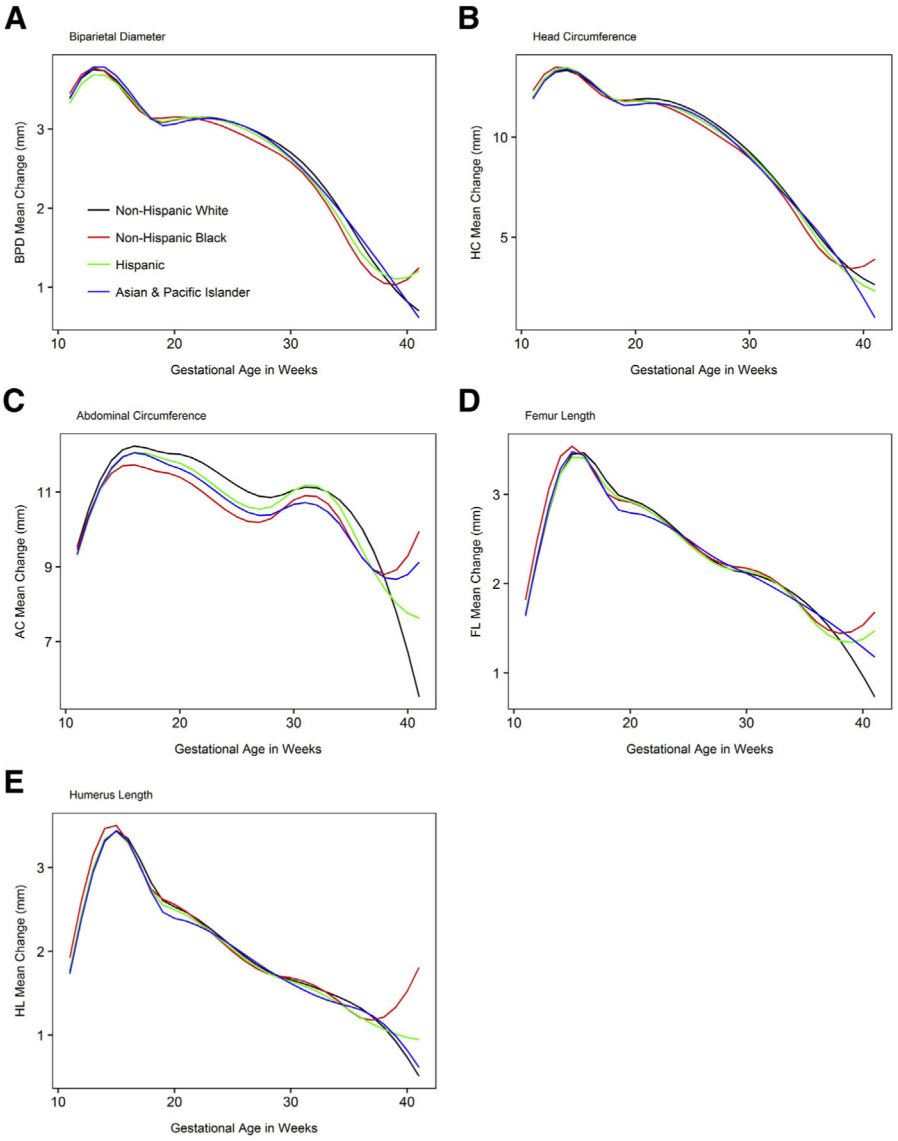

FIGURE 2:

Growth velocity (g/wk) of fetal anthropometric measurements by race/ethnicity and gestation, *Eunice Kennedy Shriver* National Institute of Child Health and Human Development fetal growth studies–singletons

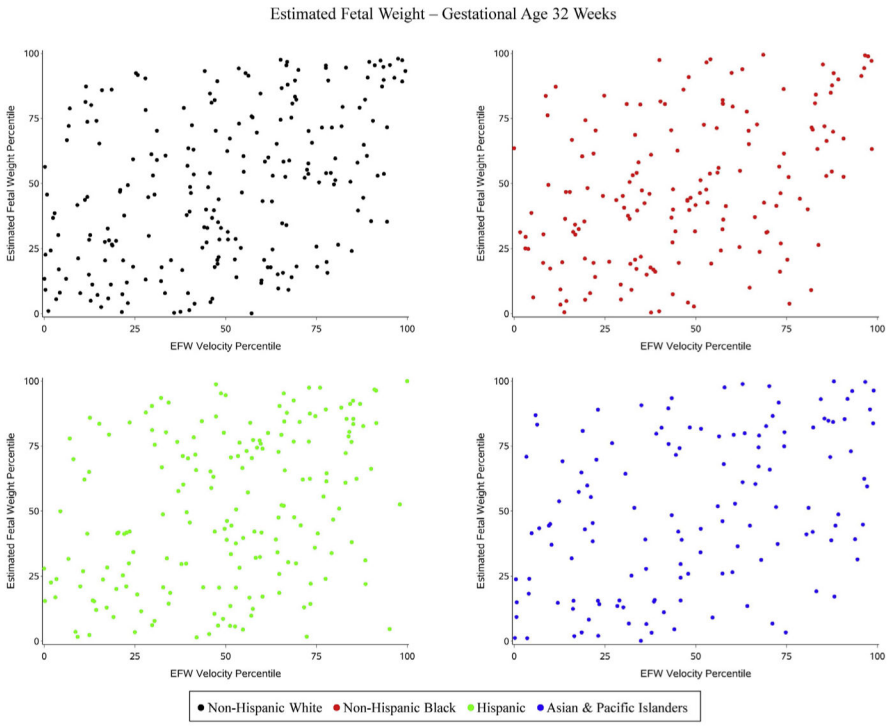

FIGURE 3:

Estimated fetal weight (EFW) velocity percentile by EFW percentile by race/ethnicity and gestation, *Eunice Kennedy Shriver* National Institute of Child Health and Human Development fetal growth studies–singletons

TABLE 1

Race/ethnic-specific percentiles for fetal growth velocity of anthropometric measurements by gestational age, *Eunice Kennedy Shriver* National Institute of Child Health and Human Development fetal growth studies

	Percentile				
Gestational age, wk	**5th**	**10th**	**50th**	**90th**	**95th**
Biparietal diameter, mm-white					
11	2.4	2.6	3.4	4.2	4.4
12	2.4	2.7	3.6	4.6	4.9
13	2.3	2.6	3.8	4.9	5.3
14	2.1	2.4	3.7	5.1	5.5
15	1.7	2.1	3.6	5.2	5.6
16	1.3	1.8	3.4	5.2	5.7
17	0.9	1.4	3.3	5.2	5.7
18	0.6	1.2	3.1	5.2	5.8
19	0.4	1.0	3.1	5.3	6.0
20	0.2	0.8	3.1	5.5	6.2
21	0.0	0.7	3.1	5.7	6.4
22	−0.1	0.6	3.2	5.9	6.7
23	−0.3	0.4	3.1	6.0	6.9
24	−0.6	0.2	3.1	6.2	7.1
25	−0.8	0.0	3.1	6.3	7.2
26	−1.0	−0.2	3.0	6.4	7.4
27	−1.3	−0.4	3.0	6.5	7.5
28	−1.5	−0.6	2.9	6.5	7.6
29	−1.8	−0.8	2.8	6.6	7.7
30	−2.1	−1.0	2.7	6.6	7.8
31	−2.4	−1.3	2.6	6.6	7.8
32	−2.7	−1.6	2.4	6.6	7.8
33	−3.0	−1.9	2.2	6.6	7.8
34	−3.3	−2.2	2.0	6.4	7.7

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Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
35	−3.7	−2.5	1.8	6.3	7.6
36	−4.0	−2.8	1.6	6.1	7.5
37	−4.3	−3.1	1.3	6.0	7.4
38	−4.6	−3.3	1.1	5.9	7.2
39	−4.8	−3.6	1.0	5.7	7.1
40	−5.0	−3.8	0.8	5.6	7.1
41	−5.2	−3.9	0.7	5.6	7.0
Head circumference, mm-white					
11	9.0	9.7	12.0	14.4	15.1
12	9.2	10.0	12.8	15.7	16.6
13	9.0	10.0	13.3	16.7	17.7
14	8.4	9.5	13.3	17.3	18.5
15	7.6	8.8	13.1	17.6	18.9
16	6.5	7.9	12.7	17.7	19.2
17	5.5	7.0	12.3	17.8	19.4
18	4.5	6.1	11.9	17.9	19.7
19	3.8	5.6	11.8	18.3	20.2
20	3.3	5.2	11.9	18.9	20.9
21	2.8	4.8	11.9	19.4	21.5
22	2.2	4.3	11.9	19.8	22.1
23	1.5	3.7	11.8	20.2	22.6
24	0.7	3.1	11.6	20.5	23.1
25	−0.1	2.4	11.4	20.7	23.4
26	−0.9	1.7	11.0	20.8	23.6
27	−1.8	0.9	10.7	20.9	23.8
28	−2.8	0.0	10.2	20.9	23.9
29	−3.7	−0.8	9.8	20.8	24.0
30	−4.7	−1.7	9.3	20.6	23.9

