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MATERNAL-FETAL MEDICINE

Correlation of short-term variation and Doppler parameters with adverse perinatal outcome in small-for-gestational age fetuses at term

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Abstract

Objective To evaluate the association of short-term variation (STV) and Doppler parameters with adverse perinatal outcome in small-for-gestational-age (SGA) fetuses at term.

Methods In this retrospective single-center study 97 patients with singleton SGA fetuses at term (≥ 37 + 0 weeks' gestation) were examined. Inclusion criteria were a birth weight < 10th centile, cephalic presentation and planned vaginal birth. Only cases with available Doppler measurements of umbilical artery (UA) and middle cerebral artery (MCA) with calculated cerebroplacental ratio (CPR) in combination with a computerized CTG (cCTG) and STV 72 h prior to delivery were eligible for analysis. Pulsatility indices (PI) were converted into multiples of median (MoM), adjusted for gestational age.

The association between Doppler indices and STV values with mode of delivery [secondary cesarean delivery (CD), operative vaginal delivery (OVD), as well as secondary CD and OVD due to fetal distress] and neonatal outcome [UA blood pH ≤ 7.15 and the need of admission to the neonatal intensive care unit (NICU)] was analyzed using logistic regression analysis.

Results There was a significant association between UA PI MoM and the rate of CD. CD due to fetal distress, OVD and OVD due to fetal distress did not show a correlation with the evaluated Doppler parameters. Furthermore, we did not find an association between low UA birth pH and Doppler parameters while neonates with the need of admission to NICU had significant higher UA PI MoM and significant lower MCA PI MoM and CPR MoM. Regarding STV, a significant effect of low STV on NICU admission was found while none of the other assessed outcome parameters were significantly associated with STV.

Conclusion STV and Doppler parameters in SGA fetuses at term are significantly associated to the rate of NICU admission.

Keywords Doppler · Cerebroplacental ratio · Fetal distress · Short-term variation · Computerized CTG · Cardiotocography · SGA · small-for-gestational age

Introduction

Small-for-gestational age (SGA) is a collective term for newborns with a birth weight < 10th centile [1]. Most of these fetuses are small but healthy. In contrast, some fetuses may have suffered from placental insufficiency [2] and are pathologically growth-restricted. While early intrauterine growth restriction (IUGR) is diagnosed < 32 weeks' gestation and is accompanied by low fetal weight and Doppler abnormalities or oligohydramnios, definition of late-onset IUGR is an ongoing discussion. Recently, a Delphi consensus defined late IUGR [3] "by two solitary [abdominal circumference (AC) or estimated fetal weight (EFW) < 3rd centile] and four contributory parameters [AC or EFW < 10th centile, AC or

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EFW crossing centiles by > two quartiles on growth charts and cerebroplacental ratio (CPR) < 5th centile or umbilical artery (UA) pulsatility index (PI) > 95th centile] [4]. In contrast to early IUGR, most of late-onset IUGR fetuses may not be noticed by pathological resistances in the UA.

Several studies suggest that “brain-sparing”, recognized by vasodilatation of the middle cerebral artery (MCA) and consequently low CPR, can identify fetuses with alterations in blood flow due to increased placental resistance [5, 6]. Previous studies demonstrated that a low CPR, especially in SGA fetuses, increases the risk of adverse perinatal outcome [6–9]. Therefore, its measurement is gaining higher importance in prenatal management.

Apart from Doppler sonography, computerized CTG (cCTG) is an important option to monitor intrauterine growth-restricted fetuses [10]. By calculation of short-term variation (STV) objective evaluation of fetal condition is possible. Studies demonstrated that low antepartum STV correlates to stillbirth and severe birth acidemia [11–13].

Recently the TRUFFLE (Trial of Randomized Umbilical and Fetal Flow in Europe) study showed that optimal delivery timing of early growth-restricted fetuses is possible by assessing both fetal Doppler parameters and STV [14]. A secondary analysis of the TRUFFLE cohort showed that CPR is not associated to both survival until first discharge without severe neonatal morbidity and neurodevelopmental outcome after 2 years [15].

Currently there are no data regarding the monitoring combination of Doppler and STV in SGA fetuses at term.

Therefore, this study aimed to examine the association of both STV and Doppler parameters with adverse perinatal outcome in this group of fetuses.

Methods

A study with a similar study design has recently been published regarding the association between STV, Doppler parameters and adverse perinatal outcome in low-risk fetuses at term. However, in this this study all SGA fetuses have been excluded [16].

