



Article ID: HCO 23046065

Processed by Minitex on: 2/13/2020 12:18:15 PM

This material comes to you from the University of Minnesota collection or another participating library of the Minitex Library Information Network.

Patrons, please contact your library for questions about this document.

Libraries, for more information, visit: <http://minitex.umn.edu>

If you have any questions about this service, please email medd@minitex.umn.edu or call 612-625-8318

Title: Current Opinion in Obstetrics and Gynecology

ArticleTitle: Preventing term stillbirth benefits and limitations of using fetal growth reference charts

ArticleAuthor: Halimeh, Rawada

Vol: 31 No: 6 Date: Dec 2019 Pages: 365-374

Copyright: CCG

NOTICE CONCERNING COPYRIGHT RESTRICTIONS:

The copyright law of the United States [[Title 17, United StatesCode](#)] governs the making of photocopies or other reproductions of copyrighted materials.

Under certain conditions specified in the law, libraries and archives are authorized to furnish a photocopy or other reproduction. One of these specific conditions is that the photocopy is not to be "used for any purpose other than private study, scholarship, or research." If a user makes a request for, or later uses, a photocopy or reproduction for purposes in excess of "fair use," that user may be liable for copyright infringement.

This institution reserves the right to refuse to accept a copying order if, in its judgment, fulfillment of that order would involve violation of copyright law.



Preventing term stillbirth: benefits and limitations of using fetal growth reference charts

Rawad Halimeh^{a,b,c}, Karen Melchiorre^{a,b,c}, and Basky Thilaganathan^{a,b,c}

Purpose of review

This review examines the variation in clinical practice with regards to ultrasound estimation of fetal weight, as well as calculation of fetal weight centiles.

Recent findings

Placental dysfunction is associated with fetal smallness from intrauterine malnutrition as well as fetal disability and even stillbirth from hypoxemia. Although estimating fetal weight can be done accurately, the issue of which fetal weight centile chart should be used continues to be a contentious topic. The arguments against local fetal growth charts based on national borders and customization for variables known to be associated with disease are substantial. As for other human diseases such as hypertension and diabetes, there is a rationale for the use of an international fetal growth reference standard. Irrespective of the choice of fetal growth reference standard, a significant limitation of small for gestational age (SGA) detection programs to prevent stillbirth is that the majority of stillborn infants at term were not SGA at the time of demise.

Summary

Placental dysfunction can present with SGA from malnutrition and/or stillbirth from hypoxemia depending on the gestational age of onset. Emerging data show that at term, fetal Doppler arterial redistribution is associated more strongly with perinatal death than fetal size. Properly conducted trials of the role for maternal characteristics, fetal size, placental biomarkers, and Doppler assessing fetal well-being are required urgently.

Keywords

estimated weight, growth charts, growth references, growth restriction, growth standards, weight centile, small for gestational age, stillbirth

INTRODUCTION

Stillbirth is a tragic event that has major psychological, social, and economic effects on mothers, families, and society in general [1]. The United Kingdom still has one of the highest rates of stillbirth in industrialized countries at 3.87 stillbirths per 1000 births – with two-thirds of stillbirths occurring near term at gestations beyond 34 weeks [2]. There is a long-established association between fetal size and stillbirth, with the risk of stillbirth increasing for smaller relative fetal size or poor growth [3]. This observation has lent support to the argument that majority of stillbirth occurs as a consequence of placental dysfunction and, therefore, they are potentially avoidable if delivery is effected before fetal demise. Therefore, most strategies for stillbirth prevention rely on ultrasound or serial fundal height measurement to screen for disturbances in fetal growth [4].

Fetal growth restriction (FGR) is defined as the failure of the fetus to reach its growth potential and

is considered the commonest major complications of pregnancy [5]. It is a major risk factor for fetal stillbirth as well as other fetal comorbidities such as hypoxic ischemic encephalopathy and cerebral palsy [6–9]. However, as fetal growth potential is difficult to define, small for gestational age (SGA), defined as estimated fetal weight (EFW) below the 10th percentile, is commonly used as a proxy for FGR secondary to placental dysfunction. There is

^aDepartment of Obstetrics and Gynaecology, St. George Hospital University Medical Center, Beirut, Lebanon, ^bDepartment of Obstetrics and Gynaecology, FMU, Spirito Santo Tertiary Level Hospital of Pescara, Pescara, Italy and ^cDepartment of Obstetrics and Gynaecology, Fetal Medicine Unit, St George's University Hospitals NHS Foundation Trust, London, United Kingdom

Correspondence to Basky Thilaganathan, MD, PhD, FRCOG, Department of Obstetrics and Gynaecology, Fetal Medicine Unit, St. George's University Hospitals NHS Foundation Trust, Blackshaw Road, London SW17 0QT, United Kingdom. E-mail: basky@pobox.com

Curr Opin Obstet Gynecol 2019, 31:365–374

DOI:10.1097/GCO.0000000000000576

KEY POINTS

- Accurately estimating fetal weight can be achieved by using validated multiparameter fetal biometry formulae.
- Establishing fetal weight centile can be undertaken using population/customized fetal growth references or international fetal growth standards.
- Population charts are limited by the lack of a believable biological explanation for how nationality or national borders influence fetal growth.
- Although certain maternal characteristics are associated with altered fetal growth, the very same variables also predispose to increased fetal mortality questioning the rationale for customization.
- Stillbirth prevention policy-based identifying SGA fetuses are significantly limited by the finding that at term, the majority of antenatal stillbirths are appropriately grown at the time of intrauterine demise.
- Fetal Doppler arterial redistribution is more strongly associated with perinatal death at term than fetal size.

some retrospective evidence to suggest that antenatal detection of SGA fetuses could potentially halve the risk of stillbirths through appropriate antenatal surveillance and timely delivery [10,11].

A policy of SGA detection first requires ultrasound estimation of fetal weight followed by calculation of the fetal weight centile by the use of a fetal weight reference chart or standard [12–14]. Currently, countless fetal weight calculators and fetal weight references exist which add to the clinical complexity and variability in outcomes. To add to the confusion, some academics have suggested customization of fetal weight charts for certain maternal characteristics and others have challenged the effectiveness and unexpected negative outcomes related to a policy of screening for SGA fetuses [15–19]. This review outlines the background, benefits, and limitations of health policies and programs targeted at SGA detection to prevent stillbirth.