Gestational age, wk	Percentile				
	5th	**10th**	**50th**	**90th**	**95th**
31	−5.7	−2.6	8.7	20.4	23.8
32	−6.7	−3.5	8.1	20.1	23.6
33	−7.8	−4.5	7.4	19.7	23.3
34	−8.8	−5.5	6.6	19.2	22.9
35	−9.9	−6.5	5.9	18.7	22.4
36	−10.9	−7.4	5.1	18.2	21.9
37	−11.8	−8.3	4.4	17.6	21.5
38	−12.6	−9.0	3.8	17.2	21.1
39	−13.3	−9.7	3.3	16.8	20.8
40	−13.8	−10.2	2.9	16.6	20.5
41	−14.3	−10.7	2.6	16.4	20.5
Abdominal circumference, mm-white					
11	6.4	7.1	9.5	12.1	12.9
12	6.7	7.5	10.5	13.7	14.6
13	6.7	7.7	11.3	15.1	16.2
14	6.5	7.6	11.8	16.3	17.6
15	5.9	7.3	12.1	17.3	18.8
16	5.2	6.7	12.2	18.1	19.8
17	4.3	6.0	12.2	18.7	20.6
18	3.4	5.3	12.1	19.3	21.4
19	2.5	4.6	12.0	19.9	22.2
20	1.7	3.9	12.0	20.6	23.1
21	0.8	3.2	11.9	21.2	23.9
22	−0.2	2.4	11.8	21.7	24.6
23	−1.1	1.6	11.6	22.1	25.2
24	−2.1	0.8	11.4	22.6	25.9
25	−3.1	0.0	11.2	23.0	26.5
26	−4.0	−0.8	11.0	23.4	27.1

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
27	−4.9	−1.5	10.9	23.9	27.8
28	−5.6	−2.1	10.9	24.5	28.5
29	−6.3	−2.6	10.9	25.2	29.4
30	−6.9	−3.1	11.1	26.0	30.3
31	−7.6	−3.6	11.1	26.7	31.2
32	−8.4	−4.2	11.1	27.3	32.0
33	−9.2	−4.9	11.0	27.8	32.7
34	−10.2	−5.7	10.8	28.2	33.3
35	−11.2	−6.5	10.5	28.4	33.7
36	−12.3	−7.5	10.0	28.6	34.0
37	−13.6	−8.6	9.4	28.5	34.1
38	−14.9	−9.8	8.7	28.2	34.0
39	−16.3	−11.2	7.8	27.8	33.7
40	−17.9	−12.6	6.7	27.2	33.2
41	−19.6	−14.2	5.5	26.4	32.5
Femur length, mm–white					
11	1.2	1.3	1.7	2.1	2.2
12	1.5	1.7	2.3	2.9	3.1
13	1.8	2.0	2.8	3.7	4.0
14	1.8	2.1	3.2	4.4	4.8
15	1.7	2.0	3.5	5.0	5.5
16	1.3	1.7	3.5	5.4	5.9
17	0.8	1.3	3.3	5.6	6.2
18	0.2	0.8	3.1	5.7	6.4
19	−0.3	0.4	3.0	5.8	6.7
20	−0.6	0.1	2.9	6.1	7.0
21	−1.0	−0.2	2.9	6.3	7.3
22	−1.4	−0.5	2.8	6.5	7.6

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
23	−1.8	−0.9	2.7	6.6	7.8
24	−2.2	−1.2	2.6	6.8	8.0
25	−2.6	−1.5	2.5	6.9	8.2
26	−3.0	−1.9	2.4	7.0	8.4
27	−3.4	−2.2	2.3	7.1	8.6
28	−3.7	−2.4	2.2	7.3	8.8
29	−4.0	−2.7	2.1	7.4	9.0
30	−4.2	−2.9	2.1	7.6	9.3
31	−4.5	−3.1	2.1	7.8	9.5
32	−4.8	−3.3	2.0	7.9	9.7
33	−5.0	−3.6	2.0	8.1	9.9
34	−5.3	−3.8	1.9	8.2	10.0
35	−5.6	−4.1	1.8	8.2	10.2
36	−5.9	−4.3	1.7	8.3	10.3
37	−6.3	−4.6	1.5	8.3	10.3
38	−6.6	−4.9	1.4	8.2	10.3
39	−6.9	−5.2	1.2	8.2	10.3
40	−7.2	−5.5	1.0	8.1	10.2
41	−7.6	−5.8	0.7	7.9	10.1
Humerus length, mm-white					
11	1.3	1.4	1.8	2.1	2.3
12	1.7	1.9	2.4	3.0	3.2
13	2.0	2.2	2.9	3.8	4.0
14	2.0	2.3	3.3	4.4	4.8
15	1.8	2.1	3.4	4.9	5.3
16	1.3	1.8	3.3	5.1	5.6
17	0.8	1.3	3.1	5.1	5.7
18	0.2	0.8	2.8	5.1	5.7

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
19	−0.3	0.3	2.6	5.1	5.8
20	−0.6	0.1	2.5	5.2	6.0
21	−0.9	−0.2	2.5	5.4	6.2
22	−1.2	−0.5	2.4	5.5	6.4
23	−1.6	−0.8	2.3	5.6	6.6
24	−1.9	−1.0	2.2	5.7	6.7
25	−2.2	−1.3	2.1	5.7	6.8
26	−2.5	−1.6	1.9	5.8	6.9
27	−2.8	−1.8	1.8	5.8	7.0
28	−3.1	−2.0	1.8	5.9	7.1
29	−3.3	−2.2	1.7	6.0	7.3
30	−3.5	−2.4	1.7	6.1	7.4
31	−3.7	−2.6	1.6	6.2	7.5
32	−3.9	−2.8	1.6	6.3	7.7
33	−4.1	−2.9	1.5	6.3	7.8
34	−4.3	−3.1	1.5	6.4	7.9
35	−4.5	−3.3	1.4	6.5	8.0
36	−4.7	−3.5	1.3	6.5	8.1
37	−5.0	−3.7	1.2	6.5	8.1
38	−5.2	−3.9	1.1	6.5	8.1
39	−5.5	−4.1	0.9	6.4	8.0
40	−5.7	−4.4	0.7	6.3	8.0
41	−6.1	−4.7	0.5	6.1	7.8
Estimated fetal weight, g-white					
11	4	5	8	13	14
12	5	6	11	16	18
13	7	8	14	21	23
14	9	11	18	26	29

Gestational age, wk	Percentile				
	5th	**10th**	**50th**	**90th**	**95th**
15	11	14	23	33	37
16	14	17	29	42	46
17	17	21	36	52	57
18	20	25	44	64	70
19	23	29	52	77	85
20	25	33	61	92	101
21	27	36	70	107	118
22	28	39	80	124	138
23	29	42	90	143	159
24	29	44	101	163	182
25	28	46	113	185	207
26	27	48	125	209	235
27	25	49	138	235	264
28	23	50	152	263	297
29	20	51	167	294	332
30	16	51	183	327	370
31	10	49	198	360	408
32	0	44	211	392	447
33	−14	36	221	423	484
34	−32	23	227	451	518
35	−54	5	229	474	547
36	−81	−16	227	493	572
37	−111	−41	222	508	594
38	−142	−67	214	520	612
39	−175	−95	203	529	626
40	−209	−124	191	535	638
41	−244	−155	176	539	648
Biparietal diameter, mm-black					