Study population

This retrospective study was performed at a single tertiary referral center (University Hospital Erlangen, Erlangen, Germany) between January 2016 and April 2018.

Cases fulfilling the following criteria were included in this study: singleton pregnancies, gestational age at delivery beyond ≥ 37 weeks, birth weight < 10th centile, cephalic presentation and planned vaginal birth. Only cases with available Doppler measurements of umbilical artery (UA) and middle cerebral artery (MCA) in combination with a computerized CTG (cCTG) and calculated STV 72 h prior to delivery [8] were included in this study. Gestational age was calculated from the last menstrual period and confirmed by a crown-rump length measurement at the first-trimester scan.

Exclusion criteria were as follows: birth weight ≥ 10th centile, primary cesarean delivery, cervical dilatation of > 4 cm at ultrasound scan, scan-to-delivery interval > 72 h, multiple pregnancies, known fetal anomaly, intrauterine fetal deaths or evidence of intrauterine infection.

Stored data on maternal age, parity, ethnicity, body mass index (BMI), fetal sex, gestational diabetes, smoking status, hypertensive disorders, history of cesarean delivery and induction of labor (IOL) were queried from our database (ViewPoint 5.6.28.55; ViewPoint Bildverarbeitung GmbH, Weßling, Germany).

The present study was approved by the local Ethics committee (Klinisches Ethikkomitee des Universitätsklinikums Erlangen).

Cardiotocography and Doppler sonography

As usual in our obstetric department cCTG was performed routinely in every patient for up to 60 min or until the Dawes/Redman criteria were met. STV were calculated by the Oxford Sonicaid 8002 system (Oxford Instruments Ltd., Medical Division, Abingdon, UK) [13] or an equivalent Dawes–Redman software-based algorithm [17].

Ultrasound examinations were performed immediately after cCTG. Voluson E8/S8/e machines (GE Medical Systems, Zipf, Austria) equipped with a 2–8 MHz convex probe were used. Women were placed in a slightly left lateral position during the examination and Doppler measurements were performed during periods of fetal quiescence and in the absence of fetal tachycardia.

To obtain fetal brain Doppler, MCA closest to the transducer was measured. Doppler gate was positioned in the proximal third to derive blood flow velocities at an angle ≤ 20° [18].

UA waveforms were recorded in a free-floating loop of the umbilical cord with an angle of insonation < 20°.

CPR was calculated as the ratio between MCA and UA pulsatility indices [19]. Doppler indices were converted into multiples of median (MoM), adjusted for gestational age as described by Morales-Rosello et al. [2].

For calculation of birth weight centiles Intergrowth-21st standard was used [20]. Only experienced physicians (minimum of 2 years of training) performed Doppler measurements.

Clinical management

Induction of labour was performed due to several indications: gestational diabetes, premature rupture of the membranes, maternal request, pregnancies at or beyond 41 weeks gestation, abnormal fetal Dopplers and oligohydramnios.

Continuous fetal heart rate monitoring was obtained during labor and was classified according to the NICE guideline [21] as described in our recently published study [16].

Outcome definitions

Maternal outcome parameters were the need of secondary cesarean delivery (CD), operative vaginal delivery (OVD), as well as secondary CD and OVD due to fetal distress. CD and OVD due to fetal distress were based on CTG abnormalities, presence of meconium-stained liquor and abnormal fetal scalp blood samples [22].

Neonatal outcomes included umbilical artery (UA) blood pH ≤ 7.15 and the need of admission to the neonatal intensive care unit (NICU).

Outcome data were saved in our database.

Statistical analysis

For the descriptive analysis of our sample, continuous variables are reported as median and range. Categorical variables are reported as numbers and percentages.

To analyse the effect of STV and Doppler measurements on the probability of adverse perinatal outcome, logistic regression models were fitted with the outcome parameters as response and STV and Doppler measurements as explanatory variables. For all effect estimates, odds ratios (OR) are reported with 95% confidence interval (CI) and p values (likelihood-ratio test, effectively comparing the OR to 1), setting the significance level to 0.05.

All statistical analyses were performed with the open source statistical programming environment R 3.5.1.

Results

In total, 97 women fulfilled the inclusion criteria and were eligible for analysis. The demographic characteristics and perinatal outcomes of the study population are summarized in Tables 1 and 2.

