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Tomasz Fuchs[A, B, D, F], Krzysztof Grobelak[B–D, F], Michał Pomorski[C–F],
Mariusz Zimmer[C, E, F]

Fetal Heart Rate Monitoring Using Maternal Abdominal Surface Electrodes in Third Trimester: Can We Obtain Additional Information Other than CTG Trace?

2nd Department and Clinic of Gynaecology and Obstetrics, Wroclaw Medical University, Poland

A – research concept and design; **B** – collection and/or assembly of data; **C** – data analysis and interpretation;
D – writing the article; **E** – critical revision of the article; **F** – final approval of article

Abstract

Background. Cardiotocography (CTG) is the most widely used procedure despite its low specificity for fetal acidosis and poor perinatal outcome. Fetal electrocardiography (fECG) with transabdominal electrodes is a new, non-invasive and promising method with greater potential for detecting impairment of fetal circulation. This study is the first that attempts to assess the usefulness of fECG in comparison to CTG during antepartum period.
Objectives. To determine if a single fECG examination along with CTG tracing and Doppler flow measurement in the fetal vessels has any additional clinical value in normal and intrauterine growth restricted (IUGR) fetuses.
Material and Methods. The study included 93 pregnancies with IUGR, 37 pregnancies with IUGR and brain sparing effect, and 324 healthy pregnant women. The T/QRS ratio, cerebro-placental ratio (CRP), and CTG tracings were analyzed. One-way analysis of variance and Spearman's rank correlation coefficient were applied. The relationship between results of the T/QRS ratio and CTG examination among the study groups was analyzed.
Results. The highest average mean value of the T/QRS ratio was recorded in the IUGR group with a normal CPR and a pathologic CTG (0.235 ± 0.014). The highest average maximum values were observed in the groups of IUGR pregnancies with a reduced CPR with normal (0.309 ± 0.100), suspicious (0.330 ± 0.102) and pathologic (0.319 ± 0.056) CTGs. Analysis of variance revealed differences between study groups regarding maximum values and the difference between maximum and minimal values of T/QRS. Correlations between groups were insignificant.
Conclusions. Higher values of T/QRS ratio in IUGR pregnancies with normal and reduced CPR than in control group regardless of the result of CTG examination may indicate minimal worsening of intrauterine fetal well-being in growth retarded fetuses. No relationship between fECG examination and CTG tracings suggests that a single fECG does not provide any additional clinically significant information determining the condition of the fetus; however, further studies are required (**Adv Clin Exp Med 2016, 25, 2, 309–316**).

Key words: cardiotocography, fetal growth restriction, fetal heart rate, fetal electrocardiography, antepartum fetal monitoring.

Methods of monitoring fetal well-being, both in the antepartum period and during labor, are constantly developed as they assist in identifying fetal hypoxia and reducing perinatal mortality and morbidity. From the first attempts of monitoring fetal heart rate and registering electrical activity of the fetal heart, researchers sought out a precise description of intrauterine fetal condition and an accurate assessment of the risk of fetal hypoxia.

Cardiotocography (CTG) is the most widely used method of monitoring fetal heart rate despite its low specificity for fetal acidosis and poor perinatal outcome [1]. It is derived from simple auscultation of the fetal heart, but currently Doppler ultrasound CTG is used for monitoring. Fetal electrocardiography has a greater potential for detecting impairment of fetal circulation; however, it is technically more difficult to perform than CTG.

First attempts to register the fetal electrocardiogram (fECG) date back to 1906, but a more accurate assessment of fECG tracings with a presentation of the phenomena characteristic for hypoxia was reported much later [2].

Intrapartum fECG has slowly gained in importance after the development of more precise methods of registering electrical signals and confirming relationships between the condition of the fetus and parameters such as changes in the ST interval and *T*-wave, the value of T/QRS ratio, the pH of umbilical cord blood sampled during labor, concentration of lactates in the fetal blood, etc. [3]. Intrapartum fECG requires placing electrodes on the fetal scalp and can be carried out with sufficient cervical dilation. Scalp electrodes are used in the STAN system [4]. An alternative to this invasive examination is a monitoring system with the use of electrodes placed on the maternal abdomen that can be performed at earlier stages of pregnancy. A transabdominal ECG can be performed with the Monica AN24 Monitor (Monica Healthcare, Nottingham, UK), MindChild Medical (North Andover, MA) and KOMPOREL (ITAM, Zabrze, Poland) [5]. The new system of spatiotemporal filtering used in the KOMPOREL allows for a decrease in the number of detection errors which significantly increases the detection performance for signals of very different quality [6, 7].