FORMULAE TO ESTIMATE FETAL WEIGHT

Ultrasound estimation of fetal weight is an essential prerequisite to calculating fetal weight centile for the identification of pregnancies at risk of SGA or large-for-gestational-age (LGA) birth. EFW may be derived from various fetal measurements or combinations of measurements of fetal head circumference, biparietal diameter, femur length, and abdominal circumference – with more than 50 publications providing formulae for clinical use. However, the majority of these formulae were derived from relatively small

studies and most remain clinically unvalidated. Furthermore, there is no clinical consensus regarding the most appropriate formula to be used to calculate fetal weight.

A recent prospective study utilized data from a cohort of 5163 pregnancies between 22 and 43 weeks' gestation, where a live birth occurred within two days of the ultrasound examination to evaluate the accuracy of existing formulae for estimating fetal weight [20^{***}]. The authors evaluated 70 different formulae – some using single fetal measurements and others utilizing a composite of between two and four fetal biometric measures. The mean percentage error and absolute mean error was used to compare the accuracy of the various EFW formulae to predict actual birth weight (Fig. 1) [21]. They demonstrated that the formula reported in 1985 by Hadlock *et al.* [21], from measurements of head circumference, abdominal circumference, and femur length, provides the most accurate prediction of birth weight and can be used for assessment of all babies, including those suspected to be either SGA or LGA.

A similar evaluation was carried out in twin pregnancy where the risk of SGA, FGR, and adverse perinatal outcomes are higher [22]. This was a retrospective cohort study including 4280 singleton and 586 twin fetuses where routine ultrasound biometry was undertaken within 2 days of live birth. Ultrasound estimation of fetal weight is less accurate in twin than in singleton pregnancies. Furthermore, formulae that include a combination of head, abdomen and femur measurements perform best in both singleton and twin pregnancies. As for

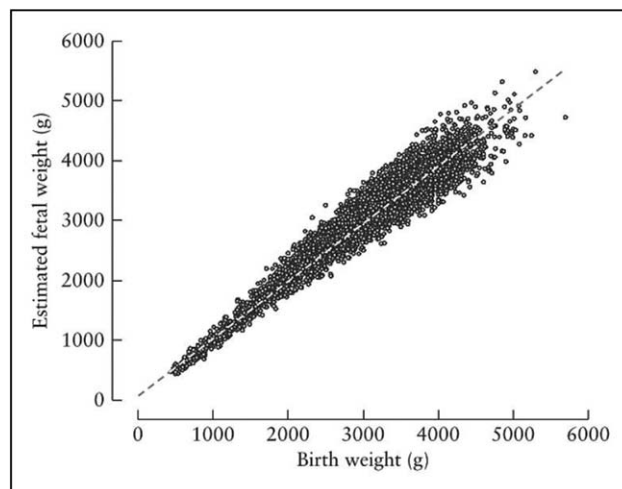


FIGURE 1. Association between birth weight and estimated fetal weight derived from model of Hadlock *et al.* [21] using measurements of head circumference, abdominal circumference, and femur length in the study population ($r=0.959$, $P<0.0001$). Reproduced with permission from Hammami *et al.* [20^{***}].

singleton pregnancy, the best prediction of inter-twin birth-weight discordance was achieved using the Hadlock head circumference, abdominal circumference, and femur length formula [21].

CHARTS TO ESTIMATE FETAL WEIGHT CENTILE

Only once fetal weight has been accurately calculated; we can use fetal weight or 'growth' charts to estimate the weight centile for a given gestation. There are several published charts that purport to correctly evaluate EFW centile varying by geographical location, clinical scenario (such as ethnicity, maternal stature, parity) or purporting to be an international reference standard.

Local and national charts

These are charts defined by the geography of a particular area (local) or country (national). The charts are typically constructed retrospectively from existing ultrasound biometry and birth-weight data from the source population. The developers of such charts rationalize their use on the basis that there is recognized regional variation in child and adult stature, presumably because of ethnicity, social, economic, and nutritional factors. These charts describe how babies in a particular geographical

cohort 'have grown' but do not tell us what is clinically relevant – which is how a normal baby 'should grow' [23[¶]]. The main limitation with retrospectively constructed charts is that the pregnancy cohort contains hidden maternal and fetal morbidity which may have impaired fetal growth. Some charts have used retrospective 'cleaning' of the cohort data to overcome this limitation, but such an approach is typically incomplete and does not eliminate occult health problems.

Another limitation of geographical charts is that usually preterm births are used to establish normograms despite the finding that median birthweight for babies born preterm is substantially lower than median EFW [24,25]. This difference is likely to be the consequence of pathological fetal growth in the majority of preterm births. Therefore, reference ranges for BW contain an overrepresentation of pathological pregnancies particularly for gestational ages less than 37 weeks. Nicolaides *et al.* [26[¶]] established a BW chart using fetuses still in utero, thereby overcoming the problem of underestimation of growth restriction in preterm birth. Using the latter chart, the authors demonstrated that for preterm birth, BW was below the 10th centile in a very high proportion of cases (Fig. 2) [26[¶]], both for iatrogenic causes (52.5%) and spontaneous preterm births (19.8%). The latter charts would seem the appropriate choice for screening for preterm placental dysfunction and FGR.