73 women delivered spontaneously, 15 women had a secondary CD and in 9 cases OVD was performed. Regarding CD, univariate regression analysis (Table 3) showed a significant effect of UA PI MoM (OR 5.80; CI 0.75–45.69; $p = 0.009$) whereas the effects of MCA PI MoM (OR 0.30; CI 0.02–2.86; $p = 0.31$) and CPR MoM (OR 0.11; CI 0.007–1.17; $p = 0.07$) did not reach significance.

Table 1 Demographic characteristics of the study population

Parameter	All deliveries	SVD	CD	CD due to fetal distress	OVD	OVD due to fetal distress	NICU	UA pH ≤ 7.15
Number (%)	97 (100)	73 (75.3)	15 (15.5)	10 (10.3)	9 (9.3)	8 (8.2)	23 (23.7)	9 (9.3)
Maternal age: years, median (range)	31 (18–44)	31 (18–44)	33 (25–37)	34 (25–37)	30 (20–34)	31 (28–35)	31 (20–37)	34 (18–35)
Gravida: median (range)	1 (1–7)	1 (1–7)	1 (1–3)	1 (1–3)	1 (1–3)	1 (1–3)	1 (1–3)	1 (1–3)
Para: median (range)	1 (1–6)	1 (1–7)	1 (1–3)	1 (1–3)	1 (1–3)	1 (1–3)	1 (1–3)	1 (1–3)
Maternal BMI: kg/m^2, median (range)	27.6 (20.1–43.4)	27.3 (20.1–43.4)	30.3 (22.4–37.6)	29.0 (22.4–37.6)	26.4 (23.1–29.8)	25.1 (21.6–27.8)	27.1 (22.0–39.6)	24.9 (23.1–32.4)
Ethnicity: number (%)								
Europe	53 (54.6)	41 (56.2)	6 (40.0)	5 (50.0)	6 (66.7)	6 (75.0)	12 (52.2)	3 (33.3)
Others	44 (45.4)	32 (43.8)	9 (60.0)	5 (50.0)	3 (33.3)	2 (25.0)	11 (47.8)	6 (66.7)
Gestational diabetes: number (%)	7 (7.2)	5 (6.8)	2 (13.3)	2 (20.0)	0 (0)	0 (0)	1 (4.3)	1 (11.1)
Hypertensive pregnancy disorders: number (%)	4 (4.1)	4 (5.5)	0 (0.0)	0 (0.0)	0 (0)	0 (0)	0 (0)	0 (0)
Nicotine abuse: number (%)	10 (10.3)	9 (12.3)	0 (0.0)	0 (0.0)	1 (11.1)	1 (12.5)	2 (8.7)	0 (0)
Previous caesarean delivery: number (%)	9 (9.3)	4 (5.5)	4 (26.7)	1 (10.0)	1 (11.1)	1 (12.5)	2 (8.7)	1 (11.1)

SVD spontaneous vaginal delivery *CD* cesarean delivery *OVD* operative vaginal delivery *GA* gestational age *CPR* cerebroplacental ratio, *STV* short-term variation, *UA* umbilical artery *NICU* Neonatal intensive care unit

Table 2 Obstetrical and fetal characteristics of the study population

Parameter	All deliveries	SVD	CD	CD due to fetal distress	OVD	OVD due to fetal distress	NICU	UA pH ≤ 7.15
Number (%)	97 (100)	73 (75.3)	15 (15.5)	10 (10.3)	9 (9.3)	8 (8.2)	23 (23.7)	9 (9.3)
Induction of labor: number (%)	64 (66.0)	46 (63.0)	12 (80.0)	9 (90.0)	6 (66.7)	6 (75.0)	21 (91.3)	5 (55.6)
Pathological CTG: number (%)	36 (37.1)	18 (24.7)	10 (66.7)	10 (100.0)	8 (88.9)	8 (100.0)	15 (65.2)	7 (77.8)
Oxytocin use for slow progress in labor: number (%)	20 (20.6)	13 (17.8)	3 (20.0)	2 (20.0)	4 (44.4)	3 (37.5)	7 (30.4)	2 (22.2)
GA at scan: weeks, median (range)	39.3 (36.6–41.4)	39.1 (36.9–41.0)	40.3 (37.0–41.4)	39.9 (37.0–41.1)	40.0 (39.1–40.9)	40.0 (39.1–40.6)	38.0 (37.0–40.9)	39.7 (37.6–41.0)
Interval scan to delivery: Days, median (range)	1.0 (0–3)	1.0 (0–3)	1.0 (0–3)	1.0 (0–3)	1.0 (0–2)	1.0 (0–2)	1.0 (1–3.0)	1.0 (0.0–1.0)
GA at delivery: weeks, median (range)	39.4 (37.0–41.9)	39.4 (37.0–41.3)	40.6 (37.0–41.4)	40.2 (37.3–41.3)	40.2 (39.1–41.0)	40.2 (39.1–40.9)	38.3 (37.1–41.0)	39.7 (39.7–41.1)
Fetal sex male: number (%)	60 (61.9)	41 (56.2)	12 (80.0)	9 (90.0)	7 (77.8)	6 (75.0)	19 (82.6)	4 (44.4)
Birth weight: g, median (range)	2580 (1660–3030)	2550 (1660–2980)	2600 (1970–2970)	2580 (1970–2850)	2720 (2260–2940)	2720 (2260–2930)	2370 (1660–2940)	2490 (2380–2850)