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Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
11	2.5	2.7	3.4	4.3	4.5
12	2.5	2.7	3.7	4.7	5.0
13	2.3	2.6	3.8	5.0	5.3
14	2.0	2.4	3.7	5.1	5.6
15	1.6	2.1	3.6	5.2	5.7
16	1.2	1.7	3.4	5.2	5.7
17	0.9	1.4	3.2	5.2	5.8
18	0.6	1.1	3.1	5.3	5.9
19	0.4	1.0	3.1	5.4	6.1
20	0.2	0.8	3.2	5.6	6.3
21	0.0	0.7	3.1	5.8	6.5
22	−0.2	0.5	3.1	5.9	6.7
23	−0.5	0.3	3.1	6.0	6.9
24	−0.7	0.1	3.0	6.2	7.1
25	−1.0	−0.1	3.0	6.2	7.2
26	−1.2	−0.3	2.9	6.3	7.3
27	−1.5	−0.6	2.8	6.4	7.5
28	−1.7	−0.8	2.8	6.5	7.6
29	−2.0	−1.0	2.7	6.5	7.7
30	−2.3	−1.2	2.6	6.6	7.7
31	−2.5	−1.5	2.4	6.6	7.8
32	−2.9	−1.8	2.3	6.5	7.8
33	−3.2	−2.1	2.1	6.4	7.7
34	−3.6	−2.4	1.8	6.3	7.6
35	−3.9	−2.8	1.6	6.1	7.4
36	−4.3	−3.1	1.3	5.9	7.3
37	−4.5	−3.3	1.1	5.8	7.2
38	−4.7	−3.4	1.1	5.8	7.2

Gestational age, wk	Percentile				
	5th	**10th**	**50th**	**90th**	**95th**
39	−4.8	−3.5	1.0	5.8	7.2
40	−4.8	−3.5	1.1	5.9	7.4
41	−4.7	−3.4	1.2	6.2	7.6
Head circumference, mm-black					
11	9.2	9.9	12.3	14.9	15.6
12	9.4	10.2	13.1	16.2	17.1
13	9.0	10.0	13.5	17.2	18.2
14	8.3	9.4	13.5	17.7	18.9
15	7.2	8.5	13.1	17.9	19.3
16	6.0	7.5	12.6	17.9	19.5
17	4.9	6.5	12.1	18.0	19.7
18	4.0	5.7	11.8	18.2	20.1
19	3.4	5.2	11.8	18.7	20.7
20	2.8	4.8	11.9	19.3	21.4
21	2.1	4.2	11.8	19.7	22.0
22	1.4	3.6	11.7	20.1	22.5
23	0.6	2.9	11.4	20.4	22.9
24	−0.3	2.2	11.2	20.6	23.3
25	−1.2	1.4	10.9	20.7	23.6
26	−2.1	0.7	10.5	20.8	23.8
27	−3.0	−0.1	10.2	20.9	24.0
28	−3.9	−0.9	9.8	20.9	24.2
29	−4.7	−1.7	9.4	21.0	24.3
30	−5.7	−2.5	9.0	20.9	24.4
31	−6.6	−3.4	8.4	20.7	24.3
32	−7.7	−4.3	7.8	20.4	24.1
33	−8.8	−5.4	7.0	20.0	23.7
34	−10.0	−6.5	6.2	19.4	23.2

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
35	−11.1	−7.6	5.3	18.7	22.6
36	−12.2	−8.6	4.5	18.1	22.1
37	−12.9	−9.3	3.9	17.7	21.7
38	−13.5	−9.8	3.6	17.5	21.6
39	−13.8	−10.1	3.4	17.5	21.6
40	−13.9	−10.2	3.5	17.8	22.0
41	−13.9	−10.0	3.9	18.4	22.6
Abdominal circumference, mm-black					
11	5.9	6.6	9.5	12.5	13.4
12	6.0	6.9	10.4	14.1	15.2
13	5.8	6.9	11.1	15.5	16.8
14	5.3	6.6	11.5	16.7	18.2
15	4.6	6.1	11.7	17.7	19.4
16	3.7	5.4	11.7	18.5	20.5
17	2.7	4.6	11.6	19.2	21.4
18	1.7	3.8	11.6	19.8	22.3
19	0.7	3.0	11.5	20.5	23.2
20	−0.3	2.2	11.4	21.2	24.1
21	−1.3	1.3	11.2	21.8	24.9
22	−2.4	0.4	11.0	22.3	25.6
23	−3.5	−0.5	10.8	22.7	26.3
24	−4.6	−1.4	10.5	23.2	26.9
25	−5.6	−2.2	10.3	23.7	27.6
26	−6.5	−2.9	10.2	24.2	28.4
27	−7.3	−3.6	10.2	24.9	29.2
28	−8.1	−4.1	10.3	25.7	30.2
29	−8.6	−4.5	10.5	26.6	31.4
30	−9.2	−5.0	10.8	27.6	32.5

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
31	−10.0	−5.5	10.9	28.4	33.6
32	−10.9	−6.2	10.9	29.1	34.5
33	−11.9	−7.1	10.7	29.6	35.2
34	−13.1	−8.1	10.3	29.9	35.7
35	−14.4	−9.3	9.7	30.0	36.0
36	−15.7	−10.3	9.2	30.1	36.3
37	−16.7	−11.2	8.9	30.4	36.7
38	−17.5	−11.9	8.8	30.8	37.4
39	−18.1	−12.3	8.9	31.6	38.3
40	−18.5	−12.6	9.3	32.6	39.5
41	−18.8	−12.6	10.0	34.1	41.2
Femur length, mm-black					
11	1.3	1.4	1.8	2.2	2.4
12	1.7	1.9	2.5	3.1	3.3
13	2.0	2.2	3.1	4.0	4.3
14	1.9	2.3	3.4	4.7	5.1
15	1.7	2.1	3.5	5.2	5.7
16	1.2	1.7	3.4	5.4	6.0
17	0.6	1.1	3.2	5.5	6.2
18	0.1	0.7	3.0	5.6	6.3
19	−0.3	0.3	2.9	5.8	6.6
20	−0.7	0.1	2.9	6.0	7.0
21	−1.1	−0.2	2.9	6.3	7.3
22	−1.4	−0.6	2.8	6.4	7.5
23	−1.8	−0.9	2.7	6.6	7.8
24	−2.2	−1.2	2.6	6.7	8.0
25	−2.6	−1.5	2.5	6.9	8.2
26	−3.0	−1.9	2.4	7.0	8.4

Gestational age, wk	Percentile 5th	10th	50th	90th	95th
27	−3.3	−2.1	2.3	7.1	8.6
28	−3.6	−2.4	2.2	7.3	8.8
29	−3.9	−2.6	2.2	7.5	9.0
30	−4.1	−2.8	2.2	7.6	9.3
31	−4.4	−3.0	2.1	7.8	9.5
32	−4.7	−3.3	2.1	7.9	9.7
33	−5.0	−3.5	2.0	8.0	9.9
34	−5.4	−3.8	1.9	8.1	10.0
35	−5.7	−4.1	1.7	8.1	10.0
36	−6.0	−4.4	1.6	8.1	10.1
37	−6.2	−4.6	1.5	8.2	10.2
38	−6.4	−4.8	1.4	8.3	10.3
39	−6.6	−4.9	1.5	8.4	10.5
40	−6.7	−5.0	1.5	8.7	10.8
41	−6.8	−5.0	1.7	9.0	11.2
Humerus length, mm-black					
11	1.4	1.5	1.9	2.4	2.5
12	1.8	2.0	2.6	3.3	3.5
13	2.0	2.3	3.2	4.1	4.4
14	2.0	2.3	3.5	4.8	5.2
15	1.6	2.0	3.5	5.1	5.6
16	1.1	1.5	3.3	5.2	5.8
17	0.4	1.0	3.0	5.2	5.9
18	−0.1	0.5	2.7	5.2	6.0
19	−0.5	0.1	2.6	5.3	6.2
20	−0.9	−0.1	2.6	5.5	6.4
21	−1.2	−0.4	2.5	5.7	6.6
22	−1.6	−0.8	2.4	5.8	6.8

	Percentile				
Gestational age, wk	5th	10th	50th	90th	95th
23	−2.0	−1.1	2.2	5.9	7.0
24	−2.3	−1.4	2.1	5.9	7.1
25	−2.6	−1.7	2.0	6.0	7.2
26	−3.0	−1.9	1.9	6.1	7.3
27	−3.2	−2.2	1.8	6.2	7.5
28	−3.5	−2.4	1.7	6.2	7.6
29	−3.7	−2.6	1.7	6.4	7.8
30	−3.9	−2.7	1.7	6.5	8.0
31	−4.1	−2.9	1.7	6.6	8.1
32	−4.4	−3.1	1.6	6.7	8.3
33	−4.6	−3.3	1.5	6.8	8.4
34	−4.8	−3.5	1.4	6.8	8.4
35	−5.1	−3.8	1.3	6.8	8.5
36	−5.3	−4.0	1.2	6.9	8.5
37	−5.5	−4.1	1.2	6.9	8.7
38	−5.6	−4.2	1.2	7.1	8.9
39	−5.6	−4.2	1.3	7.3	9.1
40	−5.6	−4.1	1.5	7.7	9.6
41	−5.6	−4.0	1.8	8.2	10.1
Estimated fetal weight, g-black					
11	4	5	9	13	15
12	5	6	11	17	19
13	6	8	15	22	24
14	8	10	19	28	31
15	10	13	23	35	39
16	12	16	29	44	48
17	15	19	36	54	60
18	17	22	43	65	72