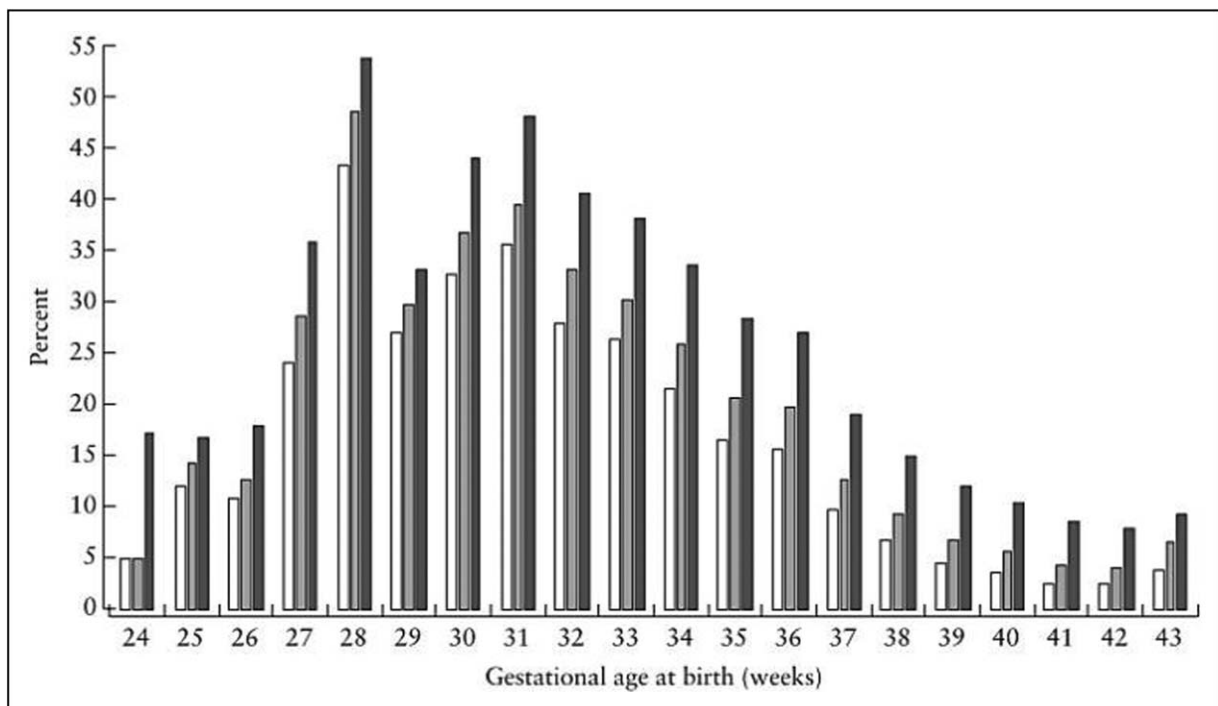


FIGURE 2. Percentage of cases in a cohort of 95 579 pregnancies with birth weight below 3rd (clear bars), 5th (grey bars) and 10th (dark bars) percentiles of reference range of birth weight according to gestational age. Reproduced with permission from Nicolaides *et al.* [26[¶]].

Despite the apparent limitations, local and national charts are in wide usage across the world, even though it is not clear how multicultural populations are represented in such charts. An unresolved major issue that undermines the justification for the use of such charts is a believable biological explanation for how nationality/national borders influence fetal growth.

Customized charts

A potential approach to deal with the limitations of population-based local or national growth charts is customization, where expected fetal growth is modulated according to individual variables that are known to affect fetal growth [27]. Proponents of customized growth charts established the growth potential of each fetus according to physiological variations in maternal characteristics such as height, weight, ethnic origin, parity, and fetal sex, but not for disease such as premature birth, smoking, hypertensive disorders, or diabetes [28–32]. It has been suggested customizing expected fetal growth for these variables will result in improved diagnosis of SGA pregnancies at risk of adverse outcome [33]. For instance, it has been suggested that the use of customized charts will reduce the number of pregnancies classified as SGA to approximately 10% when used in Asian or low BMI populations. The latter groups typically have much higher rates of SGA when classified using population-based fetal growth charts, which supposedly identify ‘normally small’ rather than FGR babies as risk of adverse outcome.

Although it is certainly true that certain maternal characteristics are associated with altered fetal growth, the very same variables also predispose to increased fetal morbidity and mortality. For example, customization ‘normalizes’ smaller fetuses in Asian and Afro-Caribbean women, when women from these ethnicities are also at increased risk of stillbirth [34]. Similarly, other variable used in customized fetal growth charts such as maternal age, weight, and parity have also been shown to be related to risk of stillbirth [35,36]. Apart from the concern that customization of fetal growth is ‘normalizing’ for variables that predispose to pregnancy disease, there is also the question of biological rationale for customization. The well-accepted associations between these variables and fetal weight cannot be causative, as it is inconceivable that the 1–2% of genes that determine maternal skin color are also coincidentally responsible for controlling fetal growth. Similarly, the placenta cannot ‘know’ the age of the mother, her weight or parity, making the latter variables proxy markers for uteroplacental dysfunction rather than directly controlling fetal growth [37].

Regardless of the justification for the use of customization, it is important to recognize that customization was proposed as a means of better identifying at-risk pregnancies. However, systematic evaluation of the use of customization has failed to show increased performance in the detection of adverse pregnancy outcome in several large or prospectively conducted studies [38,39[■],40].

International reference standard

The popularity of local, national or customized fetal growth reference charts is based on the reasoning that approximately 10% of fetuses in any given population should be SGA. This assumption is fundamentally at odds with the known variation in rates of neonatal malnutrition at birth worldwide (Fig. 3) ranging from as high as 27% in South Asia to a low of 7% in Europe [41]. This variation in malnutrition at birth is attributed to differences in nutrition, maternal comorbidity, and other socio-economic factors – and is used as justification by proponents of an international fetal growth reference standard [23[■],42].

Fetal growth reference standards are prescriptive charts that are constructed prospectively in populations that have been screened before recruitment to ensure minimal bias from detrimental environmental and medical confounders that may affect fetal growth. So as opposed to retrospective local or national charts that describe how fetuses in a certain population have grown, fetal growth reference standards describe how fetuses should grow if they were free of any environmental or clinical constraints. Two consortiums used this approach to define optimal fetal growth reference standards [23[■],43]. The Intergrowth-21st consortium adapted the same stringent standards to control for environmental and medical confounders as was used for the well-established WHO Child Growth Standards [44]. Intergrowth-21st showed that human growth in low-risk environments is very similar in fetuses regardless of where they live or their ethnic/racial background [23[■]]. These findings would suggest that perinatal health and fetal growth are mainly affected by the environmental, nutritional, and socioeconomic factors across populations [23[■]]. In contrast, the National Institute of Child Health and Human Development (NICHD) consortium ‘standardized’ pregnancies by hospital, which introduced bias as it does not necessarily remove environmental constraints [23[■]]. The NICHD study showed that fetal growth was minimally – but significantly different in four self-reported ethnic groups [43]. Interestingly, the NICHD study also demonstrated that marital status, level of education,

