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MATERNAL-FETAL MEDICINE

Correlation of short-term variation and Doppler parameters with adverse perinatal outcome in low-risk fetuses at term

Florian M. Stumpfe[1] · Sven Kehl[1] · Jutta Pretscher[1] · Friederike Baier[1] · Christian M. Bayer[1] · Eva Schwenke[1] · Michael O. Schneider[1] · Andreas Mayr[2] · Ralf L. Schild[3] · Matthias Schmid[2] · Matthias W. Beckmann[1] · Florian Faschingbauer[1]

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Abstract

Objective To evaluate the association of short-term variation (STV) and Doppler parameters with adverse perinatal outcome in low-risk fetuses at term.

Methods This was a retrospective study of 1008 appropriate–for-gestational age (AGA) term fetuses. Doppler measurements [umbilical artery (UA), middle cerebral artery (MCA), and cerebroplacental ratio (CPR)] and computerized CTG (cCTG) with STV analysis were performed prior to active labor (≤ 4 cm cervical dilatation) within 72 h of delivery. The association between Doppler indices and STV values with adverse perinatal outcome was analyzed using univariate regression analysis.

Results No significant association between Doppler parameters and the need for secondary cesarean delivery (CD) or operative vaginal delivery (OVD) was shown. Regarding fetuses delivered by CD due to fetal distress, regression analyzes revealed significantly higher UA PI MoM. However, the differences in MCA PI MoM and CPR MoM were not statistically significant. Fetuses with the need for emergency CD showed significantly higher UA PI MoM, lower MCA PI MoM and lower CPR MoM. Neonates with a 5-min Apgar score < 7 had significantly lower MCA PI MoM and neonatal acidosis (UA pH ≤ 7.10) showed a significant association with UA PI MoM. None of the assessed outcome parameters were significantly associated to STV.

Conclusion Doppler indices assessed close to delivery in low-risk fetuses at term show a moderate association with adverse outcome parameters, whereas STV does not appear to predict poor perinatal outcome in this group of fetuses.

Keywords Doppler · Cerebroplacental ratio · Fetal distress · Fetal compromise · Short-term variation · Computerized CTG

Introduction

Identifying fetuses with high risk of adverse perinatal outcome remains challenging. It is well known that placental insufficiency leads to fetuses which frequently fail to reach their genetic growth potential. Predicting the genetic growth potential of a fetus is difficult. Therefore, birth weight below the 10th centile is usually used to define fetuses at increased risk for adverse perinatal outcome [1].

However, there are also fetuses with birth weight above the 10th centile (appropriate–for-gestational age-AGA fetuses) which are apparently well grown but do not reach their growth potential as a result of placental insufficiency. Doppler sonography with the assessment of the cerebroplacental ratio (CPR) can help to identify these fetuses [2, 3]. Previous studies demonstrate that fetuses with a low CPR, irrespective of their growth, are at a higher risk of adverse perinatal outcome compared to fetuses with a normal CPR [4–7]. Therefore, measurement of CPR has become more important in monitoring fetuses, especially fetuses near term.

✉ Florian M. Stumpfe
florian.stumpfe@uk-erlangen.de

[1] Department of Obstetrics and Gynecology, Erlangen University Hospital, Universitätsstraße 21-23, 91054 Erlangen, Germany

[2] Department of Medical Informatics, Biometry and Epidemiology, Rheinische Friedrich-Wilhelms-University of Bonn, Bonn, Germany

[3] Department of Obstetrics and Perinatal Medicine, Perinatalzentrum Hannover, Diakovere Krankenhaus gGmbH, Hannover, Germany

Cardiotocography (CTG) remains the most frequently used fetal monitoring technology in daily clinical practice. However, a recently published Cochrane review showed no evidence to support the use of CTG as a screening test for intrapartum compromise [8]. This could be related to the high observer variability which reduces specificity [9]. The computerized cardiotocogram (cCTG) was developed to increase the objectivity and reproducibility. Part of this system is the computerized calculation of short-term variation (STV). The beat-to-beat variation cannot be visually assessed. Low STV in antepartum cCTG has been shown to correlate to stillbirth and severe birth acidemia [10–12]. Published literature confirms that monitoring algorithms combining both fetal Doppler and STV assessment can improve perinatal outcome in severe early-onset growth-restricted fetuses [13].

Currently there is no study regarding this monitoring combination for low-risk pregnancies at term.