Reports of antepartum use of fECG are scarce in the literature. In the present study, the authors aimed to determine if a single fECG examination along with a CTG tracing and measurement of Doppler vascular flows in the fetal vessels has any additional clinical value in physiological pregnancies and those complicated by intrauterine growth restriction (IUGR).

Material and Methods

The study group consisted of 454 Caucasian women whose pregnancies ranged from 28 to 42 weeks of gestation. Of these patients, 93 were pregnancies with IUGR, 37 pregnancies with IUGR with brain sparing effect, and 324 healthy pregnant women. All IUGR cases were with asymmetric fetal growth type 2 developed as a result of impaired function of the placenta. IUGR was defined as an estimated fetal weight below the 5th percentile calculated on the basis of fetal biparietal diameter, abdominal circumference, head circumference and femur length measurements which persisted or deepened in subsequent sonographic examinations. Additionally, the head circumference to abdominal circumference ratio was impaired, the birth weight was below 10th percentile, and ponderal index also below 10th percentile. The presence of IUGR in features was checked at the first examination after delivery carried out by a neonatologist. All pregnancies were singleton. All subjects were healthy and presented normal clinical findings such as concentration of electrolytes (Na, K, Ca, Mg) and C-reactive protein. All had undergone ultrasound examinations (first and second trimester scan). Gestational age was estimated on the basis of the date of the last menstrual period and verified by ultrasound measurements (biparietal diameter, head circumference, abdominal circumference, and femur length). With each patient, both methods indicated the same gestational age. All recordings were performed in the 2nd Department and Clinic of Gynecology and Obstetrics of the Wroclaw Medical University. The study was approved by the Commission of Bioethics at Wroclaw Medical University. Each patient gave written, informed consent prior to entering the study. The study was conducted in compliance with the ethical principles from the Declaration of Helsinki.

Velocimetry parameters were obtained from the fetal middle cerebral and the umbilical artery. The ultrasound and Doppler measurements were performed using the ultrasound scanner Voluson Expert E8 (GE Healthcare, Zipf Austria), with a 3.5 MHz volumetric abdominal probe with a power below 100 mW/cm^2. The following cerebroplacental parameters were calculated: fetal middle cerebral artery pulsatility index, umbilical artery pulsatility index and CPR, which is a ratio of the pulsatility indices. Values of a CPR above 1.08 were considered normal. [8]

fECG and CTG were performed at the same time with the use of the KOMPOREL fetal monitoring system from ITAM (Zabrze, Poland), which works on the basis of bioelectric signal recording and analysis. Six abdominal electrodes were placed on the maternal abdominal wall as follows: on the level of umbilicus 5 cm on the right side; on the level of umbilicus 10 cm on the right side; in the midline 5 cm above the umbilicus; on the level of umbilicus 1 cm on the left side. The so-called reference electrode was placed in the midline 10 cm below the umbilicus and the so-called return electrode 10 cm below the inguinal region on the front side of thigh. The electrode placement is shown on Fig. 1. During the test, the pregnant woman lay in the supine or left lateral recumbent position. The signal received by the sensors was amplified, filtered, analyzed, and stored by KOMPOREL software. For these purposes, a standard personal computer type PC (Hewlett-Packard, Palo Alto, CA, USA) with Windows XP operating system (Microsoft Corp., Redmond, WA, USA) was used. The recording lasted 30 min. Patients with signal

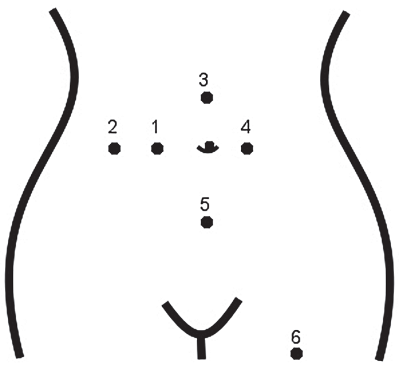

Fig. 1. Electrode placement over the abdominal wall

loss < 5% were included. T/QRS values ranging between 0.05 and 0.24 were regarded as normal, 0.24 and 0.5 raised and over 0.5 abnormal [9].