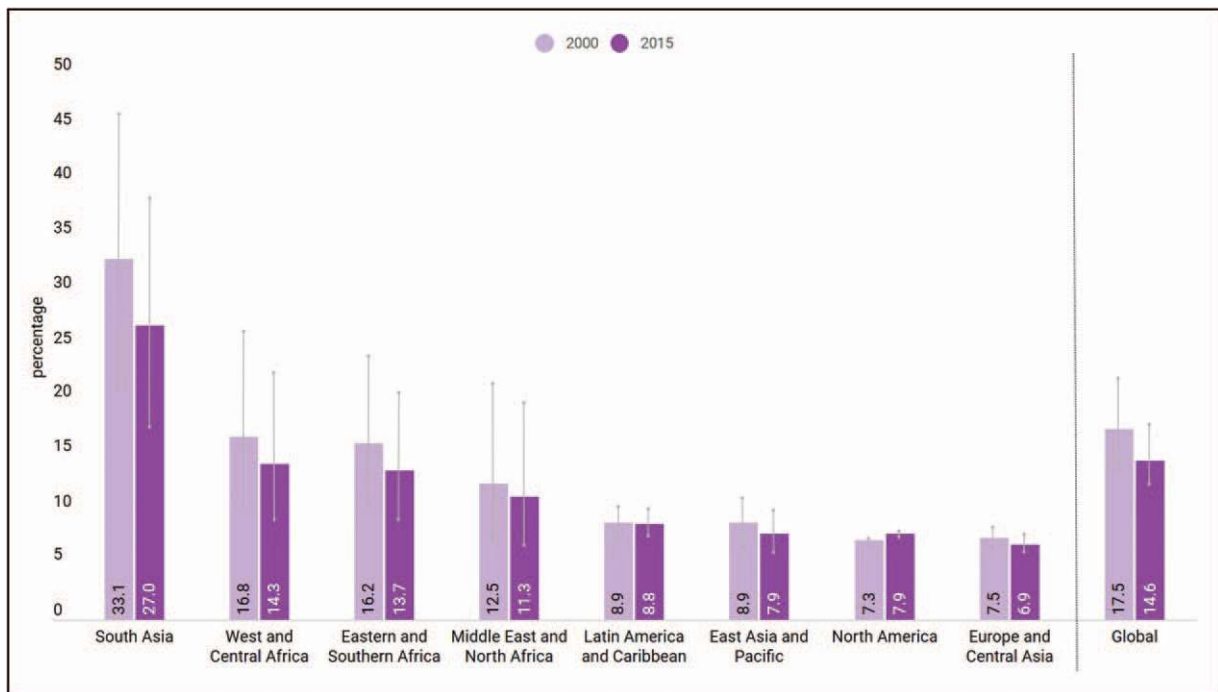


FIGURE 3. Low birth-weight prevalence by UNICEF regions. Taken from UNICEF-WHO low birth weight estimates 2019 [41].

annual income, and private insurance influenced fetal growth.

Retrospective evaluations of the Intergrowth-21 fetal growth reference standard in two large population studies concluded that there was a reduced identification of SGA fetuses and cases of perinatal death [45,46]. It should be noted that the poorer performance of the Intergrowth-21 reference standards was for a much lower number of pregnancies classified as SGA. Neither of the studies provided a comparison of screening efficiency for adverse outcome at comparable screen positive rates – which would have provided a better head-to-head comparison of different growth references and standards.

SHOULD WE ASSESS FETAL GROWTH INSTEAD OF FETAL SIZE?

Fetal growth – the relative change in fetal size over a time period – is often used as an alternative indicator of fetal well-being in screening programs using serial ultrasound assessment. Many clinicians believe that assessment of fetal growth over two or more scans is superior to assessment of fetal size alone, especially with the current uncertainty over which charts to use and whether to customize fetal size assessment by correcting for certain maternal characteristics. Although fetal growth can be objectively assessed by measuring change in fetal weight centile over the interval between scans, how these data should be interpreted is yet to be resolved.

There are no evidence-based guidelines that outline the risk of adverse outcome based on change in fetal weight centile, over the interval of fetal growth assessment, and whether the same change in growth implies similar risks at different gestations. For example, is a 20% drop in fetal weight centile over a two-week interval clinically significant and is this significance similar at 28, 32, and 36 weeks' gestation? Thresholds for intervention on the basis of pathological deviation in fetal growth are likely to depend on gestational age at onset of placental insufficiency, as well as the rate over which that growth deviation occurs and the ability of the fetus to endure such compromise. It would be churlish to assume that a given fetal growth threshold could serve to identify and prevent stillbirth at any given gestation.

In a large randomized controlled trial of early-onset fetal growth restriction less than 32 weeks, the TRUFFLE investigators demonstrated that fetal growth velocity did not help predict or prevent adverse outcome [47]. Similarly, in late pregnancy, the POP study in which women were allocated to either routine pregnancy care or serial (clinically blinded) ultrasound scans, fetal growth velocity was significantly associated with adverse outcome, but only in the SGA fetuses and not in appropriate for gestational age births [48]. Several retrospective but larger studies have also shown that growth velocity does not improve prediction of adverse pregnancy outcome because of placental dysfunction [49–51].

The authors also demonstrated that the lack of clinical benefit from assessing fetal growth held true for whether the interscan interval was large (from 20 to 36 weeks) or small (from 32 to 36 weeks).

DOES ASSESSMENT OF FETAL SIZE REDUCE STILLBIRTH AT TERM?

The prevalent clinical focus on routinely monitoring fetal size is predicated on the association with stillbirth and the desire to deliver the pregnancy before this adverse outcome occurs. However, unlike preterm stillbirth where the majority of stillborn are SGA, intrauterine demise at term occurs in appropriately grown fetuses in 60–70% of cases (Fig. 4) [52]. More recently, it has become evident that after a stillbirth, fetuses lose approximately 20% of their body weight through intrauterine maceration before birth and dehydration ex-utero before having their weight formally recorded [53]. Therefore, the 30–40% of term stillbirths that are classified as SGAs were probably incorrectly classified with a significant proportion being AGA at the time of intrauterine demise. Although it is not in doubt that there is an association between SGA and stillbirth, it is clear that a health policy focused entirely on identification of SGA fetuses not prevent the majority of stillbirths at term. The latter is supported

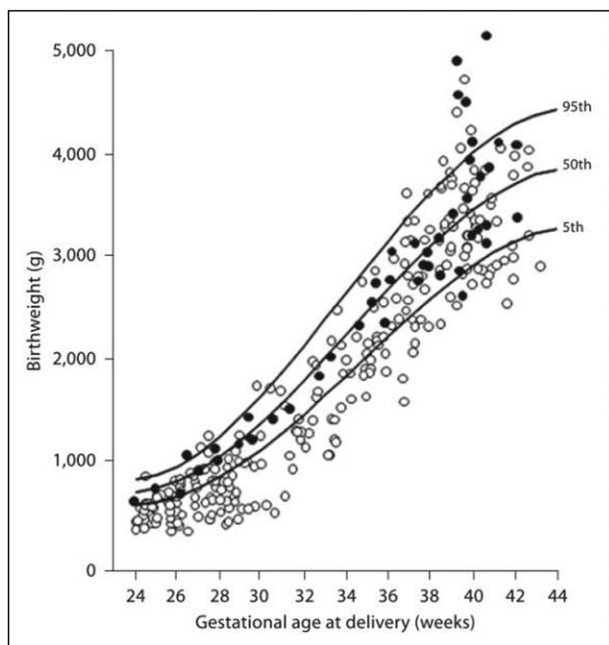


FIGURE 4. Birthweight against gestation at birth in pregnancies complicated by antepartum stillbirth (open circles) and intrapartum stillbirth (solid dots), plotted on the 5th, 50th and 95th percentiles of the normal range. Reproduced with permission from Poon *et al.* [52].

