abstract

OBJECTIVES: To provide an updated US birth weight for gestational age reference corrected for likely errors in last menstrual period (LMP)-based gestational age dating, as well as means and SDs, to enable calculation of continuous and categorical measures of birth weight for gestational age.

METHODS: From the 2009–2010 US live birth files, we abstracted singleton births between 22 and 44 weeks of gestation with at least 1 nonmissing estimate of gestational age (ie, LMP or obstetric/clinical) and birth weight. Using an algorithm based on birth weight and the concordance between these gestational age estimates, implausible LMP-based gestational age estimates were either excluded or corrected by using the obstetric/clinical estimate. Gestational age– and sex-specific birth weight means, SDs, and smoothed percentiles (3rd, 5th, 10th, 90th, 95th, 97th) were calculated, and the 10th and 90th percentiles were compared with published population-based references.

RESULTS: A total of 7,818,201 (99% of eligible) births were included. The LMP-based estimate of gestational age comprised 85% of the dataset, and the obstetric/clinical estimate comprised the remaining 15%. Cut points derived from the current reference identified ~10% of births as ≤10th and ≥90th percentiles at all gestational weeks, whereas cut points derived from previous US-based references captured variable proportions of infants at these thresholds within the preterm and postterm gestational age ranges.

CONCLUSIONS: This updated US-based birth weight for gestational age reference corrects for likely errors in gestational age dating and allows for the calculation of categorical and continuous measures of birth size. Pediatrics 2014;133:844–853

WHAT’S KNOWN ON THIS SUBJECT: Population-based references of birth weight for gestational age are useful indices of birth size in clinical and research settings.

WHAT THIS STUDY ADDS: This article uses 2009–2010 US natality data and corrects for likely errors in gestational age dating to yield an up-to-date birth weight for gestational age reference.

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KEY WORDS
reference, growth charts, gestational age, birth weight, small for gestational age, United States

ABBREVIATIONS
LGA—large for gestational age
LMP—last menstrual period
SGA—small for gestational age

All authors met each of the 3 criteria for authorship as defined in the Pediatrics Author Guidelines. Dr Talge provided significant intellectual contributions to the study conceptualization and design as well as the interpretation of findings, executed the statistical analyses, and was the primary contributor to all manuscript drafts; Dr Mudd provided significant intellectual contributions to the study conceptualization and design as well as the interpretation of findings, drafted portions of the manuscript, and provided critical revisions throughout the manuscript drafting process; Dr Sikorskii was instrumental in guiding the application and interpretation of statistical techniques that featured prominently in the manuscript (eg, 4253H, twice); and Dr Basso provided significant intellectual contributions to the study’s analytic approach, was highly involved in the interpretation of study findings, and provided critical revisions to the manuscript.

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Several population-based references for measuring birth weight for gestational age have been generated.1–4 These references are used by clinicians to identify at-risk infants who may have suffered from restricted or excessive fetal growth and by researchers to generate measures of birth size that are interpreted as indicators of maternal/fetal health or risk factors for later health outcomes. Although most previous studies have focused on the antecedents or sequelae of infants at the extremes of the birth weight for gestational age distribution (ie, small or large for gestational age [SGA or LGA]), researchers are increasingly making use of the entire distribution to inform their work (eg, birth weight z-scores).5

US population-based references report birth weights that correspond to percentile thresholds (eg, 10th, 90th), but do not include the information needed to calculate continuous measures of birth weight for gestational age (ie, means, SDs).1,4 Additionally, existing US references rely solely on gestational age estimated from maternal reports of last menstrual period (LMP).1,4,6 LMP-based estimates are prone to error, with the proportion of implausible estimates being particularly high between 28 and 31 weeks of gestation.5,7 Sources of error in LMPs include their susceptibility to digit preference as well as imprecision among women with irregular menstrual cycles or evidence of early bleeding.8–10 To date, references have relied on removal of records with implausible birth weights for gestational age to improve their accuracy.1,4 However, the widespread inclusion of obstetric/clinical estimates on birth certificates has led to additional approaches for correction. Such approaches typically involve evaluating the concordance between the LMP and obstetric/clinical estimates within a particular range (eg, 1–2 weeks), and either removing exceedingly discrepant records or replacing likely errors in LMP with the obstetric/clinical estimate.5,11,12 Birth weight for gestational age references generated from vital records have yet to reflect these advances in improving the precision of gestational age dating, despite calls to do so.11

