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Values of T/QRS ratio in pregnancies complicated by intrauterine growth restriction

Abstract

Aims: To evaluate values of T/QRS ratio in normal pregnancies and those complicated by intrauterine growth restriction (IUGR) using non-invasive method with transabdominal electrodes. Assessment of fetal well-being in IUGR pregnancies.

Methods: Fetal electrocardiograms were recorded and analyzed by KOMPOREL software from ITAM (Zabrze, Poland) and T/QRS ratios were automatically calculated. Doppler velocimetry of the middle cerebral artery and umbilical artery was carried out. The study group consisted of IUGR pregnancies with normal cerebroplacental ratios (CPRs) (n=110), IUGR pregnancies with decreased CPRs (n=29), and healthy controls (n=549). Analyses were performed between the study groups and by gestational age. T/QRS ratio variables and CPRs were calculated. Analysis of variance and linear regression were performed.

Results: Maximum values, maximum minimal value differences, and standard deviations of T/QRS ratio were significantly different between the IUGR group with reduced CPRs and normal CPRs (P=0.0009, P=0.0000, P=0.0034, respectively) as well as between the IUGR group with reduced CPRs and healthy controls (P=0.0000, P=0.0001, P=0.0009, respectively). Mean maximum values in the IUGR group with reduced CPRs exceeded normal values.

Conclusions: T/QRS ratio may be useful in assessing fetal well-being in IUGR pregnancies; however, future studies are needed to determine typical ranges of T/QRS ratio in pregnancies complicated by IUGR.

Keywords: Antepartum fetal monitoring; fetal diseases; fetal electrocardiography; fetal growth; IUGR.

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Introduction

Intrauterine growth restriction (IUGR) is one of the most common causes of fetal intrauterine death [1]. As a factor that increases perinatal infant mortality [2], IUGR constitutes a predisposition to the development of certain diseases in adulthood as well [3]. Despite recognition of this fact, for many years there has been a lack of effective treatment and prevention of IUGR, while obstetric management has remained focused on the early diagnosis of IUGR, intrauterine monitoring of fetal well-being, and timing of delivery.

The diagnosis of IUGR is based on estimated fetal measurements and weight assessment during ultrasound examination. One of the proposed IUGR diagnostic parameters is based on percentile rank. Estimated fetal weight below the tenth percentile for a given gestational age or below two standard deviations from average weight is suspected of having IUGR. Due to this parameter's low specificity, it is currently proposed to tighten this criterion below the fifth or even the third percentile [4]. In addition, the fetal growth potential is different in various populations, which makes the diagnosis even more difficult [5, 6]. For this reason, clinicians have to deal with a very heterogeneous group of fetuses that are in a varied physical condition.

It is known that fetal growth deficit resulting from placental dysfunction is accompanied by reduced transport of nutrients and oxygen across the placenta. The fetus then operates in a constant state of hypoxia. Adaptive mechanisms to change the intrauterine environment includes a centralization of blood circulation that enables proper functioning of vital organs, cerebral vasodilatation enhancing cerebral perfusion (brain-sparing effect), anaerobic metabolism and formation of lactic and carbonic acid as its consequence, the change of carbohydrates into fatty acids as a source of energy, and tachycardia in the first stage and bradycardia as a final stage of hypoxia [7–10].

Doppler assessment of fetal vessels facilitates the surveillance of IUGR secondary to placental dysfunction. The most significant abnormalities described in the literature include increased resistance in the umbilical artery

(UA) and compensatory flow in the middle cerebral artery (MCA) indicating cerebral redistribution. Moreover, it is possible to diagnose the severity of IUGR and its effect on fetal well-being by assessing the changes in fetal circulation [9]. Studies suggest the cerebroplacental ratio (CPR) is a better index for predicting adverse outcomes in IUGR compared to either the UA or MCA Doppler values alone [11]. The diagnosis may be more accurate adding other methods of fetal well-being assessment such as motor activity of the fetus [12].