by population studies such as by Monier *et al.* [54] in a population-based study of routine third-trimester ultrasound in 14 000 pregnancies detected only 21.7% of SGA infants and resulted in a high false-positive rate for SGA diagnosis, six-fold increase in provider-initiated preterm deliveries and unchanged perinatal mortality. In a follow-up study of over 90 000 pregnancies, the same group reported a disappointing protective effect of SGA/FGR detection than previously reported as over 40% of stillbirths occurred despite detection of SGA [55]. In a prospective study of over 45 000 pregnancies, Akolekar *et al.* [56] demonstrated that although in SGA babies had an increased risk of adverse perinatal outcome, 84% of adverse perinatal events occur in the AGA group – resulting in poor predictive performance of SGA detection for adverse perinatal outcome. Both research groups called into question a focus solely on improving SGA detection without addressing postdetection management taking into account maternal characteristics, gestational age, and Doppler assessment.

EARLY AND LATER FETAL GROWTH RESTRICTION – TWO DIFFERENT DISORDERS?

As well as reaching expert opinion on a definition of placental FGR a Delphi consensus has also been reached for both early and late-onset disease [57]. The underlying commonality between early and late gestation FGR is that they occur as a consequence of placental dysfunction. Both conditions are also associated with increased incidence of poor neurodevelopmental, cardiovascular, and metabolic long-term outcomes for the affected fetus. Early FGR is less common and represents approximately 20–30% of all cases of growth restriction. It is associated with severe placental insufficiency and preeclampsia in up to 50% of cases. Late gestation FGR is more common and constitutes approximately 70–80% of all cases of growth restriction. It is associated with mild placental insufficiency and preeclampsia in approximately 10% of cases [58]. There is ongoing debate as to whether the placental dysfunction in late gestation FGR is a consequence of milder disease compared with early-onset FGR or as a result of placental dysfunction occurring later in pregnancy.

Our understanding of placental dysfunction is based on the fundamental assumption that the association between fetal size and adverse perinatal outcome is a causative one – that is to say that fetal smallness causes stillbirth. The placenta is responsible for multiple functions such as nutrition, respiration, and excretion amongst many other life processes. As such, placental dysfunction will confer

both nutritional as well as respiratory consequences to the developing fetus [59[■]]. It should be noted that failure to meet nutritional demands result in growth deficiency and can usually be tolerated for several few days/weeks, whereas failed respiratory function results in hypoxia which can only be tolerated for minutes/hours. Fetal nutritional needs follow a logarithmic curve (Fig. 5) whilst respiratory demands show exponential growth [59[■],60]. In early-onset placental dysfunction, fetal nutrition is compromised more severely than respiration, thereby predominantly resulting in growth restriction as the main presenting feature. At this early stage of pregnancy, fetal respiratory demands are low and usually continue to be met by a dysfunctional placenta for several weeks. The latter explains why in early-onset placental dysfunction, SGA develops over several weeks of nutritional insufficiency. In contrast, late onset of placental dysfunction at term will disproportionately affect fetal respiratory demands which are increasing exponentially at this stage of pregnancy, just as nutritional demands begin to plateau. Thus, a 3000-g fetus near term that is affected by placental failure is likely to die from hypoxia related to respiratory dysfunction within a few days, long before it can become small from failing to grow over several weeks.

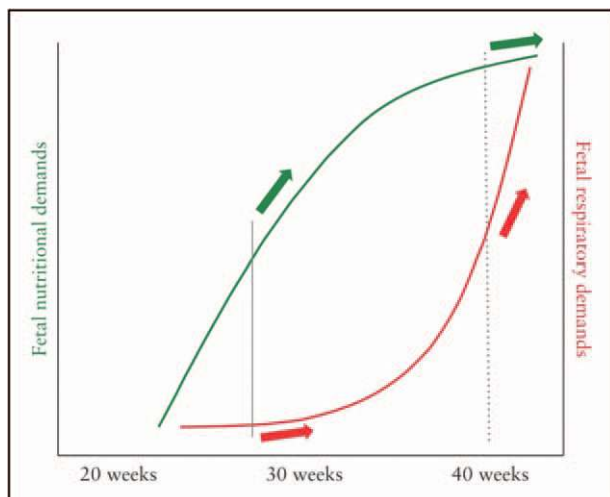


FIGURE 5. Increase in fetal nutrition (solid line) and respiratory (dashed line) demands with advancing gestation. Early onset placental dysfunction will impact at a time when fetal nutritional demands (solid arrows) rise exponentially and therefore will have a disproportionate effect on fetal growth compared with development of fetal hypoxemia and demise. Placental dysfunction at term will impact at a time when fetal respiratory needs (clear arrows) rise exponentially and therefore likely to compromise fetal well-being before fetal growth is impaired. Reproduced with permission from Thilaganathan [59[■]].

Put simply, placental dysfunction a disorder which may manifest signs of either SGA from malnutrition or stillbirth from respiratory failure. The nutritional and respiratory demands of a fetus vary significantly with advancing gestation, and the consequences of either nutritional or respiratory compromise have different presentations (SGA versus stillbirth) and temporal patterns (protracted versus rapid). Early-onset placental dysfunction presents predominantly with SGA, whereas in late-onset disease, critical fetal hypoxia may occur in a term fetus before SGA has time to develop.

MANAGEMENT OF LATE-ONSET PLACENTAL DYSFUNCTION

It is not unsurprising, given the issues surrounding fetal growth assessment, that there is real controversy and considerable variation in practice for the clinical management of late-onset FGR/placental dysfunction. In spite of these concerns, a number of definitive management decisions can be justified.

Establishing fetal size

Requires the use of validated EFW formula that can be used in any clinical setting, such as those published by Hadlock *et al.* [21] and Hammami *et al.* [20[■]] using multiple fetal biometric measures.