Our purpose was to create an updated US birth weight for gestational age reference by using an algorithm based on birth weight and the concordance between LMP and obstetric/clinical gestational age estimates. Furthermore, we provide the information needed to calculate categorical and continuous measures of birth size.

METHODS

Study Population

The study population consisted of the combined 2009 and 2010 US Live Birth Files maintained by the National Center for Health Statistics (n = 8 130 051 births to US resident women). Two estimates of gestational age are available in these data: (1) the LMP-based estimate (common to all states), and (2) the clinical or obstetric-based estimate (any given state reports one or the other, depending on whether the 1989 or 2003 version of the Certificate of Live Birth, respectively, was used). The clinical and obstetric estimates of gestational age can be informed by prenatal assessments (eg, ultrasounds), but clinical estimates also may be informed by neonatal examinations.13,14

We excluded nonsingleton births, records missing birth weight or both estimates of gestational age, and records with all available gestational age estimates either <22 weeks or >44 weeks (n = 302 516, nonmutually exclusive). This resulted in 7 827 535 singleton births eligible for inclusion. The Michigan State University Institutional Review Board deemed this study exempt.

To identify likely errors in gestational age and generate a “corrected” dataset, we applied an algorithm developed by Basso and Wilcox.12 This procedure uses LMP and/or obstetric/clinical-based estimates of gestational age, along with birth weight, to identify records with likely errors. This algorithm is described in detail elsewhere,12 but is summarized briefly here. If both the LMP and obstetric/clinical estimates of gestational age were available, they were checked to see if they were within 2 weeks of each other. In such cases, the birth weight z-score* based on the LMP estimate was examined to see if it was considered plausible for that gestational age (Fig 1, footnotes a and b). If so, the LMP estimate was retained; if not, and if the birth weight z-score based on the obstetric/clinical estimate was within the acceptable range, the obstetric/clinical estimate replaced the LMP. If neither the LMP nor the obstetric/clinical birth weight z-score was within range, the record was discarded. If the LMP and obstetric/clinical estimates differed by >2 weeks, the obstetric/clinical estimate was examined first and retained if the z-score was within range; if not, the LMP estimate was examined and retained if the z-score was within range. Finally, if only 1 estimate of gestational age was available (or within the 22–44-week window), it was examined to see if the z-score was within range and could be retained. This procedure resulted in the exclusion of 9334 records, leaving 7 818 201 births in the corrected dataset. Next, we applied the Alexander et al1 criteria (see Table 1 of that publication) to identify additional implausible birth weights for gestational age, but none were observed. We

*Birth weight z-score reference data were calculated using gestational age–specific medians (generated from the current dataset, using LMPs in the term range and obstetric/clinical estimates in the preterm range) and SDs (as reported by Kramer et al17).
then applied a nonlinear, resistant smoothing technique (4253H, twice) to reduce the impact of irregularities in the percentile curves across gestational age groups and obtain cross-age smoothed estimates. This procedure, used by previous references to which ours is compared, is not based on distributional assumptions and altered birth weight percentile thresholds by a minimum of 0 g (23 weeks) and a maximum of 69 g (43 weeks) (data not shown).