Monitoring of the heart is another method for assessing fetal status [13–15]. The use of fetal electrocardiography adds new insight into the processes occurring in the fetal heart. Phenomena observed during fetal hypoxia include PR interval prolongation, widening of the QRS complex, ST-segment depression and a lack of a T-wave or its inversion [16], changes in P-wave morphology, such as high amplitude, and the presence of a biphasic or reversed P-wave [17]. However, only the studies conducted by Rosen and Green gave a precise description of changes occurring in the ST-segment and the T-wave shape during hypoxia. They also showed that the glycogen and ATP concentrations decrease while at the same time potassium and lactate increase [18, 19]. The studies revealed the association between values of the T/QRS ratio and blood pH collected from the umbilical cord during labor [20]. It was observed that the values of the T/QRS ratio increase with the decrease in glycogen, phosphorylated creatine, and ATP in the cells, as well as with the appearance of metabolic acidosis [21]. This allowed for constructing the systems for perinatal monitoring of fetal well-being based on measurements of the T/QRS ratio [22]. Changes in the T/QRS ratio are well described in the intrapartum period [23], however, there is insufficient data concerning its behavior in pregnancies complicated by IUGR in antepartum monitoring.

Monitoring fetal heart activity is a long-standing research topic. Despite the fact that much is already known about fetal distress assessment, there is still insufficient data about the usefulness of the T/QRS ratio in antepartum monitoring, especially in complicated pregnancies. The aim of this study is to compare T/QRS ratio values among the IUGR fetuses with normal and decreased CPRs and healthy controls.

Materials and methods

Six hundred and eighty-eight pregnant Caucasian women were enrolled. They were divided into three groups: women with IUGR with normal CPRs ($n=110$), women with IUGR with decreased

CPRs ($n=29$), and healthy pregnant women with eutrophic fetuses ($n=549$). All the cases of IUGR were diagnosed as asymmetric IUGR of placental etiology. Fetuses with absent or reversed end-diastolic velocity in the umbilical artery were not included in order to exclude fetuses in very poor condition.

All pregnancies were singleton and ranged from 28 to 40 weeks of gestational age. All women had normal concentrations of electrolytes (Na, K, Ca, and Mg) and no signs of infection (negative CRP). All had undergone ultrasound examinations (first and second trimester scans). Ultrasound examination did not reveal any abnormalities in the body of the fetus that might have suggested the presence of congenital malformations or genetic disorders. In all cases, the amount of amniotic fluid was assessed and the amniotic fluid index (AFI) was calculated. In the pregnancies in the control group the amount of amniotic fluid was within the normal range, while in IUGR pregnancies with normal CPRs, the AFI ranged from 4 to 10. In five cases of IUGR pregnancies with a reduced CPR, oligohydramnion was diagnosed (AFI < 5).

The IUGR groups included patients 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 fifth 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. Moreover, the head circumference to abdominal circumference ratio was impaired, the birth weight was below the tenth percentile, and the ponderal index was also below the tenth percentile. In addition, the presence of IUGR in features was checked at the first examination after delivery carried out by a neonatologist.

Velocimetry parameters were obtained from the fetal MCA and the UA. 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/cm². Flow in the UA and the MCA was measured and on the basis of the obtained arteries spectrum and flow indices such as systolic-diastolic ratio (S/D), the resistance index (RI) and pulsatility index (PI) were automatically calculated. In order to cancel the interference from adjacent tissues, a filter of 50 Hz was used. The MCA was identified with color Doppler ultrasound after placing the fetal head in the transverse plane on the level of lateral ventricles of the brain. The Doppler gate was set at proximal portion of the MCA. The free loop of the UA was identified with color Doppler ultrasound and the gate was placed in the center of the vessel. In both arteries, an angle of insonation of <15 degrees was used. The following cerebroplacental parameters were calculated: fetal middle cerebral artery PI (MCA PI), umbilical artery PI (UA PI), and CPR, which is a ratio of the pulsatility indices. Values of a CPR above 1.08 were considered normal [11].

For the electrical signal of the fetal heart and uterine contraction activity registration, the KOMPOREL fetal monitoring system (ITAM, Zabrze, Poland) was used. This system works on the basis of bioelectric signal recording and analysis. With each patient, the recording lasted 30 min. Electrodes were placed 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; in the midline 10 cm below the umbilicus, the so-called reference electrode; and 10 cm below the inguinal region on the front side of thigh, the so-called return electrode. The quality of the signal was improved by mild skin abrasion

using sand paper material for ECG from 3M in order to remove part of the stratum corneum. Next, an additional gel layer was applied on the sensing element in order to obtain the best electrode adhesion.