Establishing fetal weight centile

In preterm pregnancies, charts established using fetuses still *in utero* to overcome the problem of underestimation of preterm growth restriction, such as developed by Nicolaides *et al.* [26[■]] should be used. Near term, irrespective of which charts are used, the majority of adverse pregnancy outcomes will occur in non-SGA pregnancies, hence the choice of fetal growth reference charts is unlikely to have a major clinical impact. This makes the case for use of an international fetal growth reference standard so that meaningful comparisons of SGA rates between countries and before/after birth can be made.

Assessing fetal well-being

In preterm pregnancies should include the use of computerized cardiotocography and ductus venosus Doppler up to 32 weeks gestation along with indicated delivery for reversed end-diastolic umbilical artery blood flow from 32 weeks and for absent end-diastolic umbilical artery blood flow from 34 weeks [61]. Near term, even though the risk of stillbirth is increased in SGA pregnancies, the

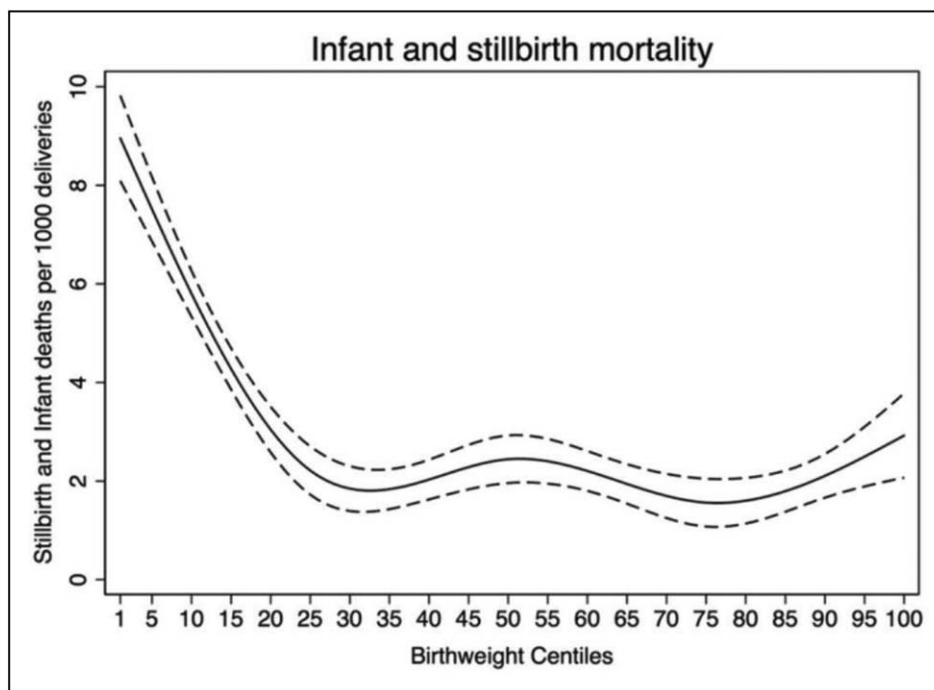


FIGURE 6. Infant mortality and stillbirth according to birth-weight centiles. Reproduced with permission from Iliodromiti *et al.* [39^{***}].

majority of stillbirths occur in normally sized babies. Cerebroplacental ratio (CPR) – the ratio of the middle cerebral artery pulsatility index to the umbilical artery pulsatility index – is emerging as a potentially useful marker of fetal hypoxemia at term [62,63]. Low CPR is known to be a marker for fetal hypoxemia at term in AGA fetuses [49] and is associated with low abdominal circumference growth velocity and adverse pregnancy outcomes including stillbirth, neonatal unit admission and neonatal morbidity [49]. As the risk of perinatal mortality seems to increase only when EFW is below the 30th centile of birth weight for gestation (Fig. 6) [39^{***}], the latter population would seem to be a reasonable target for fetal Doppler/CPR evaluation. Unfortunately, it is still not evident whether the use of fetal Doppler evaluation in this subpopulation can prevent stillbirth and improve perinatal outcome. It is likely that combined evaluation of maternal characteristics, fetal size, placental biomarkers, and Doppler indices in a diagnostic algorithm may be of value in identifying pregnancies that justify earlier scheduled birth because of an increased risk of adverse outcome [64,65].

CONCLUSION

Placental dysfunction is associated with fetal smallness because of intrauterine malnutrition as well as fetal disability and even death from respiratory hypoxemia. Fetal size is universally used as a

common clinical proxy for placental dysfunction. The issue of which fetal weight centile assessment should be used continues to be a contentious topic. The arguments against local fetal growth charts based on national borders and customization for maternal variables associated with pregnancy disease are considerable. As for other human diseases such as hypertension and diabetes, the rationale for the use of an international fetal growth reference standard makes a lot of sense. Variation in national rates of SGA is perceived as a limitation of these charts, but not when one considers that these variations are aligned to the rates of neonatal malnutrition seen in these countries. Irrespective of the choice of fetal growth reference standard, a significant limitation of national SGA detection programs to prevent stillbirth is that the majority of stillborn infants at term were not SGA at the time of demise. That placental dysfunction may present either with signs of SGA from malnutrition or stillbirth from hypoxemia is explained when one understands the varying fetal nutritional and respiratory demands with advancing gestation. Emerging data show consistently that fetal Doppler arterial redistribution is associated more strongly than fetal size with perinatal death at term. Properly conducted and powered trials of the role for maternal characteristics, fetal size, placental biomarkers, and Doppler indices for assessing fetal well-being at term are now urgently required.

Acknowledgements

None.

Financial support and sponsorship

This writing of this manuscript was supported by funds from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No. 765274 (www.iPlacenta.eu).

Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

1. Murphy S, Cacciatore J. The psychological, social, and economic impact of stillbirth on families. *Semin Fetal Neonat Med* 2017; 22:129–134.
2. Flenady V, Middleton P, Smith G, *et al.* Stillbirths: the way forward in high-income countries. *Lancet* 2011; 377:1703–1717.
3. Bukowski R, Hansen N, Willinger M, *et al.* Fetal growth and risk of stillbirth: a population-based case-control study. *PLoS Med* 2014; 11:e1001633.
4. Papageorgiou A, Ohuma E, Altman D, *et al.* International standards for fetal growth based on serial ultrasound measurements: the fetal growth longitudinal study of the INTERGROWTH—21st project. *Lancet* 2014; 384:869–879.
5. Carberry A, Gordon A, Bond D, *et al.* Customised versus population-based growth charts as a screening tool for detecting small for gestational age infants in low-risk pregnant women. *Cochrane Datab Syst Rev* 2014.
6. Pilliod R, Cheng Y, Snowden J, *et al.* The risk of intrauterine fetal death in the small-for-gestational-age fetus. *Am J Obstet Gynecol* 2012; 207:318e1–318e6.
7. Pasupathy D. Rates of and factors associated with delivery-related perinatal death among term infants in Scotland. *JAMA* 2009; 302:660.
8. Bukowski R, Burgett A, Gei A, *et al.* Impairment of fetal growth potential and neonatal encephalopathy. *Am J Obstet Gynecol* 2003; 188:1011–1015.
9. McIntyre S, Blair E, Badawi N, *et al.* Antecedents of cerebral palsy and perinatal death in term and late preterm singletons. *Obstet Gynecol* 2013; 122:869–877.
10. Gardosi J, Madurasinghe V, Williams M, *et al.* Maternal and fetal risk factors for stillbirth. *Obstet Gynecol Surv* 2013; 68:329–331.
11. Lindqvist P, Molin J. Does antenatal identification of small-for-gestational age fetuses significantly improve their outcome? *Ultrasound Obstet Gynecol* 2005; 25:258–264.
12. Mayer C, Joseph K. Fetal growth: a review of terms, concepts and issues relevant to obstetrics. *Ultrasound Obstet Gynecol* 2013; 41:136–145.
13. Willness C. The Oxford handbook of organizational climate and culture by Benjamin Schneider & Karen M.Barbera (Eds.) New York, NY: Oxford University Press, 2014. \$240.00. ISBN 9780199860715. *Br J Psychol* 2016; 107:201–202.
14. McIntire D, Bloom S, Casey B, Leveno K. Birth weight in relation to morbidity and mortality among newborn infants. *N Engl J Med* 1999; 340:1234–1238.
15. Alexander G, Kogan M, Himes J. *Matern Child Health J* 1999; 3:225–231.
16. Alexander G, Himes J, Kaufman R, *et al.* A United States national reference for fetal growth. *Obstet Gynecol* 1996; 87:163–168.
17. Hadlock F, Harrist R, Martinez-Poyer J. In utero analysis of fetal growth: a sonographic weight standard. *Radiology* 1991; 181:129–133.
18. Reeves S, Bernstein I. Optimal growth modeling. *Semin Perinatol* 2008; 32:148–153.
19. Gardosi J. Customized fetal growth standards: rationale and clinical application. *Semin Perinatol* 2004; 28:33–40.
20. Hammami A, Mazer Zumaeta A, Syngelaki A, *et al.* Ultrasonographic estimation of fetal weight: development of new model and assessment of performance of previous models. *Ultrasound Obstet Gynecol* 2018; 52:35–43.
21. Hadlock FP, Harrist RB, Sharman RS, *et al.* Estimation of fetal weight with the use of head, body, and femur measurements: a prospective study. *Am J Obstet Gynecol* 1985; 151:333–337.
22. Khalil A, D'Antonio F, Dias T, *et al.* Southwest Thames Obstetric Research Collaborative (STORK). Ultrasound estimation of birth weight in twin pregnancy: comparison of biometry algorithms in the STORK multiple pregnancy cohort. *Ultrasound Obstet Gynecol* 2014; 44:210–220.
23. Papageorgiou A, Kennedy S, Salomon L, *et al.* The INTERGROWTH-21 fetal growth standards: toward the global integration of pregnancy and pediatric care. *Am J Obstet Gynecol* 2018; 218:S630–S640.
24. Maršál K, Persson P, Larsen T, *et al.* Intrauterine growth curves based on ultrasonically estimated foetal weights. *Acta Paediatr* 1996; 85:843–848.
25. Salomon L, Bernard J, Ville Y. Estimation of fetal weight: reference range at 20–36 weeks' gestation and comparison with actual birth-weight reference range. *Ultrasound Obstet Gynecol* 2007; 29:550–555.
26. Nicolaides K, Wright D, Syngelaki A, *et al.* Fetal Medicine Foundation fetal and neonatal population weight charts. *Ultrasound Obstet Gynecol* 2018; 52:44–51.
27. Chioffi G, Pedroza C, Costantine M, *et al.* Customized vs population-based growth charts to identify neonates at risk of adverse outcome: systematic review and Bayesian meta-analysis of observational studies. *Ultrasound Obstet Gynecol* 2017; 50:156–166.
28. Gardosi J, Chang A, Kalyan B, *et al.* Customised antenatal growth charts. *Lancet* 1992; 339:283–287.
29. Gardosi J, Mongelli M, Wilcox M, Chang A. An adjustable fetal weight standard. *Ultrasound Obstet Gynecol* 1995; 6:168–174.
30. Tamura R, Sabbagha R, Depp R, *et al.* Diminished growth in fetuses born preterm after spontaneous labor or rupture of membranes. *Am J Obstet Gynecol* 1984; 148:1105–1110.
31. Ott W. Intrauterine growth retardation and preterm delivery. *Am J Obstet Gynecol* 1993; 168:1710–1717.
32. Gardosi J. Prematurity and fetal growth restriction. *Early Hum Dev* 2005; 81:43–49.
33. Gardosi J. Intrauterine growth restriction: new standards for assessing adverse outcome. *Best Pract Res Clin Obstet Gynaecol* 2009; 23:741–749.
34. Muglu J, Rather H, Arroyo-Manzano D, *et al.* Risks of stillbirth and neonatal death with advancing gestation at term: a systematic review and meta-analysis of cohort studies of 15 million pregnancies. *PLoS Med* 2019; 16:e1002838.
35. Flenady V, Koopmans L, Middleton P, *et al.* Major risk factors for stillbirth in high-income countries: a systematic review and meta-analysis. *Lancet* 2011; 377:1331–1340.
36. Morales-Roselló J, Dias T, Khalil A, *et al.* Birth-weight differences at term are explained by placental dysfunction and not by maternal ethnicity. *Ultrasound Obstet Gynecol* 2018; 52:488–493.
37. de Onis M, Branca F. Childhood stunting: a global perspective. *Matern Child Nutr* 2016; 12:12–26.
38. Sovio U, Smith G. The effect of customization and use of a fetal growth standard on the association between birthweight percentile and adverse perinatal outcome. *Am J Obstet Gynecol* 2018; 218:S738–S744.
39. Iliodromiti S, Mackay D, Smith G, *et al.* Customised and noncustomised birth weight centiles and prediction of stillbirth and infant mortality and morbidity: a cohort study of 979,912 term singleton pregnancies in Scotland. *PLoS Med* 2017; 14:e1002228.
40. Odiibo A, Nwabuobi C, Odiibo L, *et al.* Customized fetal growth standard compared with the INTERGROWTH-21st century standard at predicting small-for-gestational-age neonates. *Acta Obstet Gynecol Scand* 2018; 97:1381–1387.
41. Low birthweight – UNICEF Data [Internet]. UNICEF Data, 2019. Available from: <https://data.unicef.org/topic/nutrition/low-birthweight/> [cited August 17, 2019].
42. Kiserud T, Piaggio G, Carroli G, *et al.* The World Health Organization fetal growth charts: a multinational longitudinal study of ultrasound biometric measurements and estimated fetal weight. *PLoS Med* 2017; 14:e1002220.
43. Louis G, Grewal J, Albert P, *et al.* 52: Racial/Ethnic differences in fetal growth, the NICHD fetal growth studies. *Am J Obstet Gynecol* 2015; 212:S36.
44. WHO Multicentre Growth Reference Study Group. WHO Child Growth Standards based on length/height, weight and age. *Acta Paediatr* 2006; 450:76–85.
45. Anderson N, Sadler L, McKinlay C, McCowan L. INTERGROWTH-21st vs customized birthweight standards for identification of perinatal mortality and morbidity. *Am J Obstet Gynecol* 2016; 214:509e1–509e7.
46. Francis A, Hugh O, Gardosi J. Customized vs INTERGROWTH-21st standards for the assessment of birthweight and stillbirth risk at term. *Am J Obstet Gynecol* 2018; 218:S692–S699.
47. Lees C, Marlow N, van Wassenaer-Leemhuis A, *et al.* 2-year neurodevelopmental and intermediate perinatal outcomes in infants with very preterm fetal growth restriction (TRUFFLE): a randomised trial. *Lancet* 2015; 385:2162–2172.