The objective of the present study was to evaluate the association of short-term variation and Doppler parameters with adverse perinatal outcome in low-risk fetuses at term.

Methods

Study population

This was a retrospective cohort study in a single tertiary referral center (University Hospital Erlangen, Erlangen, Germany) from January 2016 until April 2017. Cases were identified by searching our electronic database (ViewPoint 5.6.26.148; ViewPoint Bildverarbeitung GmbH, Weßling, Germany). The inclusion criteria were singleton pregnancies born at term (≥ 37 gestational weeks) that had Doppler measurements of UA and MCA in combination with a computerized CTG (cCTG) with calculated STV 72 h prior to delivery.

Exclusion criteria were cases with primary (non-labor) cesarean delivery (elective cesarean), 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. Furthermore, all fetuses with a birth weight < 10th centile (small-for–gestational age fetuses, SGA) were excluded.

The study was approved by the local Ethics committee.

Baseline characteristics

Data on maternal age, parity, ethnicity, body mass index (BMI), fetal sex, gestational diabetes, smoking status, hypertensive disorders, and history of cesarean delivery have been stored in our database.

Cardiotocography and Doppler sonography

After admission to our department and immediately before ultrasound examination, a computerized cardiotocography was conducted in the left side position for up to 60 min or until the Dawes/Redman criteria were met. The Oxford Sonicaid 8002 system (Oxford Instruments Ltd., Medical Division, Abingdon, UK) [12] or an equivalent Dawes–Redman software-based algorithm [14] was used for STV calculation.

Immediately after cardiotocography, ultrasound examinations were performed with Voluson E8/S8/e machines (GE Medical Systems, Zipf, Austria) using 2–8 MHz convex probes. During examination, women were placed in a slightly left lateral position with the head of the bed elevated at 45°. Doppler measurements were performed during fetal quiescence and in the absence of fetal tachycardia.

Doppler ultrasound examinations of the middle cerebral artery (MCA) were performed by visualizing both branches of the MCA at the circle of Willis. As described previously [15], Doppler gate was positioned in the proximal third of the MCA. Blood flow velocities were derived at an angle of insonation of ≤ 20°. The wall filter was set at 120 Hz and pulse repetition frequency ranged from 4 to 6 kHz. Pulsatility (PI) and resistance (RI) indices were calculated automatically from the mean values of a minimum of three uniform heart cycles.

Umbilical artery (UA) waveforms were obtained in a free–floating loop of the umbilical cord as described by Acharya [16]. In all cases, the angle of insonation was kept at < 20°. Angle correction was used if the angle was not zero.

CPR was calculated as the ratio between MCA and UA pulsatility indices [17]. Doppler indices were converted into multiples of median (MoM) correcting for gestational age as described by Morales-Rosello et al. [3]. Birth weight centiles were calculated as reported by Yudkin et al. [18].

All examinations were performed by experienced physicians with more than two years of training.

Gestational age was calculated from the last menstrual period, and was confirmed by or recalculated with crown–rump length measurements of the first trimester (in accordance with the recommendations of the American College of Obstetricians and Gynecologists, ACOG) [19].

Clinical management

Clinical management followed local protocols and guidelines. All deliveries were supervised by staff obstetricians. During labor, continuous fetal heart rate monitoring was obtained. CTG tracings were classified according to the NICE guideline [20].

Normal CTG: baseline 110–160 beats per min (bpm), variability > 5 bpm and the absence of decelerations.

Suspicious CTG (one non-reassuring criterion present): baseline 100–109 bpm or 161–180 bpm, variability < 5 bpm for less than 90 min, recurrent typical variable decelerations or a single prolonged deceleration for up to 3 min.

Pathological CTG: more than one non-reassuring criterion or the presence of any abnormal feature, including baseline < 100 or > 180 bpm or sinusoidal patterns (more than 10 min), variability < 5 bpm for more than 90 min, recurrent atypical variable decelerations for more than 30 min, late decelerations for more than 30 min, and a single prolonged deceleration for more than 3 min.

Outcome definitions

Maternal outcome parameters were the need for secondary cesarean delivery (CD), operative vaginal delivery (OVD), as well as secondary CD and OVD due to fetal distress and the need for emergency CD. Neonatal outcomes were 5-min Apgar score < 7 and UA pH directly after delivery ≤ 7.10.