The study results were statistically analyzed using the Statistica software v 9.1 (StatSoft, Tulsa, OK, USA). To describe intervariability within quantitated parameters the following variables were calculated: mean (\bar{x}), median (M), range (min, max), difference in the range (max-min), and the standard deviation (SD) of T/QRS ratios. For *post-hoc* comparison, the method of least significant difference (LSD) was used. The T/QRS ratio variables and gestational age were used to construct a linear regression equation. By assuming that the independent variable is the week of gestation, the equation is as follows: $T/QRS = b_0 + b_{GA} \times GA$, where b_0 and b_{GA} are the regression coefficients. The significance test of equation coefficients was calculated with a confidence interval assuming a 95% confidence level. Standardized beta coefficients (β) were calculated in order to compare the rate of change of analyzed parameters. A P-value <0.05 was considered statistically significant.

All electrocardiography (ECG) recordings, sonographic fetal measurements and Doppler velocimetry measurements were performed between January 2010 and December 2011 in the II Department of Gynecology and Obstetrics of the Wrocław Medical University, Wrocław, Poland. In the healthy control group, the examination was performed in an outpatient setting during routine obstetric visits. The women with IUGR pregnancies were hospitalized. The study was approved by the Commission of Bioethics at the Wrocław Medical University. Written informed consent was obtained prior to the patient entering the study. The study was conducted according to the Declaration of Helsinki.

Results

The study included 688 Caucasian women. The patients with IUGR were otherwise healthy with no concomitant disorders. The patients age range was between 17 and 46 years of age ($\bar{x}=30.19$, SD 4.53). None of the studied subject smoke. Characteristics of study patients are presented in Table 1. There were no significant differences between study groups.

Characteristics of T/QRS ratio variables are presented in Table 2. *Post-hoc* comparison of mean maximum values, mean standard deviations and mean differences between maximum and minimal values revealed significant differences. These variables in the IUGR group with reduced CPRs were statistically significantly different from the healthy controls and the IUGR group with normal CPRs. The probabilities for *post-hoc* testing are presented in Table 2.

To examine the relations between gestational age and T/QRS variables regression analysis was used. The results of the regression equation were not significantly different, although the comparison between scatter plots of two-dimensional regression equations for variables showed interesting trends. For the maximum values

Table 1: Characteristics of study groups.

	Age mean (SD)	Age range	HBD mean (SD)	HBD range	Weight (kg) (SD)	Height (cm) (SD)	BMI mean (SD)	P 1 (%)	P 2 (%)	P 3 (%)	P 4 (%)	P 5 (%)
Control group (n=549)	30.4 (4.32)	17-46	35.08 (3.95)	28-40	75.23 (12.15)	166.54 (6.16)	27.02 (4.47)	301 (55)	156 (28)	74 (13)	14 (3)	4 (1)
IUGR normal CPR ratio (n=110)	29.34 (5.5)	18-41	34.52 (2.83)	28-40	72.25 (11.85)	165.02 (5.75)	26.92 (4.49)	78 (71)	21 (18)	7 (6)	4 (4)	0 (0)
IUGR reduced CPR ratio (n=29)	29.45 (0.3)	23-37	34.31 (2.71)	28-39	81.36 (5.01)	166.41 (5.56)	26.09 (3.93)	12 (41)	15 (52)	1 (3)	1 (3)	0 (0)

SD=standard deviation, BMI=body mass index, P=pregnancy (1=first; 2=second; 3=third; 4=fourth; 5=fifth), IUGR=intrauterine growth restriction, CPR=cerebro-placental ratio, HBD=hebdomas, week of gestational age.

Table 2: Characteristics of T/QRS ratio and probabilities for *post-hoc* tests.

T/QRS variables	Study groups						Test value		LSD test; probabilities for tests <i>post-hoc</i> ; P-values		
	Normal CPR		Reduced CPR		Controls		F	P-value	Normal CPR vs. reduced CPR	Normal CPR vs. controls	Reduced CPR vs. controls
	Mean	SD	Mean	SD	Mean	SD					
Mean	0.165	0.076	0.179	0.048	0.156	0.068	2.12	0.1213	0.3148	0.2261	0.0778
SD	0.043	0.021	0.055	0.021	0.042	0.020	5.57	0.0040	0.0034	0.8247	0.0009
Median	0.158	0.075	0.172	0.049	0.150	0.068	1.91	0.1489	0.3471	0.2446	0.0955
Maximum	0.282	0.102	0.352	0.107	0.276	0.100	7.91	0.0004	0.0009	0.5716	0.0001
Minimal	0.094	0.060	0.089	0.040	0.086	0.051	1.02	0.3609	0.6664	0.1567	0.7606
Max-min	0.188	0.077	0.263	0.114	0.190	0.078	11.80	0.0000	0.0000	0.8269	0.0000

CPR=cerebro-placental ratio, LSD=least significant difference, SD=standard deviation, F=test function value, max-min=difference between maximum and minimal value of T/QRS ratio. P-values >0.05 are statistically significant and they are marked in bold.

and differences between maximum and minimal values, the regression line descends in the healthy controls and the IUGR group with normal CPRs, but rises sharply in the IUGR group with reduced CPRs, while for the mean, median, and minimal values and for the standard deviation all the regression lines rise slightly. As an example of this trend, a two-dimensional regression equation (the difference between maximum and minimal values of the T/QRS ratio vs. gestational age) for each study group is shown in Figure 1.