48. Sovio U, White I, Dacey A, *et al.* Screening for fetal growth restriction with universal third trimester ultrasonography in nulliparous women in the Pregnancy Outcome Prediction (POP) study: a prospective cohort study. *Lancet* 2015; 386:2089–2097.
49. Khalil A, Morales-Rosello J, Khan N, *et al.* Is cerebroplacental ratio a marker of impaired fetal growth velocity and adverse pregnancy outcome? *Am J Obstetr Gynecol* 2017; 216:606e1–606e10.
50. Ciobanu A, Formoso C, Syngelaki A, *et al.* Prediction of small-for-gestational-age neonates at 35-37 weeks' gestation: contribution of maternal factors and growth velocity between 20 and 36 weeks. *Ultrasound Obstetr Gynecol* 2019; 53:488–495.
51. Ciobanu A, Anthoulakis C, Syngelaki A, *et al.* Prediction of small-for-gestational-age neonates at 35-37 weeks' gestation: contribution of maternal factors and growth velocity between 32 and 36 weeks. *Ultrasound Obstetr Gynecol* 2019; 53:630–637.
52. Poon L, Volpe N, Muto B, *et al.* Birthweight with gestation and maternal characteristics in live births and stillbirths. *Fetal Diagn Ther* 2012; 32:156–165.
53. Man J, Hutchinson J, Ashworth M, *et al.* Effects of intrauterine retention and postmortem interval on body weight following intrauterine death: implications for assessment of fetal growth restriction at autopsy. *Ultrasound Obstetr Gynecol* 2016; 48:574–578.
54. Monier I, Blondel B, Ego A, *et al.* Poor effectiveness of antenatal detection of fetal growth restriction and consequences for obstetric management and neonatal outcomes: a French national study. *BJOG* 2014; 122:518–527.
55. Ego A, Monier I, Skaare K, Zeitlin J. Antenatal detection of fetal growth restriction and stillbirth risk: a population-based case–control study. *Ultrasound Obstetr Gynecol* 2019.
56. Akolekar R, Panaitescu A, Ciobanu A, *et al.* Two-stage approach for prediction of small for gestational age neonates and adverse perinatal outcome by routine ultrasound examination at 35-37 weeks' gestation. *Ultrasound Obstetr Gynecol* 2019.
57. Gordijn S, Beune I, Thilaganathan B, *et al.* Consensus definition of fetal growth restriction: a Delphi procedure. *Ultrasound Obstetr Gynecol* 2016; 48:333–339.
58. Figueras F, Gratacós E. Update on the diagnosis and classification of fetal growth restriction and proposal of a stage-based management protocol. *Fetal Diagn Ther* 2014; 36:86–98.
59. Thilaganathan B. Ultrasound fetal weight estimation at term may do more harm than good. *Ultrasound Obstetr Gynecol* 2018; 52:5–8.
 ■■■ Opinion piece highlighting the importance of distinguishing the disorder of placental dysfunction from the signs of the disorder SGA (from malnutrition) and stillbirth (from hypoxia). The author explains how the signs of placental dysfunction vary with the gestational age of disease onset.
60. Dunsworth H, Warren A, Deacon T, *et al.* Metabolic hypothesis for human altriciality. *Proc Natl Acad Sci* 2012; 109:15212–15216.
61. Bilardo C, Hecher K, Visser G, *et al.* Severe fetal growth restriction at 26-32 weeks: key messages from the TRUFFLE study. *Ultrasound Obstetr Gynecol* 2017; 50:285–290.
62. Vollgraff Heidweiller-Schreurs C, De Boer M, Heymans M, *et al.* Prognostic accuracy of cerebroplacental ratio and middle cerebral artery Doppler for adverse perinatal outcome: systematic review and meta-analysis. *Ultrasound Obstetr Gynecol* 2018; 51:313–322.
63. Conde-Agudelo A, Villar J, Kennedy S, Papageorgiou A. Predictive accuracy of cerebroplacental ratio for adverse perinatal and neurodevelopmental outcomes in suspected fetal growth restriction: systematic review and meta-analysis. *Ultrasound Obstetr Gynecol* 2018; 52:430–441.
64. Kalafat E, Morales-Rosello J, Thilaganathan B, *et al.* Risk of operative delivery for intrapartum fetal compromise in small-for-gestational-age fetuses at term: an internally validated prediction model. *Am J Obstetr Gynecol* 2018; 218:134e1–134e8.
65. Kalafat E, Morales-Rosello J, Scarinci E, *et al.* Risk of operative delivery for intrapartum fetal compromise in small-for-gestational-age fetuses at term: external validation of the IRIS algorithm. *J Matern-Fetal Neonat Med* 2019; 1–10.