According to our national guidelines, emergency CD were defined as secondary CD with a defined indication-delivery interval of less than 10 min [21, 22]. Indication for emergency CD was based on persistent abnormal CTG tracings after intravenous infusion of partusisten and abnormal fetal scalp blood according to the guideline of the German Society of Gynecology and Obstetrics (pH < 7.20 and base excess < − 9.8—metabolic acidosis) during intrapartum monitoring [23].

Secondary CD and OVD due to fetal distress were based on the CTG abnormalities, presence of meconium-stained liquor and abnormal fetal scalp blood samples [24].

Outcome data were collected from the maternity, fetal and neonatal records in our database.

Statistical analysis

Continuous variables are reported as median and interquartile range (IQR), categorical variables as numbers, and percentages. Pair-wise Pearson's correlation coefficient was used to calculate a correlation between STV and Doppler parameters.

To analyze the association of STV and Doppler parameters with adverse perinatal outcome, we computed logistic regression models with the adverse outcome as response, and STV and Doppler parameters as explanatory variables. For all effect estimates, we report the odds ratios (OR) with 95% confidence interval (CI) and p value (likelihood ratio test, effectively comparing the OR to 1), setting the significance level to 0.05.

High-risk fetuses were identified as those with low STV (≤ 4.5 ms) [25] or low CPR MoM values (≤ 0.6765) [3]. The occurrence of perinatal outcomes in these groups was analyzed. We report numbers, percentages and p values as obtained from Fisher's exact test (testing for independence).

All statistical analyzes were performed with the open source statistical programming environment R 3.4.0.

Results

The search generated a total of 1008 women who fulfilled the inclusion criteria. The characteristics of the study population and the various subgroups with regard to adverse perinatal outcome, and corresponding Doppler and CTG measurements are provided in Table 1.

778 (77.2%) women delivered spontaneously, 133 women (13.2%) had a secondary CD and 97 (9.6%) had an OVD.

Univariate regression analysis showed no significant association between Doppler parameters and the need for secondary CD ($n = 133$) (UA PI MoM: OR 1.83; $p = 0.16$; MCA PI MoM: OR 1.16; $p = 0.61$; CPR MoM: OR 1.09; $p = 0.78$) or OVD ($n = 97$) (UA PI MoM: OR 1.94; $p = 0.18$; MCA PI MoM: OR 0.95; $p = 0.82$; CPR MoM: OR 0.49; $p = 0.06$) (Table 2) (Fig. 1a–d).

Regarding the fetuses delivered by CD due to fetal distress ($n = 33$), regression analyzes revealed significantly higher UA PI MoM (OR 5.08; $p = 0.02$). Differences regarding MCA PI MoM and CPR MoM did not reach statistical significance (MCA PI MoM: OR 0.88; $p = 0.85$; CPR MoM: OR 0.64; $p = 0.47$). Furthermore, no significant association between Doppler parameters and the need for OVD due to fetal distress was found (UA PI MoM: OR 1.45; $p = 0.57$; MCA PI MoM: OR 1.12; $p = 0.79$; CPR MoM: OR 0.68; $p = 0.42$).

By contrast, fetuses with the need for emergency CD ($n = 8$) showed significantly higher UA PI MoM (OR 9.70; $p = 0.03$), lower MCA PI MoM (MCA PI MoM: OR 0.07; $p = 0.04$), and lower CPR MoM (CPR MoM: OR 0.003; $p < 0.001$).

Neonates with a 5-min Apgar score < 7 ($n = 20$) showed significantly lower MCA PI MoM (OR 0.16; $p = 0.02$). There were no differences regarding UA PI MoM (OR 0.90; $p = 0.92$) or CPR MoM (OR 0.21; $p = 0.07$).

Regression analysis of UA pH ≤ 7.10 ($n = 34$) showed a significant association with UA PI MoM (OR 5.19; $p = 0.02$); however, no association was found for MCA PI MoM and CPR PI MoM (MCA PI MoM: OR 1.31; $p = 0.62$; CPR MoM: OR 0.44; $p = 0.19$) (Table 2).

Fetuses with a low-CPR MoM < 0.6765 ($n = 88$) had a significantly higher rate of emergency CD (4.5% vs. 0.4%; $p = 0.003$), CD due to fetal distress (8.0% vs. 2.8%; $p = 0.02$) and low 5-min Apgar score < 7 (5.7% vs. 1.6%; $p = 0.02$) (Table 3). Overall, no differences were shown for the other outcome parameters (Table 3) (Fig. 2a, b).