To examine whether secular changes in perinatal outcomes explained differences observed between previous references and our newly created one, we created a “comparison” dataset that applied the gestational age cleaning process used to obtain previous US-based references. For this purpose, we restricted our data to births with nonmissing LMP estimates of gestational age between 22 and 44 weeks in the 2009 and 2010 US natality datasets (n = 7 301 492), applied the Alexander et al criteria to identify records with implausible birth weights for gestational age (26 738 records removed, final n = 7 274 754), and used the 4253H, twice smoothing technique.

**Analysis Plan**

We first described the corrected dataset according to gestational age estimation method and demographic characteristics. We then calculated gestational age–specific skewness and kurtosis values to evaluate their departure from normality and, hence, the appropriateness of means and SDs as summaries of the birth weight distributions. Next, we calculated birth...
TABLE 1 Means, SDs, and Smoothed Percentiles for Birth Weight (g) for Gestational Age Within the Corrected Dataset: US Male Singleton Live Births (2009–2010)

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The corrected dataset uses both LMP- and clinical/obstetric-based estimates of gestational age and reflects the application of the Basso and Wilcox algorithm to correct likely errors in gestational age and excludes implausible birth weights for gestational age.

weights corresponding to thresholds used to define SGA and LGA births (ie, 3rd, 5th, 10th, 90th, 95th, and 97th percentiles), along with the median (50th percentile). Descriptive statistics were then recalculated separately for males and females. We did not calculate race/ethnicity-specific estimates, because differences in birth weight by race/ethnicity may reflect disparities in obstetric care, environmental exposures, and social circumstances. We then compared the corrected reference to those published by Alexander et al, based on 1991 US natality data, and Oken et al, based on 1999–2000 US natality data, because both provided population-level, sex-specific estimates for most birth weight for gestational age reference measures. Specifically, the 10th and 90th percentiles derived from these references, as well as from the comparison dataset, were applied to the corrected dataset to evaluate the degree to which each captured the expected lowest and highest 10% of births. Finally, we compared the corrected dataset reference with a commonly used Canadian one that reports gestational age– and sex-specific means and SDs, which are not available in US references generated from vital records data.

The Canadian reference is based on a national dataset (excluding Ontario) of singleton births between 1994 and 1996, with gestational age based primarily on early ultrasounds. We did not compare our corrected reference to (1) those combining individual birth weight references under investigation here into a single reference, or (2) standards, which are generated following the exclusion of maternal/fetal health characteristics associated with alterations in birth weight (eg, congenital anomalies). Standards differ conceptually from references, and exclusion criteria used to generate them cannot be rigorously applied given the limitations of vital records data.

RESULTS

The LMP-based estimate of gestational age comprised 85% of the records in the corrected dataset, and the obstetric/clinical estimates comprised the remaining 15% (Fig 1). The percentage of LMP-based estimates that were reassigned downward (5.4% overall) or upward (3.6% overall) or discarded (0.08% overall) at each gestational week is provided in the online supplement (Supplemental Table 4). The observed patterns closely resemble those reported by Basso and Wilcox (e-Appendix), with LMPs reassigned upward in 11% to 42% and 1% to 6% of the time in the preterm and term ranges, respectively; LMPs were reassigned downward 46% to 98% of the time in the postterm range (Supplemental Table 4).

Within the corrected dataset, ~90% of births occurred at term (37–41 weeks), whereas 8% and 2% of births occurred within the preterm (<37 weeks) and postterm (≥42 weeks), respectively. Males comprised 51% of the births, and 49% of infants were first-borns. With respect to maternal race/ethnicity, non-Hispanic white was the most prevalent (54%), followed by Hispanic (24%), non-Hispanic black (15%), and Asian/other (7%). None of these characteristics varied significantly from those in the comparison dataset (Supplemental Table 5). However, there were slightly higher rates of preterm (10%) and postterm (5%) births in the comparison dataset.