SVD spontaneous vaginal delivery *CD* cesarean delivery *OVD* operative vaginal delivery *GA* gestational age *CPR* cerebroplacental ratio, *STV* short-term variation, *UA* umbilical artery *NICU* neonatal intensive care unit

Fetuses delivered by secondary CD due to fetal distress showed higher UA PI MoM (OR 4.66; CI 0.41–47.94; $p = 0.21$), lower MCA PI MoM (OR 0.09; CI 0.003–1.71; $p = 0.12$) and lower CPR MoM (OR 0.12; CI 0.005–1.87; $p = 0.14$). However, none of these variables had a significant effect on the outcome.

No significant associations between Doppler parameters and OVD (UA PI MoM: OR 0.85; CI 0.04–10.99; $p = 0.91$; MCA PI MoM: OR 4.62; CI 0.35–55.32; $p = 0.24$; CPR MoM: 2.47; CI 0.18–26.71; $p = 0.48$) and OVD due to fetal distress were found (UA PI MoM: OR 1.36; CI 0.07–18.43; $p = 0.83$; MCA PI MoM: OR 5.29; CI 0.35–70.97; $p = 0.22$; CPR MoM: OR 2.18; CI 0.13–26.54; $p = 0.56$).

Regarding perinatal outcome, logistic regression analysis indicated a significant association between Doppler parameters and NICU admission (UA PI MoM: OR 14.36; CI 2.31–107.61; $p = 0.004$; MCA PI MoM: OR 0.02; CI 0.001–0.22; $p = 0.001$; CPR MoM: OR 0.02; CI 0.001–0.19; $p < 0.0001$) whereas no significant association for UA pH < 7.15 was found (UA PI MoM: OR 0.19; CI 0.005–3.47; $p = 0.287$; MCA PI MoM: OR 0.18; CI 0.006–3.29; $p = 0.27$; CPR MoM: OR 0.99; CI 0.06–11.84; $p = 0.998$).

STV was significantly lower in fetuses admitted to NICU (OR 0.83; CI 0.67–0.99; $p = 0.04$). However, none of the other evaluated parameters were significantly associated with STV.

Discussion

This study aimed to evaluate the association between Doppler parameters and STV in SGA fetuses at term.

Doppler parameters

Presented data revealed a significant association between UA PI MoM and the need of CD, whereas MCA PI MoM and CPR MoM showed a trend towards lower indices without

Table 3 Univariate logistic regression analyses for prediction of adverse perinatal outcome