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
19	18	25	50	78	86
20	19	27	58	92	102
21	19	29	66	107	119
22	19	31	75	123	138
23	19	32	84	141	158
24	17	33	94	161	181
25	15	34	104	182	205
26	13	34	115	205	232
27	10	34	127	230	261
28	6	34	141	258	293
29	2	34	155	288	328
30	−3	33	170	320	366
31	−11	30	183	353	404
32	−23	23	195	385	442
33	−39	12	203	414	477
34	−60	−4	207	439	509
35	−86	−25	205	458	535
36	−113	−46	202	477	559
37	−139	−67	200	495	584
38	−163	−87	200	516	611
39	−184	−103	202	539	641
40	−204	−117	209	569	678
41	−220	−127	221	606	722
Biparietal diameter, mm-Hispanic					
11	2.3	2.5	3.3	4.1	4.4
12	2.3	2.6	3.6	4.6	4.9
13	2.2	2.5	3.7	4.9	5.2
14	2.0	2.4	3.7	5.1	5.5

	Percentile				
Gestational age, wk	**5th**	**10th**	**50th**	**90th**	**95th**
15	1.7	2.1	3.6	5.2	5.6
16	1.3	1.7	3.4	5.2	5.7
17	0.9	1.4	3.3	5.2	5.8
18	0.6	1.1	3.1	5.2	5.9
19	0.3	0.9	3.1	5.4	6.0
20	0.2	0.8	3.1	5.6	6.3
21	0.0	0.7	3.1	5.7	6.5
22	−0.2	0.5	3.2	5.9	6.7
23	−0.4	0.4	3.1	6.1	6.9
24	−0.6	0.2	3.1	6.2	7.1
25	−0.9	0.0	3.1	6.3	7.3
26	−1.1	−0.2	3.0	6.4	7.4
27	−1.4	−0.5	2.9	6.5	7.6
28	−1.7	−0.7	2.8	6.6	7.7
29	−1.9	−0.9	2.7	6.6	7.7
30	−2.2	−1.2	2.6	6.6	7.8
31	−2.5	−1.4	2.5	6.6	7.8
32	−2.8	−1.7	2.3	6.6	7.8
33	−3.2	−2.0	2.1	6.5	7.8
34	−3.5	−2.3	1.9	6.4	7.7
35	−3.9	−2.7	1.7	6.2	7.6
36	−4.2	−3.0	1.4	6.1	7.4
37	−4.4	−3.2	1.3	6.0	7.4
38	−4.6	−3.4	1.2	5.9	7.3
39	−4.7	−3.5	1.1	5.9	7.3
40	−4.8	−3.5	1.1	6.0	7.5
41	−4.8	−3.5	1.2	6.2	7.7
Head circumference, mm-Hispanic					

Gestational age, wk	Percentile				
	5th	**10th**	**50th**	**90th**	**95th**
11	8.4	9.2	12.0	15.0	15.8
12	8.5	9.5	12.9	16.5	17.6
13	8.2	9.3	13.4	17.7	18.9
14	7.5	8.8	13.5	18.5	19.9
15	6.4	7.9	13.3	18.9	20.6
16	5.2	6.8	12.8	19.1	21.0
17	3.9	5.7	12.3	19.3	21.3
18	2.8	4.7	11.9	19.5	21.7
19	1.9	4.0	11.8	19.9	22.3
20	1.2	3.5	11.8	20.6	23.1
21	0.5	2.9	11.8	21.1	23.9
22	−0.3	2.3	11.7	21.7	24.6
23	−1.2	1.5	11.6	22.1	25.2
24	−2.1	0.8	11.4	22.5	25.7
25	−3.1	0.0	11.1	22.8	26.2
26	−4.1	−0.9	10.8	23.0	26.6
27	−5.1	−1.7	10.4	23.2	26.9
28	−6.1	−2.6	10.0	23.3	27.1
29	−7.1	−3.5	9.6	23.3	27.4
30	−8.1	−4.4	9.1	23.3	27.5
31	−9.2	−5.4	8.6	23.2	27.5
32	−10.3	−6.4	8.0	23.0	27.4
33	−11.4	−7.4	7.3	22.7	27.2
34	−12.6	−8.5	6.5	22.3	26.9
35	−13.8	−9.6	5.7	21.7	26.4
36	−14.9	−10.6	4.9	21.1	25.9
37	−15.9	−11.6	4.1	20.6	25.4
38	−16.7	−12.4	3.5	20.2	25.0

	Percentile				
Gestational age, wk	5th	10th	50th	90th	95th
39	−17.4	−13.0	3.0	19.8	24.7
40	−18.0	−13.6	2.6	19.6	24.5
41	−18.5	−14.0	2.3	19.5	24.5
Abdominal circumference, mm-Hispanic					
11	5.9	6.6	9.3	12.2	13.0
12	6.1	7.0	10.3	13.8	14.8
13	6.0	7.1	11.1	15.3	16.5
14	5.7	6.9	11.6	16.6	18.0
15	5.1	6.6	11.9	17.6	19.3
16	4.3	6.0	12.1	18.5	20.4
17	3.4	5.2	12.0	19.3	21.4
18	2.4	4.4	11.9	19.9	22.3
19	1.4	3.6	11.9	20.6	23.2
20	0.4	2.9	11.8	21.3	24.1
21	−0.6	2.0	11.6	21.8	24.9
22	−1.7	1.1	11.4	22.4	25.6
23	−2.8	0.2	11.2	22.8	26.3
24	−3.8	−0.7	10.9	23.3	26.9
25	−4.8	−1.5	10.7	23.8	27.6
26	−5.8	−2.3	10.6	24.3	28.3
27	−6.6	−3.0	10.5	24.9	29.1
28	−7.4	−3.5	10.6	25.6	30.1
29	−8.0	−4.0	10.8	26.5	31.2
30	−8.6	−4.4	11.0	27.5	32.3
31	−9.3	−4.9	11.2	28.3	33.4
32	−10.2	−5.6	11.2	29.0	34.3
33	−11.2	−6.4	11.0	29.5	35.0
34	−12.4	−7.4	10.6	29.8	35.5

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
35	−13.7	−8.6	10.1	29.9	35.7
36	−15.0	−9.8	9.4	29.9	35.9
37	−16.2	−10.9	8.9	29.9	36.1
38	−17.4	−11.8	8.4	29.9	36.3
39	−18.4	−12.7	8.0	30.1	36.6
40	−19.3	−13.5	7.8	30.4	37.0
41	−20.1	−14.2	7.6	30.8	37.7
Femur length, mm-Hispanic					
11	1.3	1.3	1.7	2.0	2.1
12	1.6	1.8	2.3	2.9	3.0
13	1.9	2.1	2.8	3.7	3.9
14	1.9	2.2	3.2	4.3	4.7
15	1.8	2.1	3.4	4.8	5.3
16	1.4	1.8	3.4	5.1	5.6
17	0.9	1.4	3.3	5.3	5.9
18	0.4	1.0	3.1	5.4	6.0
19	0.0	0.6	3.0	5.5	6.3
20	−0.3	0.3	2.9	5.7	6.6
21	−0.7	0.1	2.9	5.9	6.8
22	−1.1	−0.2	2.8	6.1	7.1
23	−1.4	−0.6	2.7	6.2	7.3
24	−1.8	−0.9	2.6	6.3	7.5
25	−2.2	−1.2	2.4	6.4	7.6
26	−2.5	−1.5	2.3	6.5	7.8
27	−2.9	−1.8	2.2	6.6	7.9
28	−3.1	−2.0	2.2	6.8	8.1
29	−3.4	−2.2	2.2	6.9	8.3
30	−3.6	−2.4	2.1	7.1	8.6