KOMPOREL software can filter artifacts, including those from the maternal abdominal muscle, extract and cancel the maternal electrocardiogram, detect the fetal QRS complex and calculate fetal heart rate, detect the P-QRS-T complex, determine *T*-wave amplitude in relation to QRS-T/QRS complex, determine the short-term and long-term variability, and filter and analyze uterine electrical activity. All these parameters were presented in graphical form, as well as stored as numerical values.

The CTG recording lasted 30 min. Fetal heart rate and its relation to uterine contractions was analyzed by the KOMPOREL software and next classified into 1 of the 3 groups according to FIGO Guidelines: normal, suspicious and pathologic [10].

Statistical analysis was performed with the computer package STATISTICA software v. 9.1 (StatSoft, Tulsa, OK, USA). Mean ± SD, median and range (min, max) of T/QRS ratios were calculated for each patient and for the study groups. For comparison of the groups, a one-way analysis of variance (ANOVA test) was carried out. For post-hoc comparison, the method of least significant difference (LSD) was used. The T/QRS ratio and CTG classification as well as diagnosis were used to construct a linear regression equation. The significance test of equation coefficients was calculated with confidence interval (CI) assuming a 95% confidence level. To examine the correlation, Spearman's rank correlation coefficient values were calculated. In all performed tests, a probability (p) value lower than 0.05 was considered statistically significant.

Results

Of the study group, 130 pregnancies were complicated by IUGR including 37 cases with the symptoms of centralization of blood circulation with the cerebroplacental ratio (CPR) below 1.08. The group of normal pregnancies consisted of 324 healthy pregnant women.

Fetal Doppler flow measurements in the umbilical artery and middle cerebral artery were within the normal range in healthy pregnancies. In pregnancies complicated by IUGR, during examination of flows in ductus venosus diastolic reverse wave were not observed and flows in the umbilical artery and middle cerebral artery were normal as well. Only in the group of 37 fetuses with brain sparring effect, the ratio of MCA PI to PI UA was abnormal.

CTG tracings were classified according to FIGO Guidelines. All grades of CTG results occurred in the 3 study groups; however, the majority of examinations were normal. The results of CTG examination with definitions of recorded pathologies are summarized in Table 1. The table presents one dominant pathology in each patient.

Short-term variability (STV) was analyzed. In the IUGR group with a normal CPR, this parameter ranged from 1.8 to 36.5 with mean value at 10.16 ± 4.98. In the IUGR group with decreased values of CPR, the values of STV ranged from 1.4 to 36.5 with mean value 11.33 ± 1.38. In women with physiological pregnancies, the values of STV ranged from 2.3 to 28.8 with mean 9.08 ± 3.91. The difference between the IUGR group with normal CPRs and the 1 with reduced CPRs was insignificant (p = 0.298). Significant differences occurred between normal pregnancies and the IUGR group without brain-sparring effect (p = 0.0354), as well as between normal pregnancies and pregnancies with IUGR and brain-sparring effect (p = 0.0095).

The T/QRS ratio variables were analyzed. In all of the groups, average mean values and average maximum values were below the cutoff level for abnormal results. The highest average mean value was recorded in the IUGR group with normal CPRs and pathologic CTGs and was on the borderline of raised outcome (mean 0.235). The highest average maximum values were observed in the groups of IUGR pregnancies with reduced CPRs regardless of the CTG result (above 0.3) and in the group of IUGR pregnancies with normal CPRs and pathologic CTGs (0.416). The T/QRS ratio variables are presented in Table 2.

One-way analysis of variance indicated the presence of significant differences between groups of normal/combined IUGR pregnancies and the result of CTG examination. These differences regarded only the mean maximum values of T/QRS ratio and the difference between maximum and minimal values of T/QRS ratio. Probabilities for *post hoc* test for the said variables are presented in Table 3. No significant differences occurred between groups with IUGR and normal or reduced CPR.