Gestational age–specific skewness and kurtosis values using the corrected dataset are presented in Supplemental Table 6. With the exception of a kurtosis value of 1.4 at 44 weeks, all values were near 0, indicating a good approximation of the birth weight distributions to normal. Because normal distributions are appropriately characterized by means and SDs, we calculated these parameters according to gestational
week and sex (Tables 1 and 2, respectively). The mean gestational age at delivery was 38.6 weeks with a SD of 2 weeks. Birth weight increased as gestational week increased, with the largest SDS observed after 33 weeks for both males and females.

**Comparisons With Previous References**

Male and female births in the corrected dataset were categorized into the 10th and 90th percentiles of birth weight for gestational age (ie, SGA, LGA) using cut points derived from the corrected dataset, the comparison dataset, and references published by Oken et al,4 Alexander et al,1 and Kramer et al.17

Table 3 provides the sex-specific proportions of these births within the preterm, term, and postterm gestational age ranges.

As expected, thresholds derived from the corrected dataset capture ∼10% of births below the 10th and above the 90th percentile across all gestational age categories (range: 9.1% to 10.9%). However, thresholds derived from the comparison dataset, along with those from previously published US-based references, captured varying proportions of SGA and LGA births within the corrected dataset, particularly within the preterm and postterm ranges. Among preterm births, the 10th percentiles derived from previous US references, as well as from our comparison dataset, captured 11% to 15% of SGA births in the corrected dataset; however, the 90th percentiles captured a markedly smaller proportion of LGA births (∼3%). Among postterm births, these cut points captured a smaller proportion of SGA births in the corrected dataset (3% to 6%), and a slightly greater proportion of LGA births (11% to 16%). The Canadian-based cut points identified a larger proportion of SGA births (18%) and a smaller proportion of LGA births (5%) in the postterm range, but ∼10% of births in the preterm and term ranges. The cut points used to identify the 10th and 90th percentiles for male singletons are displayed graphically in Fig 2 for our corrected reference, and for Oken et al,4 Alexander et al,1 and Kramer et al.17

For the 10th percentile, all references diverge from the previous US-based reference most prominently at preterm gestations (especially 28–31 weeks), the range at which epidemiologic studies note a bimodal birth weight distribution that our gestational age cleaning process eliminated (Fig 3).

We compared gestational age–specific birth weight means and SDS from the corrected dataset with the Kramer et al17 reference for males (Fig 4) and females (data not shown). Means and SDS were similar between the 2 references, except for the term and postterm ranges, where mean birth weights from the corrected dataset were lower than the Kramer et al17 estimates.

**DISCUSSION**

We provide an updated US birth weight reference for gestational age correction following age correction for implausible estimates of gestational age, along with the information needed to calculate continuous and/or categorical measures of birth size. We used 2 recent National Center for Health Statistics natality datasets, thus generating a reference that reflects the current sociodemographic composition of the United States.

The most notable difference between the current and previous US references is that LMP-based gestational age was sometimes discarded (∼1%) or reassigned using the obstetric/clinical

**TABLE 2** Means, SDs, and Smoothed Percentiles for Birth Weight (g) for Gestational Age Within the Corrected Dataset: US Female Singleton Live Births (2009–2010)

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The corrected dataset uses both LMP- and clinical/obstetric-based estimates of gestational age and reflects the application of the Basso and Wilcox12 algorithm to correct likely errors in gestational age and to exclude implausible birth weights for gestational age.
estimate (~9%) (Fig 1; Supplemental Table 4). These changes resulted in the elimination of the “second mode” in the birth weight distribution at 28 to 31 weeks, allowing for the calculation of means and SDs without further correction. Previous work suggests that the second mode primarily reflects errors in LMP dating.5,7,24 However, the accuracy of obstetric/clinical estimates should not be implicitly assumed. With ultrasound-based data,
FIGURE 3
Birth weight for gestational age histograms generated prior to (A) and following (B) application of the Basso and Wilcox\textsuperscript{12} gestational age cleaning algorithm at 28 to 31 weeks.
factors that interfere with image visualization (eg, maternal obesity) or influence fetal size early in pregnancy (eg, maternal smoking) may lead to misclassification of gestational age.\textsuperscript{25–27}

Given the potential for such systematic sources of error,\textsuperscript{28} we used an algorithm that leverages all available estimates of gestational age to identify records with likely errors in dating.