Table 1 Characteristics of the maternal and fetal study population

Parameter	All deliveries	SVD	CD	CD due to fetal distress	OVD	OVD due to fetal distress	Emergency CD	5-min Apgar score < 7	UA pH ≤ 7.10
Number (%)	1008 (100)	778 (77.2)	133 (13.2)	33 (3.3)	97 (9.6)	55 (5.5)	8 (0.7)	20 (2.0)	34 (3.4)
Maternal age: years, median	31 (28–35)	31 (28–35)	32 (29–36)	35 (31–37)	31 (28–35)	32 (28–35)	33.5 (29–36)	31.5 (29–34)	31 (28–34)
Gravida: median	2 (1–2)	2 (1–2)	1 (1–2)	1 (1–2)	1 (1–2)	1 (1–2)	1 (1.0–1.3)	1 (1–2)	2 (1–2)
Para: median	1 (1–2)	2 (1–2)	1 (1–2)	1 (1–2)	1 (1–1)	1 (1–1)	1 (1–1)	1 (1–2)	1 (1–2)
Maternal BMI: kg/m^2, median	28.6 (25.4–31.6)	28.4 (25.2–31.4)	29.4 (26.6–33.2)	30.5 (25.7–33.8)	28.3 (25.4–31.2)	28.9 (25.6–32.6)	27.7 (25.6–34.7)	31.8 (27.3–33.9)	28.7 (24.6–31.4)
Ethnicity: number (%)									
Europe	744 (73.8)	568 (73.0)	103 (77.4)	26 (78.8)	73 (75.3)	37 (67.3)	7 (87.5)	14 (70.0)	24 (70.6)
Others	264 (26.2)	210 (27.0)	30 (22.6)	7 (21.2)	24 (24.7)	18 (32.7)	1 (12.5)	6 (30.0)	24 (70.6)
Gestational diabetes: number (%)	115 (11.4)	82 (10.5)	25 (18.8)	4 (12.1)	8 (8,2/3)	5 (9.1)	0 (0.0)	1 (5.0)	3 (8.8)
Hypertensive pregnancy disorders: number (%)	26 (2.6)	20 (2.6)	5 (3.8)	1 (3.0)	1 (1.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Nicotine abuse: number (%)	31 (3.1)	26 (3.3)	5 (3.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (5.0)	0 (0.0)
Previous cesarean delivery: number (%)	130 (12.9)	79 (11.4)	36 (27.1)	7 (21.2)	15 (15.5)	9 (16.4)	1 (12.5)	1 (5.0)	5 (14.7)
Induction of labor: number (%)	427 (42.4)	318 (40.9)	63 (47.4)	17 (51.5)	46 (47.4)	27 (49.1)	4 (50.0)	13 (65.0)	14 (41.2)
Pathological CTG: number (%)	242 (24.0)	154 (19.8)	33 (24.8)	33 (100.0)	55 (56.7)	55 (100.0)	8 (100.0)	10 (50.0)	23 (67.6)
Oxytocin use for slow progress in labor: number (%)	303 (30.1)	188 (24.2)	55 (41.4)	9 (27.3)	60 (61.9)	33 (60.0)	2 (25.0)	8 (40.0)	15 (44.1)
GA at scan: weeks, median	40.0 (39.1–40.7)	40.0 (39.1–40.7)	40.1 (39.1–40.7)	40.3 (39.3–40.7)	40.3 (39.6–41.0)	40.6 (39.7–41.0)	40.1 (39.5–40.7)	40.6 (39.9–41.0)	40.0 (39.6–40.9)
Interval scan to delivery: days, median	1.0 (1–2)	1.0 (0–2)	1.0 (1–2)	1.0 (1–2)	1.0 (1–2)	1.0 (1–2)	1.5 (1–2.3)	1.0 (1–2)	1.0 (1.0–1.8)

Table 1 (continued)