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
31	−3.9	−2.6	2.1	7.2	8.8
32	−4.1	−2.8	2.1	7.4	9.0
33	−4.4	−3.1	2.0	7.4	9.1
34	−4.7	−3.3	1.8	7.5	9.2
35	−5.1	−3.6	1.7	7.5	9.2
36	−5.4	−3.9	1.5	7.5	9.2
37	−5.6	−4.1	1.4	7.5	9.3
38	−5.8	−4.3	1.4	7.5	9.4
39	−6.0	−4.4	1.3	7.6	9.5
40	−6.1	−4.5	1.4	7.8	9.7
41	−6.2	−4.6	1.5	8.1	10.0
Humerus length, mm-Hispanic					
11	1.3	1.4	1.8	2.2	2.3
12	1.7	1.9	2.4	3.0	3.2
13	2.0	2.2	3.0	3.8	4.1
14	2.0	2.3	3.3	4.5	4.8
15	1.7	2.1	3.4	4.9	5.3
16	1.2	1.7	3.3	5.1	5.6
17	0.7	1.2	3.0	5.0	5.7
18	0.1	0.6	2.7	5.0	5.7
19	−0.4	0.3	2.6	5.0	5.8
20	−0.7	0.0	2.5	5.2	6.0
21	−1.0	−0.3	2.4	5.4	6.2
22	−1.3	−0.5	2.3	5.5	6.4
23	−1.6	−0.8	2.2	5.6	6.6
24	−2.0	−1.1	2.1	5.7	6.7
25	−2.3	−1.4	2.0	5.7	6.8
26	−2.6	−1.6	1.9	5.8	6.9

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
27	−2.9	−1.9	1.8	5.8	7.1
28	−3.1	−2.1	1.7	5.9	7.2
29	−3.4	−2.3	1.7	6.0	7.3
30	−3.6	−2.5	1.6	6.1	7.5
31	−3.8	−2.6	1.6	6.2	7.6
32	−4.0	−2.8	1.5	6.3	7.7
33	−4.2	−3.0	1.5	6.3	7.8
34	−4.4	−3.2	1.4	6.4	7.9
35	−4.7	−3.4	1.3	6.4	7.9
36	−4.9	−3.6	1.2	6.4	8.0
37	−5.1	−3.8	1.1	6.5	8.0
38	−5.2	−3.9	1.1	6.5	8.1
39	−5.4	−4.0	1.0	6.5	8.2
40	−5.6	−4.2	1.0	6.6	8.3
41	−5.7	−4.3	0.9	6.7	8.4
Estimated fetal weight, g—Hispanic					
11	3	4	9	13	15
12	4	6	11	17	19
13	6	8	14	21	24
14	8	10	18	27	30
15	10	12	23	35	38
16	12	15	29	43	48
17	14	19	35	54	59
18	16	22	43	66	73
19	18	25	51	79	88
20	19	27	59	93	104
21	19	29	67	109	122
22	19	31	76	126	141

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
23	18	32	86	145	163
24	17	33	96	165	186
25	14	34	107	187	212
26	12	34	118	212	240
27	8	34	131	238	270
28	4	34	144	267	304
29	0	33	159	299	341
30	−6	32	175	334	382
31	−14	29	190	369	423
32	−27	21	203	403	464
33	−43	10	212	435	502
34	−65	−6	216	462	537
35	−93	−29	215	484	565
36	−124	−54	209	501	589
37	−154	−79	204	518	612
38	−184	−103	199	534	635
39	−211	−126	196	552	660
40	−237	−146	195	574	688
41	−261	−164	198	600	722
Biparietal diameter, mm-Asian					
11	2.4	2.6	3.4	4.2	4.4
12	2.5	2.7	3.6	4.6	4.9
13	2.4	2.7	3.8	4.9	5.2
14	2.2	2.5	3.8	5.1	5.5
15	1.8	2.2	3.7	5.2	5.6
16	1.5	1.9	3.5	5.2	5.7
17	1.1	1.5	3.3	5.1	5.7
18	0.7	1.2	3.1	5.1	5.7

	Percentile				
Gestational age, wk	**5th**	**10th**	**50th**	**90th**	**95th**
19	0.4	1.0	3.0	5.2	5.8
20	0.3	0.9	3.1	5.4	6.0
21	0.1	0.8	3.1	5.6	6.3
22	0.0	0.6	3.1	5.7	6.5
23	−0.2	0.5	3.1	5.9	6.7
24	−0.4	0.3	3.1	6.0	6.9
25	−0.7	0.2	3.1	6.2	7.1
26	−0.9	0.0	3.0	6.3	7.2
27	−1.1	−0.3	3.0	6.3	7.3
28	−1.4	−0.5	2.9	6.4	7.4
29	−1.7	−0.7	2.8	6.4	7.5
30	−2.0	−1.0	2.6	6.4	7.5
31	−2.3	−1.2	2.5	6.4	7.6
32	−2.5	−1.5	2.3	6.4	7.6
33	−2.8	−1.8	2.2	6.3	7.5
34	−3.1	−2.0	2.0	6.2	7.5
35	−3.4	−2.3	1.8	6.1	7.4
36	−3.7	−2.6	1.6	6.0	7.3
37	−4.0	−2.8	1.4	5.9	7.2
38	−4.3	−3.1	1.2	5.8	7.1
39	−4.6	−3.3	1.0	5.6	7.0
40	−4.8	−3.6	0.8	5.5	6.8
41	−5.1	−3.9	0.6	5.3	6.7
Head circumference, mm-Asian					
11	9.2	9.8	11.9	14.1	14.8
12	9.5	10.2	12.8	15.5	16.3
13	9.4	10.3	13.3	16.5	17.4
14	8.9	9.9	13.4	17.1	18.1

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
15	8.1	9.2	13.2	17.4	18.6
16	7.1	8.3	12.8	17.4	18.8
17	6.0	7.4	12.3	17.4	18.9
18	5.0	6.5	11.8	17.4	19.0
19	4.2	5.8	11.6	17.6	19.3
20	3.7	5.4	11.6	18.0	19.9
21	3.3	5.1	11.7	18.5	20.5
22	2.7	4.7	11.7	19.0	21.1
23	2.1	4.2	11.6	19.3	21.6
24	1.4	3.6	11.4	19.6	22.0
25	0.7	2.9	11.2	19.8	22.3
26	−0.2	2.2	10.9	19.9	22.5
27	−1.0	1.5	10.5	19.9	22.6
28	−1.9	0.7	10.1	19.8	22.6
29	−2.9	−0.2	9.5	19.6	22.6
30	−3.9	−1.1	9.0	19.4	22.4
31	−4.8	−2.0	8.4	19.1	22.3
32	−5.8	−2.8	7.8	18.8	22.0
33	−6.7	−3.7	7.2	18.5	21.8
34	−7.6	−4.6	6.6	18.1	21.5
35	−8.5	−5.4	5.9	17.7	21.1
36	−9.4	−6.2	5.3	17.2	20.7
37	−10.4	−7.1	4.6	16.7	20.2
38	−11.3	−8.1	3.8	16.0	19.6
39	−12.4	−9.1	2.9	15.3	18.9
40	−13.4	−10.1	2.0	14.4	18.1
41	−14.5	−11.2	1.0	13.6	17.2
Abdominal circumference, mm-Asian					

Gestational age, wk	Percentile				
	5th	**10th**	**50th**	**90th**	**95th**
11	6.2	6.8	9.3	12.0	12.7
12	6.5	7.3	10.3	13.5	14.5
13	6.5	7.5	11.1	14.9	16.1
14	6.2	7.4	11.6	16.1	17.5
15	5.7	7.0	11.9	17.1	18.7
16	5.0	6.5	12.0	17.9	19.7
17	4.1	5.8	12.0	18.6	20.5
18	3.1	5.0	11.9	19.1	21.2
19	2.2	4.2	11.7	19.6	22.0
20	1.3	3.5	11.6	20.2	22.7
21	0.4	2.7	11.5	20.7	23.4
22	−0.6	1.9	11.3	21.2	24.1
23	−1.6	1.1	11.1	21.6	24.7
24	−2.6	0.3	10.8	22.0	25.2
25	−3.5	−0.5	10.6	22.4	25.8
26	−4.4	−1.2	10.5	22.8	26.4
27	−5.2	−1.9	10.4	23.3	27.1
28	−5.9	−2.4	10.4	23.9	27.9
29	−6.5	−2.8	10.5	24.7	28.8
30	−7.1	−3.3	10.7	25.4	29.7
31	−7.8	−3.8	10.7	26.1	30.6
32	−8.6	−4.4	10.7	26.6	31.3
33	−9.5	−5.2	10.5	27.0	31.9
34	−10.5	−6.1	10.1	27.3	32.3
35	−11.6	−7.0	9.7	27.4	32.6
36	−12.7	−8.0	9.2	27.5	32.8
37	−13.7	−8.8	8.9	27.6	33.1
38	−14.5	−9.5	8.7	27.9	33.6