Table 1. Patients distribution according to CTG examination result (FIGO guidelines)

CTG classification	Control group		IUGR group		IUGR + CPR < 1.08	
Normal	286	sporadic, mild decelerations of very short duration	71	sporadic, mild decelerations of very short duration	17	sporadic, mild decelerations of very short duration
Suspicious	30	sporadic decelerations of any type unless severe (5)	18	sporadic decelerations of any type unless severe (4)	10	sporadic decelerations of any type unless severe (3)
		X		FHR 100–110 (1)		X
		FHR 160–170 (6)		FHR 160–170 (2)		FHR 160–170 (2)
		variability > 25 bpm (7)		variability > 25 bpm (5)		variability > 25 pbm (3)
		variability < 5 bpm (12)		variability < 5 bpm (6)		variability < 5 pbm (2)
Pathologic	8	periodically recurring and repeated decelerations of any type (3)	4	periodically recurring and repeated decelerations of any type (2)	10	periodically recurring and repeated decelerations of any type (6)
		FHR > 170 (5)		FHR > 170 (2)		FHR > 170 (4)

* CTG – cardiotocography; FIGO – International Federation of Gynecology and Obstetrics; IUGR – intrauterine growth restriction; CPR – cerebroplatental ratio; FHR – fetal heart rate; bpm – beats per minute.

Table 2. Variables of T/QRS ratio in the study groups

Study group	N	Average mean gestational age (SD)	Average mean T/QRS ratio (SD)	Average maximum T/QRS ratio (SD)	Average max–min T/QRS ratio (SD)
Total	454	34.94 (4.07)	0.140 (0.066)	0.255 (0.105)	0.180 (0.080)
Normal pregnancies with normal CTG	286	35.02 (4.34)	0.127 (0.056)	0.239 (0.100)	0.174 (0.079)
Normal pregnancies with suspicious CTG	30	37.13 (4.26)	0.114 (0.049)	0.205 (0.075)	0.144 (0.057)
Normal pregnancies with pathologic CTG	8	35.13 (3.68)	0.144 (0.064)	0.285 (0.116)	0.218 (0.113)
IUGR pregnancies with normal CPR and normal CTG	71	29.30 (5.81)	0.170 (0.074)	0.294 (0.103)	0.198 (0.081)
IUGR pregnancies with normal CPR and suspicious CTG	18	29.78 (5.84)	0.160 (0.105)	0.262 (0.137)	0.169 (0.088)
IUGR pregnancies with normal CPR and pathologic CTG	4	30.00 (5.72)	0.235 (0.014)	0.416 (0.036)	0.305 (0.030)
IUGR pregnancies with reduced CPR and normal CTG	17	26.88 (3.89)	0.185 (0.071)	0.309 (0.100)	0.197 (0.078)
IUGR pregnancies with reduced CPR and suspicious CTG	10	29.80 (4.96)	0.194 (0.076)	0.330 (0.102)	0.226 (0.077)
IUGR pregnancies with reduced CPR and pathologic CTG	10	29.60 (4.81)	0.184 (0.045)	0.319 (0.056)	0.210 (0.054)

* CTG – cardiotocography; IUGR – intrauterine growth restriction; CPR – cerebroplatental ratio; N – number; SD – standard deviation.

Table 3. Comparison of means of the maximum values of T/QRS ratio and the difference between maximum and minimal values of T/QRS ratio (probabilities for tests *post-hoc*, LSD test)

Study group		**1.**	**2.**	**3.**	**4.**	**5.**	**6.**
		Difference between maximum and minimal values of T/QRS ratio					
1. Normal pregnancies with normal CTG	maximum T/QRS ratio		**0.0440**	0.1224	**0.0149**	0.3374	**0.0039**
2. Normal pregnancies with suspicious CTG		0.0810		**0.0183**	**0.0013**	**0.0284**	**0.0003**
3. Normal pregnancies with pathologic CTG		0.2097	**0.0489**		0.4869	0.3635	0.5885
4. IUGR pregnancies with normal CTG		**0.0000**	**0.0000**	0.7354		0.6198	0.0849
5. IUGR pregnancies with suspicious CTG		**0.0181**	**0.0023**	0.9611	0.6277		0.0654
6. IUGR pregnancies with pathologic CTG		**0.0001**	**0.0000**	0.1650	0.0883	0.0689	