Outcome parameter	Parameter	Outcome*	No-outcome*	Univariate analyses: OR (CI)	*P* values
CD	UA PI MoM	1.22	1.09	5.80 (0.75–45.69)	0.009†
	MCA PI MoM	1.10	1.17	0.30 (0.02–2.86)	0.31
	CPR MoM	0.71	0.84	0.11 (0.007–1.17)	0.07
	STV	8.07	9.00	0.88 (0.69–1.08)	0.23
CD due to fetal distress	UA PI MoM	1.21	1.10	4.66 (0.41–47.94)	0.21
	MCA PI MoM	1.04	1.17	0.09 (0.003–1.71)	0.12
	CPR MoM	0.71	0.83	0.12 (0.005–1.87)	0.14
	STV	7.56	9.01	0.80 (0.59–1.04)	0.10
OVD	UA PI MoM	1.10	1.11	0.85 (0.04–10.99)	0.91
	MCA PI MoM	1.25	1.14	4.62 (0.35–55.32)	0.24
	CPR MoM	0.88	0.81	2.47 (0.18–26.71)	0.48
	STV	8.52	8.89	0.95 (0.72–1.21)	0.70
OVD due to fetal distress	UA PI MoM	1.13	1.11	1.36 (0.07–18.43)	0.83
	MCA PI MoM	1.26	1.14	5.29 (0.35–70.97)	0.22
	CPR MoM	0.87	0.81	2.18 (0.13–26.54)	0.56
	STV	8.81	8.86	0.99 (0.75–1.27)	0.96
NICU	UA PI MoM	1.25	1.07	14.36 (2.31–107.61)	0.004†
	MCA PI MoM	1.01	1.20	0.02 (0.001–0.22)	0.001†
	CPR MoM	0.66	0.86	0.02 (0.001–0.19)	0.0000‡
	STV	7.86	9.17	0.83 (0.67–0.99)	0.04†
UA pH ≤ 7.15	UA PI MoM	1.03	1.12	0.19 (0.005–3.47)	0.287
	MCA PI MoM	1.07	1.16	0.18 (0.006–3.29)	0.27
	CPR MoM	0.82	0.82	0.99 (0.06–11.84)	0.998
	STV	8.28	8.92	0.92 (0.69–1.17)	0.51

CD cesarean delivery, *OVD* operative vaginal delivery, *NICU* neonatal intensive care unit, *CPR* cerebroplacental ratio; *STV* short-term variation, *UA* umbilical artery, *MCA* middle cerebral artery

$^{\ddagger}p < 0.001$; $^{\dagger}p < 0.05$; *mean values

reaching statistical significance. This could be explained by the moderate sample size in our study. In comparison, Cruz-Martinez et al. [23] found a strong association between Doppler indices and CD. In their study, vasodilatation of MCA was associated with the highest risk of cesarean delivery. This is in line with another recent study conducted by Figueras et al. [24]. They prospectively evaluated 509 fetuses with late-onset SGA and noted that fetuses with an abnormal CPR were at significantly higher risk of emergency cesarean delivery due to fetal distress.

Furthermore, the latter study found a significant association between low CPR and a low UA birth pH. This is in contrast to our results as no significant correlation between Doppler parameters and UA birth pH was revealed. However, our results are consistent with further studies. Garcia-Simon et al. [25] evaluated the value of Doppler examinations in 164 SGA fetuses at term. Fetuses with abnormal CPR did not show a significant increased rate of acidosis at birth. A recent published study by Sirico et al. hypothesized that fetuses at lower birth-weight centiles physiologically show a lower CPR MoM, independent of their perinatal outcome. Hence, Sirico et al. analyzed the relationship between CPR and estimated fetal weight (EFW) in low- and high-risk singleton pregnancies, as well as the prediction of adverse perinatal outcome by CPR. They found that CPR MoM was only associated with low arterial pH when CPR was adjusted according to EFW (aCPR MoM) [26].

In the present study a significant association between Doppler parameters and risk of NICU admission was observed. This is consistent with several studies: Khalil et al. [5] showed that SGA fetuses with low CPR are at higher risk of NICU admission compared to those with normal CPR. However, fetal weight was not shown to be associated to with the need of NICU admission. Equal results were shown by Garcia-Simon et al. [25]. They reported a significantly higher risk of NICU admission in fetuses with an abnormal CPR compared to fetuses with normal Doppler parameters [25]. In addition, the study of Flatley et al. [27] examined the ability of CPR to predict adverse perinatal outcome in a low-risk cohort. Doppler parameters including CPR were found to be a significant predictor of NICU admission. However, this study did not especially focus on SGA fetuses at term.

Cardiotocography

Fetal surveillance by cardiotocography remains the most used technology in clinical practice. Regarding cCTG, studies demonstrated that STV correlates with fetal acidemia and intrauterine death in a large prospective observational study, Hecher et al. examined [10] 93 pregnancies with early-onset IUGR fetuses and showed that a combination of abnormal Ductus venosus PI and low STV is more related to perinatal death compared to fetuses with a single abnormal parameter.

Moreover, the TRUFFLE study (Trial of Randomized Umbilical and Fetal Flow in Europe) showed that optimal delivery timing of early growth-restricted fetuses is possible by assessing both fetal Doppler parameters and STV [14].