Gestational age, wk	Percentile 5th	10th	50th	90th	95th
39	−15.1	−10.0	8.7	28.4	34.2
40	−15.7	−10.4	8.8	29.1	35.1
41	−16.1	−10.7	9.1	30.1	36.3
Femur length, mm-Asian					
11	1.3	1.3	1.6	2.0	2.0
12	1.7	1.8	2.3	2.8	2.9
13	2.0	2.2	2.9	3.6	3.8
14	2.1	2.4	3.3	4.3	4.6
15	2.0	2.3	3.5	4.8	5.2
16	1.6	2.0	3.4	5.0	5.5
17	1.1	1.5	3.2	5.1	5.6
18	0.5	1.1	3.0	5.1	5.7
19	0.1	0.7	2.8	5.2	5.9
20	−0.2	0.4	2.8	5.4	6.1
21	−0.5	0.2	2.8	5.6	6.4
22	−0.8	−0.1	2.7	5.7	6.6
23	−1.1	−0.3	2.7	5.9	6.9
24	−1.5	−0.6	2.6	6.0	7.0
25	−1.8	−0.9	2.5	6.1	7.2
26	−2.1	−1.1	2.4	6.2	7.4
27	−2.4	−1.4	2.3	6.3	7.5
28	−2.7	−1.7	2.2	6.4	7.7
29	−3.0	−1.9	2.2	6.6	7.9
30	−3.2	−2.1	2.1	6.7	8.0
31	−3.5	−2.3	2.1	6.8	8.2
32	−3.7	−2.5	2.0	6.9	8.3
33	−4.0	−2.7	1.9	6.9	8.4
34	−4.3	−3.0	1.8	7.0	8.6

Gestational age, wk	Percentile				
	5th	10th	50th	90th	95th
35	−4.5	−3.2	1.8	7.1	8.7
36	−4.7	−3.4	1.7	7.1	8.8
37	−5.0	−3.6	1.6	7.2	8.8
38	−5.2	−3.8	1.5	7.2	8.9
39	−5.5	−4.0	1.4	7.2	9.0
40	−5.7	−4.2	1.3	7.2	9.0
41	−6.0	−4.5	1.2	7.3	9.1
Humerus length, mm-Asian					
11	1.3	1.4	1.7	2.1	2.2
12	1.8	1.9	2.4	2.9	3.1
13	2.0	2.2	2.9	3.7	4.0
14	2.1	2.4	3.3	4.4	4.7
15	1.9	2.2	3.4	4.8	5.2
16	1.4	1.8	3.3	4.9	5.4
17	0.9	1.3	3.0	4.9	5.4
18	0.3	0.8	2.7	4.8	5.4
19	−0.2	0.4	2.5	4.8	5.4
20	−0.5	0.1	2.4	4.9	5.6
21	−0.8	−0.1	2.4	5.0	5.8
22	−1.0	−0.3	2.3	5.2	6.0
23	−1.3	−0.6	2.2	5.3	6.2
24	−1.6	−0.8	2.2	5.4	6.3
25	−1.9	−1.1	2.1	5.4	6.5
26	−2.2	−1.3	2.0	5.5	6.6
27	−2.5	−1.5	1.9	5.6	6.7
28	−2.7	−1.8	1.8	5.6	6.8
29	−3.0	−2.0	1.7	5.7	6.9
30	−3.2	−2.2	1.6	5.7	7.0

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Gestational age, wk	Percentile 5th	10th	50th	90th	95th
31	−3.4	−2.4	1.5	5.8	7.0
32	−3.6	−2.5	1.5	5.8	7.1
33	−3.8	−2.7	1.4	5.9	7.2
34	−4.0	−2.9	1.4	6.0	7.3
35	−4.2	−3.0	1.3	6.0	7.4
36	−4.3	−3.1	1.3	6.1	7.5
37	−4.5	−3.3	1.2	6.1	7.6
38	−4.7	−3.5	1.1	6.1	7.6
39	−5.0	−3.7	1.0	6.1	7.6
40	−5.2	−4.0	0.8	6.0	7.5
41	−5.5	−4.2	0.6	5.9	7.4
Estimated fetal weight, g-Asian					
11	5	5	9	13	14
12	6	7	11	16	17
13	8	9	14	20	22
14	10	11	18	26	28
15	12	14	23	32	35
16	14	17	28	40	43
17	17	21	34	49	54
18	20	25	42	60	65
19	23	28	49	72	78
20	25	32	57	85	93
21	27	35	66	99	109
22	29	38	75	114	126
23	30	41	84	131	145
24	31	44	95	149	166
25	31	47	105	169	188
26	30	49	117	191	213

Gestational age, wk	**Percentile**				
	5th	**10th**	**50th**	**90th**	**95th**
27	30	51	129	214	239
28	28	52	142	239	267
29	26	54	155	265	298
30	23	54	169	294	331
31	17	52	182	322	364
32	9	48	193	350	397
33	−2	41	201	376	428
34	−18	30	207	399	457
35	−37	15	209	419	482
36	−58	−2	208	437	505
37	−82	−21	206	452	526
38	−106	−40	203	466	545
39	−131	−61	198	479	564
40	−157	−83	193	492	582
41	−184	−105	187	506	601

Week corresponds to exact week (eg, 11 wk = 11.0 wk).

Estimated fetal weight was calculated using Hadlock et al.[9]

TABLE 2

Pairwise race/ethnic *P* values for weekly fetal growth velocity of anthropometric measurements by gestational age, *Eunice Kennedy Shriver* National Institute of Child Health and Human Development fetal growth studies

Gestational age, wk	Global	Asian vs black	Asian vs Hispanic	Asian vs white	Black vs Hispanic	Black vs white	Hispanic vs white
Biparietal diameter, mm							
11	1.0000	.8700	.3722	.4844	.1754	.2406	.7532
12	1.0000	.8621	.2940	.3628	.2407	.3026	.7886
13	1.0000	.4863	.1978	.2134	.3820	.4208	.8577
14	.3837	.1052	.0900	.0640	.7804	.7155	.9782
15	.0051	.0009	.0151	.0022	.2994	.5838	.5565
16	.0031	.0005	.0431	.0027	.0753	.4018	.2896
17	.7162	.1194	.7091	.2052	.1879	.6941	.3228
18	1.0000	.8817	.5604	.8132	.6109	.6490	.3322
19	.2141	.0357	.1141	.4514	.5572	.0815	.2853
20	.0968	.0161	.0255	.2010	.8859	.1396	.2044
21	.2925	.2149	.0487	.3500	.4064	.6878	.2015
22	.7600	.8122	.2258	.7177	.1267	.5191	.3308
23	.3534	.1917	.6449	.9282	.0589	.1771	.5391
24	.2096	.0478	.9633	.7395	.0349	.0638	.7530
25	.0817	.0136	.7017	.6669	.0216	.0209	.9650
26	.0229	.0038	.5295	.6818	.0126	.0048	.7972
27	.0042	.0012	.4195	.8237	.0083	.0007	.5079
28	.0027	.0036	.4245	.7966	.0216	.0004	.2414
29	.0718	.1315	.6855	.4086	.2176	.0120	.1674
30	.3755	.4884	.9138	.2870	.5220	.0626	.1953
31	.4262	.5810	.9182	.2534	.6270	.0710	.1762
32	.1607	.3751	.7426	.2421	.5514	.0268	.1076
33	.0068	.0514	.3441	.2826	.2952	.0011	.0310
34	.0006	.0016	.0679	.6914	.1218	<.0001	.0127