* *Post-hoc* comparison presenting probabilities of differences between study groups: above slanted line for difference between maximum and minimal values of T/QRS ratio and below slanted line for maximum values of T/QRS ratio; CTG – cardiotocography; IUGR – intrauterine growth restriction; significant probabilities are marked in bold.

Spearman's rank correlation coefficient showed no statistical dependence between variables of the T/QRS ratio and the result of CTG examination. All correlations were weak and insignificant.

Discussion

Fetal heart rate monitoring is one the methods of fetal well-being assessment. Fetal CTG has been recommended in fetal care both in the intrapartum period and during labor since the 1960s. Many researchers in various studies have proved the high sensitivity of the standard CTG alongside with its low specificity for prediction of life threatening conditions of the fetus. This has caused the increase in caesarean section deliveries and instrumental vaginal births; however, it has not reduced infant mortality and frequency of incidence of cerebral palsy [11, 12]. In meta-analysis performed by Pattison and McCowan on assessment standard CTG in trials conducted on high-risk pregnancies, no benefits were observed in relation to reduced perinatal mortality or morbidity [1]. Moreover, the large variation in interpretation of CTG tracings by obstetricians and midwives seems to be the main factor limiting the effectiveness and reliability of the method [13].

The imperfection of CTG, despite being a gold standard in the supervision of fetal well-being, imposes the necessity of searching for a more objective method of antenatal monitoring. Introducing computerized cardiotocography and unified cardiotocographic nomenclature by The International Federation of Gynecology and Obstetrics (FIGO) has given insight into the pathophysiology of fetal hypoxia. Many studies have revealed that heart rate reduction in the fetus and the presence of repeated late decelerations in CTG traces performed intrapartum are related to fetal hypoxia. Moreover, STV below 3 ms regarded as worsening of fetal well-being is highly correlated with the grade of hypoxia, acidosis, and the risk of intrauterine death [14–16]. Anseschi et al. in their study proved that a value of STV below 4.5 ms along with other risk factors may be regarded as a threshold below which timing of delivery should be considered in order to improve perinatal outcomes in pregnancies complicated by IUGR [17]. In our study, the values of STV in CTG traces were also analyzed. In cases of IUGR with normal flows in the umbilical artery and middle cerebral artery in the fetus, the average value of STV was 10.05 ms (range 1.8–36.5; SD 4.98). In cases of IUGR with CPRs below 1.08, the average value of STV was 11.33 (range 1.4–36.5; SD 7.15). However, the difference between said groups was not statistically significant ($p = 0.298$).

In clinical practice, fetal ECG has gained in importance after the introduction of computer signal processing. In the published literature, there are many studies presenting benefits from the use of computer analysis of the ST segment during labor [18, 19].

This method delivers information about the fetal heart's capability to properly react in the state of

Table 4. Spearman's rank correlation coefficients between T/QRS ratio variables and CTG examination result

Variables	Normal pregnancies	Combined IUGR group	IUGR group with normal CPR	IUGR group with reduced CPR
Mean T/QTS	–0.039	0.069	–0.026	–0.028
Median T/QRS	–0.038	0.059	–0.025	–0.063
Max T/QRS	–0.046	0.071	–0.017	0.072
Min T/QRS	–0.025	0.084	0.025	0.027
Max–min T/QRS	–0.053	0.093	–0.002	0.173

* CTG – cardiotocography; IUGR – intrauterine growth restriction; CPR – cerebroplatental ratio.

hypoxia. Elevation of the ST segment and increased amplitude of the T wave presented as an increased value of T/QRS reflects the fetal heart reaction to the catecholamine release stimulated by acute hypoxia. In the case of reduced capability of the fetal heart to adapt to an environment of reduced oxygen supply, ST segment depression and its biphasic character, as well as a negative T wave, were observed [20]. It is suggested that such changes may result from the reduced amount of glycogen stored in the cells of the fetal heart, which serves as an additional source of energy. Similar symptoms were observed also in the state of acute hypoxia in sheep fetuses exposed to a chronic reduced supply of oxygen and nutrients. In studies by Rosen et al. as well as Greene et al., changes in the ST segment and shape of the *T* wave during acute hypoxia were described jointly with a drop in the amount of glycogen and ATP in the myocardium and a rise of potassium and lactate in the plasma [21, 22]. An inverse relationship was observed between T/QRS values and the pH of umbilical cord blood sampled during labor [22].