However, there is a lack of evidence in non-IUGR fetuses. Recently, we published a retrospective study on 1008 low-risk fetuses at term. This study revealed that there is no association between STV and adverse perinatal outcome. However, SGA fetuses were excluded in this analysis [16].

Regarding SGA fetuses at term, two studies showed that STV values in these fetuses do not significantly differ from STV in AGA fetuses [4, 28].

While the study by Amorim-Costa et al. did not investigate any association between STV and perinatal outcome, Graupner et al. described reference ranges for STV in late-onset SGA fetuses and examined the association between STV and perinatal outcome parameters. STV of 86 late-onset SGA fetuses were compared to 138 AGA controls. STV median values did not differ between controls and SGA fetuses. Moreover, there was no association between STV and low 1, 5 and 10 min Apgar score as well as umbilical pH in this group of fetuses.

Nevertheless, Graupner et al. did not evaluate the association between STV and NICU admission. Our results showed significant lower STV values in fetuses admitted to NICU. Regarding the other outcome parameters our results also indicated a trend towards lower STV in fetuses with adverse perinatal outcome without achieving significance.

Strengths and limitations

This is the first study evaluating the association of both STV and Doppler parameters with mode of delivery and adverse perinatal outcome in SGA fetuses at term. However, our study has several limitations: Doppler measurements have not been performed by a single investigator as Doppler measurements were assessed during clinical routine and not under specific study conditions. Thus, a certain degree of heterogeneity in the data (possibly attenuating the measured associations) could not be avoided. However, this represents every-day clinical practice and is in line with several other large studies addressing similar issues [5, 6]. Furthermore, the power of this study was limited by the moderate sample size, which might have resulted in findings which did not reach significance despite a true underlying association.

Conclusion

In conclusion, STV and Doppler parameters are significantly associated to the rate of NICU admission in SGA fetuses at term while correlation with the other outcome parameters was poor. Due to small sample size larger prospective studies evaluating both Doppler parameters and STV in SGA fetuses are needed. However, because of lack of evidence, this study is useful to estimate the benefit of Doppler parameters and computerized fetal heart rate analysis in this group of fetuses.

Author contributions FMS: project development, data collection, data interpretation, manuscript writing—original draft. FF: project development, date interpretation, supervision, manuscript writing: review and editing. SK: data interpretation, and critical revision of the manuscript. JP: data collection, and critical revision of the manuscript. PS: data collection, and critical revision of the manuscript. AM: data analysis, data interpretation, and critical revision of the manuscript. RLS: supervision, and critical revision of the manuscript. MS: data analysis, and critical revision of the manuscript. MWB: supervision, and critical revision of the manuscript. MOS: data collection, and manuscript writing—original draft.

Compliance with ethical standards

Conflict of interest Author FMS declares that he has no conflict of interest. Author FF declares that he has no conflict of interest. Author SK declares that he has no conflict of interest. Author JP declares that she has no conflict of interest. Author PS declares that he has no conflict of interest. Author AM declares that he has no conflict of interest. Author RLS declares that he has no conflict of interest. Author MS declares that he has no conflict of interest. Author MWB declares that he has no conflict of interest. Author MOS declares that he has no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (Klinisches Ethikkomitee des Universitätsklinikums Erlangen) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

References

1. American College of Obstetricians and Gynecologists (2013) ACOG practice bulletin no. 134: fetal growth restriction. Obstet Gynecol 121(5):1122–1133
2. Morales-Rosello J et al (2014) Changes in fetal Doppler indices as a marker of failure to reach growth potential at term. Ultrasound Obstet Gynecol 43(3):303–310
3. Gordijn SJ et al (2016) Consensus definition of fetal growth restriction: a Delphi procedure. Ultrasound Obstet Gynecol 48(3):333–339