Gestational age, wk	Global	Asian vs black	Asian vs Hispanic	Asian vs white	Black vs Hispanic	Black vs white	Hispanic vs white
35	.0266	.0044	.0753	.6790	.1922	.0052	.1113
36	.0323	.0054	.0766	.3828	.2523	.0327	.3145
37	.0099	.0016	.0448	.1390	.2095	.0652	.5580
38	.2100	.0350	.1725	.0952	.3721	.5118	.7721
39	1.0000	.6468	.8073	.3893	.8062	.6976	.4979
40	1.0000	.8580	.8528	.6465	.9986	.4927	.4767
41	1.0000	.6449	.7087	.7924	.9188	.4299	.4831
Head circumference, mm							
11	.1044	.3068	.5486	.4107	.7279	.0174	.1152
12	.1577	.5337	.5668	.2943	.9669	.0263	.0721
13	.1792	.9936	.5869	.1602	.4925	.0507	.0299
14	.0240	.2477	.6064	.0411	.0546	.1809	.0040
15	.0002	.0007	.6280	.0012	<.0001	.7234	<.0001
16	.0003	<.0001	.7648	.0038	<.0001	.1247	.0032
17	.0806	.0198	.8082	.2700	.0134	.1795	.1923
18	1.0000	.6399	.6275	.9985	.3132	.5983	.5907
19	.5930	.0988	.2730	.2660	.6614	.5414	.9287
20	.4231	.0983	.1749	.0705	.8705	.8012	.7091
21	.5842	.8867	.5106	.1075	.5617	.0974	.3515
22	.0575	.1734	.8401	.2788	.2561	.0096	.1995
23	.0129	.0210	.4293	.5586	.1499	.0022	.1590
24	.0044	.0043	.2681	.7774	.1027	.0007	.1442
25	.0015	.0013	.2051	.8839	.0722	.0003	.1308
26	.0004	.0006	.1882	.8792	.0484	<.0001	.1138
27	.0001	.0005	.2291	.7403	.0342	<.0001	.0999
28	.0011	.0074	.4741	.4684	.0550	.0002	.1316
29	.1850	.3117	.8731	.2831	.2445	.0308	.3725
30	1.0000	.9442	.4888	.2594	.4513	.2342	.7318
31	1.0000	.8676	.3966	.2785	.4879	.3619	.9037

Gestational age, wk	Global	Asian vs black	Asian vs Hispanic	Asian vs white	Black vs Hispanic	Black vs white	Hispanic vs white
32	1.0000	.9499	.4210	.3264	.3788	.2827	.9471
33	.4473	.3174	.6546	.4916	.1612	.0745	.8640
34	.0673	.0149	.5943	.9001	.0638	.0112	.6459
35	.0452	.0075	.2321	.4401	.1512	.0300	.5755
36	.0548	.0091	.1619	.3727	.2883	.0630	.5280
37	.1113	.0186	.1286	.4929	.5004	.0771	.3483
38	1.0000	.6548	.4691	.7732	.7725	.4323	.2806
39	1.0000	.3282	.8306	.3952	.4663	.8303	.5600
40	.9307	.1551	.5849	.3265	.4227	.5929	.7294
41	.6551	.1092	.4896	.3044	.4160	.5091	.8135
Abdominal circumference, mm							
11	1.0000	.8308	.9676	.5573	.7650	.6459	.4506
12	1.0000	.9908	.9633	.5559	.9651	.4251	.4385
13	.9382	.7016	.9650	.5415	.6829	.1564	.4158
14	.0376	.2731	.9886	.4919	.1771	.0063	.3738
15	<.0001	.0114	.8970	.3648	.0016	<.0001	.3525
16	.0011	.0034	.6498	.3729	.0009	.0002	.6678
17	.0428	.0576	.5783	.4974	.0117	.0071	.9101
18	.1753	.2909	.4829	.4061	.0490	.0292	.9082
19	.1602	.7728	.2996	.1623	.0919	.0267	.6953
20	.0030	.7069	.1699	.0233	.0253	.0005	.2835
21	<.0001	.3753	.1697	.0031	.0110	<.0001	.0715
22	<.0001	.2455	.2767	.0024	.0201	<.0001	.0391
23	.0005	.2351	.4399	.0072	.0448	<.0001	.0460
24	.0019	.2677	.5565	.0185	.0783	.0003	.0638
25	.0056	.3312	.5951	.0324	.1133	.0009	.0892
26	.0162	.4546	.5500	.0436	.1511	.0027	.1320
27	.0851	.7443	.4135	.0536	.2196	.0142	.2430
28	.6160	.6704	.2438	.1027	.4563	.2269	.6531

Gestational age, wk	Global	Asian vs black	Asian vs Hispanic	Asian vs white	Black vs Hispanic	Black vs white	Hispanic vs white
29	1.0000	.2725	.1864	.3626	.9077	.7321	.6024
30	.8562	.1782	.1427	.5534	.9869	.3626	.3096
31	.6473	.1353	.1079	.5608	.9671	.2890	.2425
32	.4196	.0961	.0699	.4412	.9133	.2997	.2360
33	.2232	.0706	.0372	.2108	.7948	.4893	.3274
34	.4633	.2284	.0814	.0772	.6738	.7192	.9238
35	.8970	.7576	.5156	.1495	.7684	.3127	.4355
36	1.0000	.9008	.9086	.2699	.9883	.3362	.3061
37	1.0000	.8034	.7533	.5031	.5621	.6801	.2956
38	1.0000	.6087	.5031	.6442	.2275	.2993	.7835
39	.7977	.6293	.6215	.3334	.3189	.1330	.6418
40	.7461	.6572	.7208	.2985	.4115	.1244	.4881
41	.7577	.6710	.7802	.2947	.4692	.1263	.4309
Femur length, mm							
11	.0677	.7544	.0443	.0211	.0354	.0113	.8232
12	.1058	.3783	.0277	.0176	.0898	.0540	.9548
13	.0761	.0711	.0127	.0136	.3234	.3901	.8257
14	.0023	.0004	.0028	.0098	.6259	.1624	.4475
15	<.0001	<.0001	.0001	.0129	<.0001	<.0001	.0564
16	<.0001	<.0001	.0047	.6480	<.0001	<.0001	.0195
17	<.0001	<.0001	.7999	.2277	<.0001	<.0001	.1160
18	<.0001	.0083	.3346	.0686	<.0001	<.0001	.3191
19	.0066	.6576	.0486	.0242	.0032	.0011	.6993
20	.0323	.8393	.0161	.0138	.0062	.0054	.8911
21	.0372	.5977	.0981	.0553	.0137	.0062	.7362
22	.1869	.2231	.6663	.3975	.0799	.0311	.6479
23	.6597	.1099	.5377	.8651	.2800	.1334	.6407
24	.4515	.0752	.2021	.3905	.5419	.3182	.6720
25	.3542	.0590	.0907	.1825	.7704	.5352	.7255

Gestational age, wk	Global	Asian vs black	Asian vs Hispanic	Asian vs white	Black vs Hispanic	Black vs white	Hispanic vs white
26	.2872	.0484	.0479	.0867	.9433	.7638	.8101
27	.1946	.0454	.0324	.0410	.9382	.9788	.9595
28	.1976	.0896	.0572	.0329	.9003	.6964	.7787
29	.9440	.4461	.4041	.1573	.9934	.5576	.5253
30	1.0000	.9679	.8773	.6329	.8451	.6681	.4961
31	1.0000	.8117	.5661	.9905	.7522	.8134	.5570
32	1.0000	.7681	.4712	.7552	.6836	.9929	.6816
33	1.0000	.9286	.5574	.5813	.6217	.6445	.9873
34	1.0000	.5875	.8561	.5643	.6910	.2564	.4182
35	1.0000	.3766	.3746	.8400	.9334	.2497	.2317
36	1.0000	.3621	.2651	.9749	.8913	.3622	.2610
37	1.0000	.4336	.2203	.7604	.6869	.6282	.3597
38	1.0000	.9989	.5483	.5229	.5405	.5147	.9635
39	1.0000	.5735	.8323	.6210	.6906	.2680	.4377
40	1.0000	.4753	.6192	.7083	.7876	.2579	.3494
41	1.0000	.4412	.5355	.7560	.8388	.2645	.3249
Humerus length, mm							
11	.3523	.8522	.9748	.0897	.8640	.0587	.0596
12	.4189	.4144	.7705	.0698	.5673	.2104	.0872
13	.2874	.0685	.4913	.0479	.2117	.8825	.1554
14	.0014	.0002	.1672	.0262	.0099	.0332	.4058
15	<.0001	<.0001	.0053	.0145	<.0001	<.0001	.4808
16	<.0001	<.0001	.0005	.2998	<.0001	<.0001	.0119
17	<.0001	<.0001	.1189	.5098	.0003	<.0001	.0196
18	.0002	.0270	.9100	.1355	.0213	<.0001	.0761
19	.1350	.5740	.1227	.0225	.2230	.0335	.3957
20	.0236	.1059	.0096	.0039	.2037	.1023	.7333
21	.1770	.6654	.0737	.0295	.1204	.0455	.6738
22	.2829	.3267	.6413	.3886	.1232	.0472	.6761