When cut points derived from previous US references were applied to our corrected dataset, discrepancies were most apparent in the pre- and postterm ranges. Among preterm births, previous references capture a greater proportion of births below the 10th percentile and a markedly lower proportion of births above the 90th percentile compared with the current reference. This is likely because we were able to eliminate the second mode of the birth weight distribution in the preterm gestational age range, which resulted in a reduction in the birth weight thresholds. In fact, among early preterm births, only a small minority of the infants falling above the 90th percentile according to our reference would be identified using previous references. Among postterm births, previous references capture substantially fewer births below the 10th percentile, but similar rates of births above the 90th percentile. In the corrected dataset, LMP-based gestational age in the postterm range was reassigned downward using the obstetric/clinical estimate 46\% to 98\% of the time (Supplemental Table 4), likely resulting in the inclusion of births that would have otherwise been excluded.

We also compared our reference with Kramer et al.\textsuperscript{17} as it was based primarily on ultrasound estimates of gestational age. With the exception of the postterm range, our reference captured similar rates of births below the 10th and above the 90th percentile across a range of gestational ages. Kramer et al\textsuperscript{17} is also the only North American population-based reference to report gestational age–specific means and SDs. These parameters exhibit considerable similarity to ours, except beyond 40 weeks of gestation. Post hoc analyses revealed that when our reference was generated including only obstetric/clinical estimates of gestational age and maternal white, non-Hispanic race/ethnicity, these discrepancies were virtually eliminated (data not shown).

The gestational age– and sex–specific parameters provided in the current reference allow for the incorporation of both categorical and continuous measures of birth size in data analysis. Given the growing appreciation for the
impacted by perinatal risks across the birth weight for gestational age distribution, along with the development of statistical methods allowing for localization of effects within a given distribution (eg, quantile regression), the time is ripe for this information to be available based on data from the US population. However, there are some interpretational caveats to consider. First, our reference, along with previous population-based references, is based on cross-sectional data and does not reflect the longitudinal growth trajectory of individual infants. It is possible that longitudinal assessments of fetal size, although more expensive and challenging to obtain, would yield estimates that diverge from those presented here. Second, this reference does not address the fact that preterm infants are smaller than their counterparts who are in utero at the same gestational week. Thus, for preterm infants, the birth weight for gestational age percentile derived from a reference generated by using peers born at the same gestational week is likely higher than one derived from a reference that includes in utero counterparts. Third, our reference does not address controversies surrounding population-based versus "customized" birth weight references, which take into account maternal height and demographic characteristics in the evaluation of birth size. We also do not address the conceptual differences between references and standards, the latter of which are generated following the exclusion of maternal/fetal conditions associated with alterations in birth weight. Discussion of conceptual differences is beyond the scope of this article, but there is mixed or scant evidence regarding the clinical advantages afforded by customization or standards, respectively. Our reference may inform these important debates by enabling comparisons that are likely unselected for the maternal/fetal characteristics of interest. Fourth, although we collapsed 2 years of vital records data to generate the current reference, cell sizes are smaller at the extremes of the gestational age range. As a result, these estimates may be less reliable, particularly when stratified by other factors (eg, sex). Thus, although we have corrected for likely errors in gestational age, our reference must still be interpreted considering the issues described above. Despite these caveats, our reference is up to date, reflects the current socio-demographic composition of the United States, and applies recently developed algorithms to correct likely errors in gestational age. The need for such a reference has been specifically expressed in the literature, as concerns regarding the validity of any analysis based solely on LMPs have become increasingly appreciated. Comparisons with other references, along with extensive data presented here and in the online supplement, will allow researchers and clinicians to weigh the appropriateness of our reference against their specific needs.

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