Currently, in many health care centers attempts to use fetal ECG in combination with CTG during labor have been undertaken. In meta-analysis performed by Olofsson et al. 5 randomized trials conducted in Sweden, Denmark, France, Finland, and Great Britain were analyzed. Researchers compared the use of intrapartum CTG plus ST segment analysis to monitoring based on CFG alone [23]. In the group monitored by both methods, a lower number of operative deliveries and metabolic acidosis in newborns were observed, whereas in France and Finland, the number of confirmed cases of metabolic acidosis was higher than in the control group. The authors of the meta-analysis link the differences in outcomes with differences in study design and group size. Undoubtedly, additional research assessing efficacy of fetal ECG is required before this method can become a standard tool in intrapartum monitoring.

The reports on the use of fetal ECG in the antepartum period are scarce in the literature. In his paper, Fuchs reported changes of T/QRS ratio values in physiological pregnancies between 28 and 42 weeks' gestation [24]. The highest values were observed in pre-term and post-term pregnancies, while the lowest were in the peripartum period. Such a condition is probably caused by decreased vascular resistance in the placenta vessels in advancing pregnancy, which results in reduced cardiac workload confirmed by the lowest values of the T/QRS ratio between 37 and 41 weeks of gestation. In pregnancies after 42 gestational weeks, the supply of oxygen and nutrients to the fetus decreases due to the placenta aging process and its progressing insufficiency. Increased values of T/QRS ratios in this period may indicate worsening of intrauterine fetal well-being.

In the present study, the average and maximum values of the T/QRS ratio appeared to be higher in pregnancies complicated by IUGR both with normal and deteriorated vascular flows in the umbilical artery and middle cerebral artery in the fetus than in healthy pregnancies. The highest T/QRS ratio values were found in IUGR pregnancies with suspicious or pathologic CTG results; however, no significant differences were shown between CTG grades and variables of the T/QRS ratio in the study groups. In a large number of patients, especially those complicated by IUGR, CTG results appeared to be within a normal range, while minor changes in the ST segment and the T wave were observed. It is probable that increased values of the T/QRS ratio in pregnancies complicated by IUGR indicate deterioration of intrauterine environment forcing the fetus to adapt. Reduced nutritional ability of an insufficient placenta, decreased glycogen storage in the fetal heart, and as a consequence a reduced ability to function normally in the condition of chronic hypoxia and periodic exacerbation of oxygen supply may be visible in recorded ECG traces as increased values of the T/QRS ratio.

CPR is used for predicting adverse outcomes in IUGR fetuses. This index is defined as a ratio of pulsatility indices of the middle cerebral artery of the fetus and umbilical artery. Studies suggest that it is a better index for predicting unfavorable perinatal outcomes in pregnancies complicated by IUGR compared to flow assessment of either the umbilical artery or middle cerebral artery alone [8]. The CPR value allows integrated information to be obtained about the placenta (umbilical artery) and fetal response (middle cerebral artery) to an unfavorable intrauterine environment. Sensitivity of CPR in prediction of adverse perinatal outcomes in pregnancies complicated by IUGR varies from 63% to 68% in studies performed by authors [8, 25]. The factor which limits the use of CPR in clinical practice is its variability depending on the stage of pregnancy. In many papers, the value of CPR equal to 1.08 was considered a threshold below which results were regarded as abnormal [8, 26]. To eliminate CPR's dependence on gestational age Baschat and Gembruch developed tables of reference ranges for this parameter against gestational age [27]. The study conducted by Obido et al. did not reveal significant differences in efficacy in prediction of adverse perinatal outcomes between the use of gestational age-specific reference levels and a categorical threshold of 1.08. This study has a limitation of such a small sample size, retrospective design, and relatively small numbers of adverse perinatal outcomes; however, it shows similar efficiency of both methods. The clinical value of CPR decreases after 34 weeks of gestational age which is probably caused by differences in adaptation of the fetus to chronic hypoxia in regard to its maturity [25, 28]. In the present study, 27 cases of pregnancies complicated by IUGR presented a CPR value below 1.08. In this group of patients, average and maximum values of the T/QRS ratio were higher than in normal pregnancies as well as in pregnancies complicated by IUGR without the symptoms of centralization of blood circulation. These differences were, however, insignificant.