Gestational age, wk	Global	Asian vs black	Asian vs Hispanic	Asian vs white	Black vs Hispanic	Black vs white	Hispanic vs white
23	.3042	.0507	.5096	.7372	.1646	.0759	.7170
24	.0746	.0124	.1747	.2710	.2111	.1147	.7592
25	.0282	.0047	.0751	.1164	.2474	.1510	.7939
26	.0142	.0024	.0411	.0620	.2711	.1810	.8244
27	.0122	.0020	.0328	.0458	.2942	.2157	.8600
28	.0648	.0108	.0756	.0857	.3803	.3213	.9214
29	1.0000	.3090	.5374	.5142	.6422	.6384	.9888
30	1.0000	.8860	.7291	.7179	.8420	.8342	.9977
31	1.0000	.5173	.4540	.3856	.9344	.8515	.9151
32	1.0000	.3838	.3702	.2357	.9919	.7674	.7710
33	.9431	.4136	.4388	.1572	.9584	.5439	.5057
34	1.0000	.9482	.9838	.2642	.9293	.2926	.2269
35	1.0000	.4772	.4080	.8617	.9449	.3401	.2673
36	1.0000	.3853	.2932	.8566	.8788	.4643	.3570
37	1.0000	.5503	.3059	.7773	.6714	.7440	.4462
38	1.0000	.5990	.8527	.9143	.4530	.4904	.9278
39	1.0000	.2790	.5729	.8837	.5666	.3029	.6436
40	1.0000	.2338	.4292	.8118	.6529	.3053	.5528
41	1.0000	.2210	.3775	.7791	.6989	.3171	.5256
Estimated fetal weight, g							
11	.3754	.2569	.2183	.0626	.8540	.4098	.5770
12	.5213	.2988	.2594	.0869	.8554	.4283	.6045
13	.9086	.3690	.3420	.1514	.8858	.5089	.6700
14	1.0000	.5153	.5608	.4171	.9850	.8502	.8572
15	1.0000	.9312	.6757	.3281	.5632	.1949	.5712
16	.0018	.5595	.0422	.0003	.2207	.0102	.1486
17	.0013	.6562	.0410	.0002	.1289	.0020	.1094
18	.0005	.9288	.0741	.0004	.0452	<.0001	.0745
19	<.0001	.2445	.1402	.0004	.0023	<.0001	.0241

Gestational age, wk	Global	Asian vs black	Asian vs Hispanic	Asian vs white	Black vs Hispanic	Black vs white	Hispanic vs white
20	<.0001	.0143	.2582	<.0001	<.0001	<.0001	.0012
21	<.0001	.0007	.4784	<.0001	<.0001	<.0001	<.0001
22	<.0001	.0005	.8811	.0002	.0002	<.0001	.0002
23	<.0001	.0013	.8340	.0047	.0021	<.0001	.0017
24	<.0001	.0033	.7138	.0243	.0082	<.0001	.0066
25	<.0001	.0059	.6973	.0506	.0150	<.0001	.0147
26	<.0001	.0088	.7779	.0593	.0163	<.0001	.0242
27	<.0001	.0165	.9797	.0437	.0126	<.0001	.0398
28	.0003	.0951	.5342	.0330	.0175	<.0001	.1210
29	.1261	.6678	.2204	.0666	.0934	.0210	.5557
30	.5364	.7215	.0894	.0926	.1942	.2092	.8980
31	.3154	.5145	.0526	.0877	.2145	.3350	.7072
32	.2157	.4886	.0360	.0580	.1668	.2593	.7192
33	.1579	.7137	.0376	.0263	.0856	.0663	.9937
34	.0638	.5909	.2599	.0446	.0973	.0106	.4040
35	.2008	.2982	.8518	.3011	.3762	.0335	.2027
36	.6105	.2515	.3986	.6656	.7519	.1017	.1847
37	1.0000	.2600	.1703	.9394	.8087	.2659	.1704
38	1.0000	.7451	.2485	.5176	.4104	.7748	.5296
39	1.0000	.7357	.7016	.5292	.4702	.3194	.8294
40	1.0000	.5711	.9765	.5935	.5525	.2548	.6171
41	1.0000	.5050	.8829	.6399	.6076	.2406	.5359

Week corresponds to exact week (eg, 11 wk = 11.0 wk).

P values obtained by Wald test with adjustment for maternal age, height, weight, parity, job, marital status, insurance, income, education, and infant sex.

TABLE 3

Example of different scenarios for 2 ultrasounds obtained between 28–32 weeks of gestation by self-identified maternal race/ethnicity

Non-Hispanic white			
28 wk EFW	32 wk EFW	EFW percentile at 32 wk	Velocity percentile from 28–32 wk
1354	1960	50th	5th
1202	1960	50th	50th
1067	1960	50th	95th
Non-Hispanic black			
28 wk EFW	32 wk EFW	EFW percentile at 32 wk	Velocity percentile from 28–32 wk
1292	1837	50th	5th
1134	1837	50th	50th
996	1837	50th	95th
Hispanic			
28 wk EFW	32 wk EFW	EFW percentile at 32 wk	Velocity percentile from 28–32 wk
1317	1878	50th	5th
1150	1878	50th	50th
1005	1878	50th	95th
Asian and Pacific Islander			
28 wk EFW	32 wk EFW	EFW percentile at 32 wk	Velocity percentile from 28–32 wk
1267	1830	50th	5th
1132	1830	50th	50th
1011	1830	50th	95th

EFW, estimated fetal weight.

TABLE 4

Characteristics by fetal growth velocity and estimated fetal weight percentile category for pregnancies with ultrasound at mean of 32 SD 1.5 weeks of gestation

Characteristics	Total n = 1605	Velocity <5th percentile		Velocity ≥5th percentile		*P*value
		EFW <5th percentile n = 14	EFW ≥5th percentile n = 57	EFW <5th percentile n = 62	EFW ≥5th percentile n = 1472	
Race/ethnicity, no. (%)						.760
Non-Hispanic white	458 (28)	2 (14)[a]	17 (30)	16 (26)	423 (29)	
Non-Hispanic black	387 (24)	4 (29)	12 (21)	17 (27)	354 (24)	
Hispanic	448 (28)	4 (29)	12 (21)	18 (29)	414 (28)	
Asian and Pacific Islander	312 (19)	4 (29)	16 (28)	11 (18)	281 (19)	
Height, mean (SD), cm	163 (7)	160 (6)	164 (7)	161 (6)	163 (7)	.044
Maternal prepregnancy BMI, mean (SD), kg/m^2	23.4 (3)	23.7 (4)	22.6 (3)	22.8 (3)	23.5 (3)	.046
Parity, no. (%)						.152
0	769 (48)	7 (50)	29 (51)	22 (36)	711 (48)	
1	576 (36)	3 (21)	23 (40)	30 (48)	520 (35)	
≥2	260 (16)	4 (29)	5 (9)	10 (16)	241 (16)	
Infant sex, no. (%)						.305
Male	834 (52)	7 (50)	31 (54)	25 (40)	771 (52)	
Female	771 (48)	7 (50)	26 (46)	37 (60)	701 (48)	
Birthweight, mean (SD), kg	3325 (422)[b]	2550 (295)	3208 (382)	2867 (420)	3357 (405)	<.001
Composite neonatal outcome,[c] no. (%)						.632
No	1536 (96)	14 (100)	53 (93)	59 (95)	1410 (96)	
Yes	69 (4)	0 (0)	4 (7)	3 (5)	62 (4)	

Standard population as detailed in Buck Louis et al.[6]

BMI, body mass index; *EFW*, estimated fetal weight.

[a]Because of rounding, percentages may not total 100;

[b]Birthweight was available for 1443 neonates;

[c]Neonatal morbidities included: metabolic acidosis (pH <7.1 and base deficit >12 mmol/L), neonatal intensive care unit stay >3 d, pneumonia, respiratory distress syndrome, persistent pulmonary hypertension, seizures, hyperbilirubinemia requiring exchange transfusion, intrapartum aspiration (meconium, amniotic fluid, blood), neonatal death, mechanical ventilation at term, necrotizing enterocolitis, hypoglycemia, hypoxic ischemic encephalopathy, periventricular leukomalacia, sepsis based on blood culture, bronchopulmonary dysplasia/chronic lung disease, retinopathy of prematurity, and birth injury.[13–17]