Parameter	All deliveries	SVD	CD	CD due to fetal distress	OVD	OVD due to fetal distress	Emergency CD	5-min Apgar score < 7	UA pH ≤ 7.10
CPR < 0.6765 MoM: number (%)	88 (8.7)	69 (8.9)	12 (9.0)	7 (21.2)	7 (7.2)	5 (9.1)	4 (50.0)	5 (25.0)	4 (11.8)
STV < 4.5 ms: number (%)	26 (2.6)	20 (2.6)	2 (1.5)	2 (6.1)	1 (1.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (5.9)
GA at delivery: weeks, median	40.1 (39.3–40.9)	40.1 (39.2–40.9)	40.3 (39.3–40.9)	40.6 (39.6–41.0)	40.4 (39.7–41.1)	40.7 (39.9–41.1)	40.2 (39.8–41.1)	40.9 (40.1–41.2)	40.1 (39.7–40.9)
Fetal sex male: number (%)	523 (51.9)	390 (50.1)	79 (59.4)	23 (69.7)	54 (55.7)	32 58.2)	5 (62.5)	13 (65.0)	22 (64.7)
Birth weight: gram, median	3450 (3200–3733	3450 (3200–3720)	3460 (3200–3740)	3280 (3100–3630)	3440 (3235–3750)	3420 (3175–3720)	3267 (3090–3468)	3545 (3108–3778)	3445 (3238–3878)

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

Average value of STV was 9.7 ms (range 2.4–18.9 ms, SD 3.41). None of the evaluated outcome parameters showed any significant association with the STV of cCTG in the univariate regression analyzes (Table 2). Furthermore, fetuses with a low STV ≤ 4.5 ms ($n = 26$) did not show any significant different outcome compared to fetuses with a STV > 4.5 ms ($n = 982$) (Table 3).

Moreover, there was no correlation between STV values and any of the Doppler parameters (r ranging between 0.00 and 0.04).

Discussion

In this study, the association of STV and Doppler parameters with adverse perinatal outcome in low-risk fetuses at term was evaluated.

Mode of delivery

Our results suggest an association between low CPR values (< 0.6765 MoM) and the need for CD due to fetal distress ($p = 0.02$), which is in analogy to other published literature: in a prospective evaluation of 400 low-risk pregnancies, Prior et al. [5] showed that fetuses with low CPR were more likely to be delivered by CD due to fetal distress than infants with a normal CPR (odds ratios 6.1; $p < 0.001$). Similar results were found by Khalil et al.: in their retrospective study, 9772 patients were included and Doppler CPR MoM was significantly lower in pregnancies requiring CD or OVD for presumed fetal compromise [6]. While in the latter study, both CD and OVD were associated with low CPR, the rate of OVD (neither overall nor in the group due to fetal distress) in our analyzes did not show any association with low CPR, which concurs with the results of Prior et al.

Neonatal outcome

In this cohort study, fetuses with a low CPR (< 0.6765 MoM) had significantly higher rates of low 5-min Apgar scores (< 7). Similar results were shown by Ropacka-Lesiak et al., evaluating 148 post-date pregnancies. In their study, fetuses with a CPR < 1.1 had a significantly higher rate of 5-min Apgar scores below 7 (27.5% vs. 1.3%, $p < 0.0001$) [26]. This is in contrast to another more recent study of Prior et al. [7], comparing perinatal outcome in 775 AGA fetuses with CPR below or above 0.6765 MoM. In that prospective study, no significant differences could be found regarding 5-min Apgar scores (2.0% vs. 1.2%; $p = 0.63$).

In analogy to several other studies [5, 7], the present results indicate no significant association between low CPR values and low UA pH at birth. However, some authors were able to demonstrate associations between low CPR and acidosis at birth in high-risk and low-risk cohorts [26–28]. Possible reasons for these varying results are different CPR

Table 2 Univariate logistic regression analyzes for prediction of adverse perinatal outcome