The limitation of the study is the small number of patients in the groups burdened with the most severe pathologies.

Additional research is required to evaluate the efficacy of T/QRS measurement in complicated pregnancies and its comparison to other methods of monitoring fetal well-being during the antepartum period.

The authors concluded that in antepartum period, values of T/QRS ratio recorded in IUGR pregnancies with normal and reduced CPR were higher than in control group regardless of the result of CTG examination. This may indicate worsening of intrauterine fetal well-being in growth retarded fetuses. No relationship was found between fECG examination and CTG tracings suggesting that a single fECG does not provide any additional clinical information determining the condition of the fetus; however, further studies are required.

References

[1] **Pattison N, McCowan L:** Cardiotocography for antepartum fetal assessment. Cochrane Database Syst Rev 2000, 2, CD001068.

[2] **Sameni R, Clifford GD:** A Review of Fetal ECG Signal Processing; Issues and Promising Directions. Open Pacing Electrophysiol Ther J 2010, 1, 4–20.

[3] **Rosen KG, Amer-Wahlin I, Luzietti R, Noren H:** Fetal ECG waveform analysis. Best Pract Res Clin Obstet Gynaecol 2004, 18, 485–514.

[4] **Rosen KG, Lindecrantz K:** STAN – the Gothenburg model for fetal surveillance during labour by ST analysis of the fetal electrocardiogram. Clin Phys Physiol Meas 1989, 10, Suppl B, 51–56.

[5] **Adam J:** The future of fetal monitoring. Rev Obstet Gynecol 2012, 5, 132–136.

[6] **Kotas M, Jezewski J, Horoba K, Matonia A:** Application of spatio-temporal filtering to fetal electrocardiogram enhancement. Comput Methods Programs Biomed 2011, 104, 1–9.

[7] **Jezewski J, Matonia A, Kupka T, Roj D, Czabanski R:** Determination of fetal heart rate from abdominal signals: evaluation of beat-to-beat accuracy in relation to the direct fetal electrocardiogram. Biomed Tech (Berl) 2012, 57, 383–394.

[8] **Gramellini D, Folli MC, Raboni S, Vadora E, Merialdi A:** Cerebral-umbilical Doppler ratio as a predictor of adverse perinatal outcome. Obstet Gynecol 1992, 79, 416–420.

[9] **Westgate J, Harris M, Curnow JS, Greene KR:** Plymouth randomized trial of cardiotocogram only vs. ST waveform plus cardiotocogram for intrapartum monitoring in 2400 cases. Am J Obstet Gynecol 1993, 169, 1151–1160.

[10] **Ayres-de-Campos D, Bernardes J:** Twenty-five years after the FIGO guidelines for the use of fetal monitoring: time for a simplified approach? Int J Gynaecol Obstet 2010, 110, 1–6.

[11] **Alfirevic Z, Devane D, Gyte GM:** Continuous cardiotocography (CTG) as a form of electronic fetal monitoring (EFM) for fetal assessment during labour. Cochrane Database Syst Rev 2013, 5, CD006066.

[12] **Zimmer M, Hirnle L, Fuchs T, Florjanski J, Tomialowicz M, Klosek A, Milnerowicz-Nabzdyk E:** The influence of computer supervision of deliveries on the medical procedures during labor and neonatal post-delivery status. Ginekol Pol 2000, 71, 187–191.