4. Graupner O et al (2018) Performance of computerized cardiotocography-based short-term variation in late-onset small-for-gestational-age fetuses and reference ranges for the late third trimester. Arch Gynecol Obstet 299:353–360
5. Khalil AA et al (2015) The association between fetal Doppler and admission to neonatal unit at term. Am J Obstet Gynecol 213(1):57 e1–57.e7
6. Khalil AA et al (2015) Is fetal cerebroplacental ratio an independent predictor of intrapartum fetal compromise and neonatal unit admission? Am J Obstet Gynecol 213(1):54 e1–54 e10
7. Morales-Rosello J et al (2015) Poor neonatal acid-base status in term fetuses with low cerebroplacental ratio. Ultrasound Obstet Gynecol 45(2):156–161
8. Prior T et al (2013) Prediction of intrapartum fetal compromise using the cerebroumbilical ratio: a prospective observational study. Am J Obstet Gynecol 208(2):124 e1–124 e6
9. Prior T et al (2015) Are fetuses that fail to achieve their growth potential at increased risk of intrapartum compromise? Ultrasound Obstet Gynecol 46(4):460–464
10. Hecher K et al (2001) Monitoring of fetuses with intrauterine growth restriction: a longitudinal study. Ultrasound Obstet Gynecol 18(6):564–570
11. Galazios G et al (2010) Fetal distress evaluation using and analyzing the variables of antepartum computerized cardiotocography. Arch Gynecol Obstet 281(2):229–233
12. Anceschi MM et al (2003) Validity of short term variation (STV) in detection of fetal acidemia. J Perinat Med 31(3):231–236
13. Street P et al (1991) Short-term variation in abnormal antenatal fetal heart rate records. Am J Obstet Gynecol 165(3):515–523
14. Lees CC et al (2015) 2 year neurodevelopmental and intermediate perinatal outcomes in infants with very preterm fetal growth restriction (TRUFFLE): a randomised trial. Lancet 385(9983):2162–2172
15. Stampalija T et al (2017) Is middle cerebral artery Doppler related to neonatal and 2-year infant outcome in early fetal growth restriction? Am J Obstet Gynecol 216:521 e1–521 e13
16. Stumpfe FM et al (2019) Correlation of short-term variation and Doppler parameters with adverse perinatal outcome in low-risk fetuses at term. Arch Gynecol Obstet 299(2):411–420
17. Schiermeier S, Westhof G, Daumer M, Scholz M, Hatzmann W (2006) Short-time variations of fetal heart rate and the FIGO-CTG-Score—first experience with a combination of these two parameters. Geburtsh Frauenheilk 66:752–755
18. Bahlmann F et al (2002) Blood flow velocity waveforms of the fetal middle cerebral artery in a normal population: reference values from 18 weeks to 42 weeks of gestation. J Perinat Med 30(6):490–501
19. Baschat AA, Gembruch U (2003) The cerebroplacental Doppler ratio revisited. Ultrasound Obstet Gynecol 21(2):124–127
20. Villar J et al (2014) International standards for newborn weight, length, and head circumference by gestational age and sex: the newborn cross-sectional study of the INTERGROWTH-21st Project. Lancet 384(9946):857–868
21. National Collaborating Centre for Women's and Children's Health (2017) Intrapartum care: care of healthy women and their babies during childbirth (NICE Guideline 190). RCOG Press
22. Genuttis N, Bolz M, Briese V (2017) Can the rate of C-sections performed in a level I perinatal center be reduced?—an analysis of the University Gynecology Clinic Rostock, 2008–2014. Geburtshilfe Frauenheilkd 77(7):771–779
23. Cruz-Martinez R et al (2011) Fetal brain Doppler to predict cesarean delivery for nonreassuring fetal status in term small-for-gestational-age fetuses. Obstet Gynecol 117(3):618–626
24. Figueras F et al (2015) An integrated model with classification criteria to predict small-for-gestational-age fetuses at risk of adverse perinatal outcome. Ultrasound Obstet Gynecol 45(3):279–285
25. Garcia-Simon R et al (2015) Cervical condition and fetal cerebral Doppler as determinants of adverse perinatal outcome after labor induction for late-onset small-for-gestational-age fetuses. Ultrasound Obstet Gynecol 46(6):713–717
26. Sirico A et al (2018) Prediction of adverse perinatal outcome by cerebroplacental ratio adjusted for estimated fetal weight. Ultrasound Obstet Gynecol 51(3):381–386
27. Flatley C, Kumar S (2018) Is the fetal cerebroplacental ratio better that the estimated fetal weight in predicting adverse perinatal outcomes in a low risk cohort? J Matern Fetal Neonatal Med 32:1–7
28. Amorim-Costa C, Campos DA, Bernardes J (2017) Cardiotocographic parameters in small-for-gestational-age fetuses: how do they vary from normal at different gestational ages? A study of 11687 fetuses from 25 to 40 weeks of pregnancy. J Obstet Gynaecol Res 43(3):476–485