Parameter	Outcome	No outcome	Univariate analyzes: OR (CI)	*p* value
CD				
UA PI MoM	1.02	0.99	1.83 (0.78–4.15)	0.16
MCA PI MoM	1.37	1.36	1.16 (0.65–2.02)	0.61
CPR MoM	1.04	1.03	1.09 (0.59–1.98)	0.78
STV	9.44	9.76	0.97 (0.92–1.03)	0.32
CD due to fetal distress				
UA PI MoM	1.09	0.99	5.08 (1.36–17.40)	0.02†
MCA PI MoM	1.35	1.36	0.88 (0.29–2.59)	0.85
CPR MoM	1.00	1.03	0.64 (0.18–2.06)	0.47
STV	9.28	9.73	0.96 (0.86–1.06)	0.44
OVD				
UA PI MoM	1.02	0.99	1.94 (0.73–4.80)	0.18
MCA PI MoM	1.35	1.36	0.93 (0.47–1.77)	0.82
CPR MoM	0.98	1.04	0.49 (0.49–0.22)	0.06
STV	10.06	9.68	1.03 (0.97–1.09)	0.30
OVD due to fetal distress				
UA PI MoM	1.01	0.99	1.45 (0.38–4.62)	0.57
MCA PI MoM	1.37	1.36	1.12 (0.47–2.55)	0.79
CPR MoM	1.00	1.03	0.68 (0.25–1.69)	0.42
STV	10.76	9.65	1.09 (1.01–1.17)	0.03†
Emergency CD				
UA PI MoM	1.20	0.99	9.70 (1.30–52.59)	0.03†
MCA PI MoM	1.14	1.36	0.07 (0.004–0.91)	0.04†
CPR MoM	0.72	1.03	0.003 (0.0001–0.09)	0.0004‡
STV	9.18	9.72	0.95 (0.74–1.16)	0.64
5-min Apgar score < 7				
UA PI MoM	0.99	0.99	0.90 (0.08–5.94)	0.92
MCA PI MoM	1.20	1.36	0.16 (0.03–0.74)	0.02†
CPR MoM	0.92	1.03	0.21 (0.03–1.10)	0.07
STV	10.38	9.70	1.06 (0.93–1.18)	0.39
UA pH ≤ 7.10				
UA PI MoM	1.09	0.99	5.19 (1.42–17.64)	0.02†
MCA PI MoM	1.38	1.36	1.31 (0.45–3.56)	0.62
CPR MoM	0.97	1.03	0.44 (0.12–1.48)	0.19
STV	9.44	9.73	0.98 (0.87–1.08)	0.62

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

‡$p < 0.001$, †$p < 0.05$

cut-off values, small sample sizes, and heterogeneous inclusion criteria of both low and high-risk pregnancies.

Overall, the presented data of the univariate regression analysis show only moderate association of Doppler indices with perinatal outcome compared to other studies [6, 7, 26]. This might result from the fact that we analyzed a low-risk collective with exclusion of all SGA fetuses. Several other studies evaluating CPR Doppler indices focused on SGA fetuses which are at higher risk of adverse perinatal outcome [27, 29, 30]. Furthermore, as we analyzed the combination of cCTG, STV, and Doppler parameters, all measurements were performed close to delivery (within 72 h). Therefore, MCA Doppler measurements might be slightly more inaccurate due to lower fetal head positions. In comparison, various other studies chose larger scan-to-delivery intervals of up to 14 days [4, 6, 31].

Computerized CTG

The calculation of STV in cCTGs can help to increase objectivity and reproducibility, and it has already been demonstrated that monitoring algorithms combining both fetal