[13] **Sweha A, Hacker TW, Nuovo J:** Interpretation of the electronic fetal heart rate during labor. Am Fam Physician 1999, 59, 2487–2500.

[14] **Guzman ER, Vintzileos AM, Martins M, Benito C, Houlihan C, Hanley M:** The efficacy of individual computer heart rate indices in detecting acidemia at birth in growth-restricted fetuses. Obstet Gynecol 1996, 87, 969–974.

[15] **Hecher K, Bilardo CM, Stigter RH, Ville Y, Hackeloer BJ, Kok HJ, Senat MV, Visser GH:** Monitoring of fetuses with intrauterine growth restriction: a longitudinal study. Ultrasound Obstet Gynecol 2001, 18, 564–570.

[16] **Ribbert LS, Snijders RJ, Nicolaides KH, Visser GH:** Relation of fetal blood gases and data from computer-assisted analysis of fetal heart rate patterns in small for gestation fetuses. Br J Obstet Gynaecol 1991, 98, 820–823.

[17] **Anceschi MM, Ruozi-Berretta A, Piazze JJ, Cosmi E, Cerekja A, Meloni P, Cosmi EV:** Computerized cardiotocography in the management of intrauterine growth restriction associated with Doppler velocimetry alterations. Int J Gynaecol Obstet 2004, 86, 365–370.

[18] **Potti S, Berghella V:** ST waveform analysis versus cardiotocography alone for intrapartum fetal monitoring: a meta-analysis of randomized trials. Am J Perinatol 2012, 29, 657–664.

[19] **Salmelin A, Wiklund I, Bottinga R, Brorsson B, Ekman-Ordeberg G, Grimfors EE, Hanson U, Blom M, Persson E:** Fetal monitoring with computerized ST analysis during labor: a systematic review and meta-analysis. Acta Obstet Gynecol Scand 2013, 92, 28–39.

[20] **Westgate JA, Bennet L, Brabyn C, Williams CE, Gunn AJ:** ST waveform changes during repeated umbilical cord occlusions in near-term fetal sheep. Am J Obstet Gynecol 2001, 184, 743–751.

[21] **Rosen KG, Kjellmer I:** Changes in the fetal heart rate and ECG during hypoxia. Acta Physiol Scand 1975, 93, 59–66.

[22] **Greene KR, Dawes GS, Lilja H, Rosen KG:** Changes in the ST waveform of the fetal lamb electrocardiogram with hypoxemia. Am J Obstet Gynecol 1982, 144, 950–958.

[23] **Olofsson P, Ayres-de-Campos D, Kessler J, Tendal B, Yli BM, Devoe L:** A critical appraisal of the evidence for using cardiotocography plus ECG ST interval analysis for fetal surveillance in labor. Part I: The randomized controlled trials. Acta Obstet Gynecol Scand 2014, 93, 556–568.

[24] **Fuchs T:** Values of T/QRS ratios measured during normal and post-term pregnancies. J Perinat Med 2014, 42, 349–357.

[25] **Bahado-Singh RO, Kovanci E, Jeffres A, Oz U, Deren O, Copel J, Mari G:** The Doppler cerebroplacental ratio and perinatal outcome in intrauterine growth restriction. Am J Obstet Gynecol 1999, 180, 750–756.

[26] **Arias F:** Accuracy of the middle-cerebral-to-umbilical-artery resistance index ratio in the prediction of neonatal outcome in patients at high risk for fetal and neonatal complications. Am J Obstet Gynecol 1994, 171, 1541–1545.

[27] **Baschat AA, Gembruch U:** The cerebroplacental Doppler ratio revisited. Ultrasound Obstet Gynecol 2003, 21, 124–127.

[28] **Odibo AO, Riddick C, Pare E, Stamilio DM, Macones GA:** Cerebroplacental Doppler ratio and adverse perinatal outcomes in intrauterine growth restriction: evaluating the impact of using gestational age-specific reference values. J Ultrasound Med 2005, 24, 1223–1228.

Address for correspondence:

Tomasz Fuchs
2nd Department and Clinic of Gynaecology and Obstetrics
Wroclaw Medical University
Borowska 213
50-556 Wrocław
Poland
E-mail: tfuchs@o2.pl

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