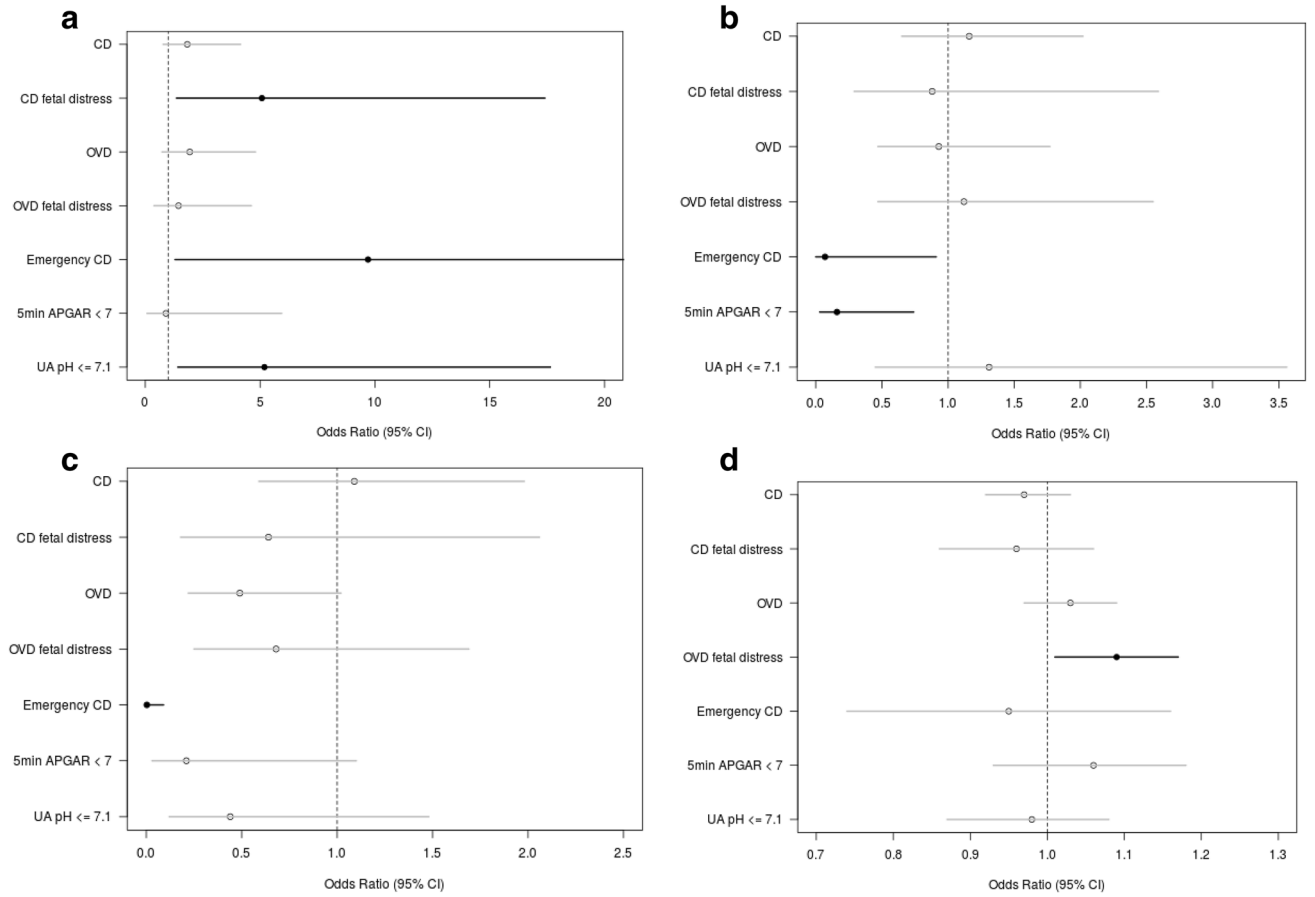

Fig. 1 Forest plots, displaying the odds ratios (OR) and corresponding 95% CI from the univariate logistic regression models for the prediction of adverse perinatal outcome: **a** UA PI MoM, **b** MCA PI MoM, **c** CPR MoM, **d** STV. The dashed vertical line refers to an OR of 1, representing independence. Significant effects ($p < 0.05$) with CIs not covering the 1 are highlighted. *CD* cesarean delivery, *OVD* operative vaginal delivery, *UA* umbilical artery

Table 3 Analysis of high-risk fetuses with low STV or low CPR

	STV			CPR MoM		
	≤ 4.5 ms	> 4.5 ms	*p* value	< 0.6765	≥ 0.6765	*p* value
CD	2/26 (7.7)	131/982 (13.3)	0.56	12/88 (13.6)	121/920 (13.2)	0.87
CD due to fetal distress	2/26 (7.7)	31/982 (3.2)	0.21	7/88 (8.0)	26/920 (2.8)	0.02†
OVD	1/26 (3.8)	96/982 (9.8)	0.50	7/88 (8.0)	90/920 (9.8)	0.71
OVD due to fetal distress	0/26 (0.0)	55/982 (5.6)	0.39	5/88 (5.7)	50/920 (5.4)	0.81
Emergency CD	0/26 (0.0)	8/982 (0.8)	1	4/88 (4.5)	4/920 (0.4)	0.003†
5-min Apgar score < 7	0/26 (0.0)	20/979 (2.0)	1	5/87 (5.7)	15/918 (1.6)	0.02†
UA pH ≤ 7.10	2/26 (7.7)	32/981 (3.3)	0.22	4/88 (4.5)	30/919 (3.3)	0.53

CD cesarean delivery, *OVD* operative vaginal delivery, *UA* umbilical artery

†$p < 0.05$

Doppler and STV assessment can improve perinatal outcome in severe early-onset growth-restricted fetuses [13, 32].

Low STV in antepartum cCTG has been shown to correlate to stillbirth and severe birth acidemia [33, 34]. However, most of these studies focused on high-risk collectives like severe early-onset growth-restricted fetuses or hypertensive pregnancy disorders [11, 25, 35–37]. So far, only few studies assessed STV in low-risk pregnancies at term [10, 38].

Our data indicate no significant association of STV and adverse perinatal outcome. Fetuses with a STV below 4.5 ms did not show increased rates of adverse outcome compared to those with higher STV values. In analogy

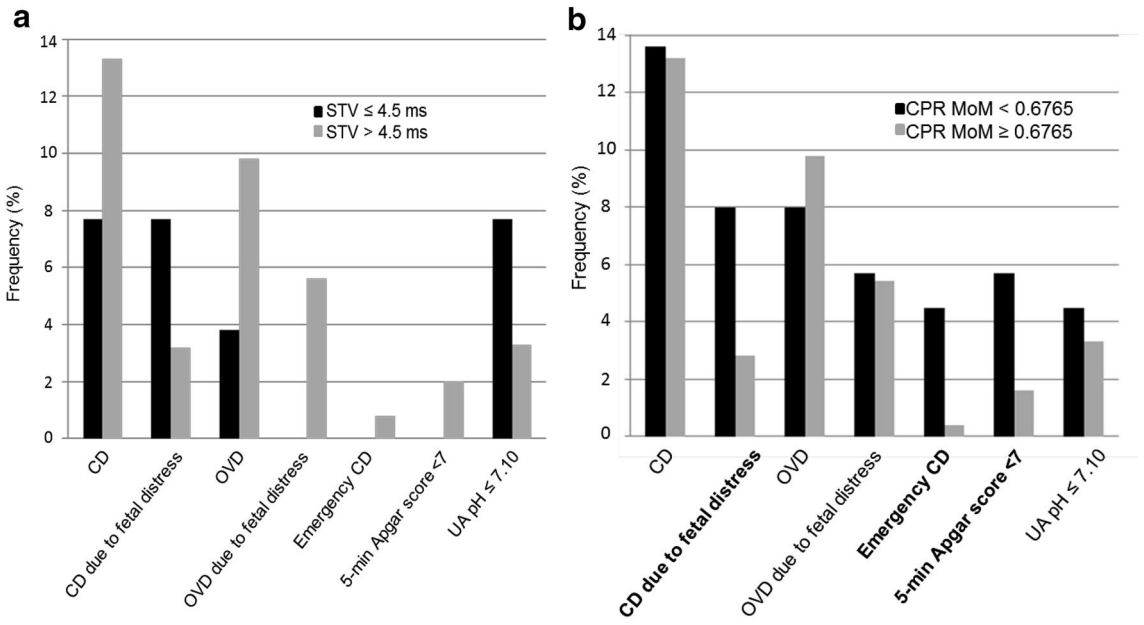

Fig. 2 Bar graph for the comparison of outcome parameters between fetuses with low (black) and normal (light gray) STV values (**a**) and CPR MoM (**b**). Significant differences ($p < 0.05$) are highlighted. *CD* cesarean delivery, *OVD* operative vaginal delivery, *UA* umbilical artery

with these results, Schiermeier et al. [39] did not show any correlation between fetal scalp pH measurements and STV in 197 fetuses during labor. Furthermore, Agrawal et al. [40] found no significant association between STV and umbilical cord artery base excess or pH in cCTGs of 51 term fetuses performed during or short before labor.

Contrary results were found by Amorim-Costa et al. in their prospective study of 145 low-risk fetuses; the physiologic development of STV throughout pregnancy was assessed [41]. They showed an increase of STV during pregnancy with a vertex at 37-week gestation. Interestingly, fetuses with a decrease of STV were more likely to be delivered by CD whereas the rates of OVD were not associated with a decrease in STV.

To the best of our knowledge, this is the first study evaluating the association of both STV and Doppler parameters with adverse perinatal outcome in low-risk fetuses at term. However, there are also some limitations: due to the retrospective design Doppler measurements were performed by several different examiners during clinical routine and not under specific study conditions. Nonetheless, this represents every day clinical practice and is in line with several other large studies addressing similar issues [6, 42]. Furthermore, midwives and physicians were not blinded to STV and Doppler measurements which might have led to an overestimation of the association with perinatal outcome.

In conclusion, Doppler indices assessed close to delivery in low-risk fetuses at term show a moderate association with adverse outcome parameters whereas STV of cCTG seems not to be able to predict poor perinatal outcome in this group of fetuses.

Authors contribution FMS conceptualization, project administration, data collection, and writing original draft. SK conceptualization, writing, review and editing. JP data collection. FB data collection. CMB data collection. ES data collection. MO Schneider: data collection. AM formal analysis. RLS supervision. MS formal analysis. MWB supervision. FF conceptualization, supervision, data collection, writing, review and editing.

Compliance with ethical standards

Conflict of interest We have no conflicts of interest to disclose.

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