Results of linear regression equations describing the difference between maximum and minimal values of the T/QRS ratio with a function of gestational age calculated for each study group are presented in Table 3.

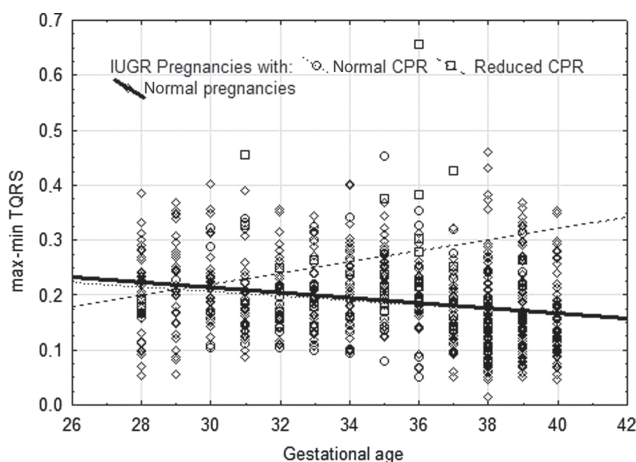


Figure 1: Scatter plots of the difference between maximum and minimal values of T/QRS ratio in consecutive gestational weeks. The regression lines are marked separately for each study group.

*IUGR=intrauterine growth restriction, CPR=cerebroplacental ratio, GA=gestational age.

Discussion

Prenatal Doppler velocimetry aids in assessment of fetal well-being and in identifying fetuses with a higher risk of possible antenatal and postnatal complications. The CPR contains information of both placental status coming from measurements in the UA and fetal status coming from measurements in the MCA. It helps clinicians to predict adverse outcomes and informs them if fetal brain sparing effect has set in [11].

In a state of chronic hypoxia, the fetus tends to protect vital organs for survival, which can be seen in Doppler measurement as preferential blood flow to the brain and myocardium. Acute hypoxia can be seen in ECG. This state during labor is well documented and researchers reported many abnormalities encompassing the changes in ECG intervals and segments [16, 17, 24].

Ranges of T/QRS values were assessed in the study conducted on the animal model. Normal values were lower than 0.3. Under induced hypoxia, the mean T/QRS values ranged between 0.17 and 0.59, returning to normal after the hypoxia resolved [19]. In human fetuses, the reference T/QRS values have only been determined intrapartum. The changes in T/QRS ratios observed during labor are associated with the increasing T-wave amplitude [22]. The use of fetal ECG for intrapartum fetal monitoring was assessed on cases of high-risk pregnancies. The T/QRS values ranging between 0.05 and 0.24 were regarded as normal, 0.24 and 0.5 as raised, and over 0.5 as abnormal [25]. In the present study, mean maximum values exceeded cut-off levels of normal values. In the group of IUGR pregnancies with reduced CPRs, it amounted to 0.352 and was significantly higher than in both other groups.

Both fetal ECG and Doppler velocimetry can be helpful in the timing of delivery, however, there are no guidelines

Table 3: Results of linear regression equation describing variables of T/QRS ratio with a function of gestational age calculated for the study groups.

Coefficient	Coefficient b	SE b	t	P	-95% CI	+95% CI	Beta (β)	SE β	-95% CI	+95% CI
Mean values of T/QRS ratio										
IUGR pregnancies with normal CPR										
b_0	0.161425	0.089054	1.812659	0.072662	-0.015096	0.337946				
b_{GA}	0.000092	0.002571	0.035648	0.971629	-0.005005	0.005189	0.003	0.096	-0.187	0.194
IUGR pregnancies with reduced CPR										
b_0	0.082441	0.116778	0.705970	0.486254	-0.157166	0.322049				
b_{GA}	0.002815	0.003393	0.829673	0.414000	-0.004147	0.009778	0.158	0.190	-0.232	0.548
Normal pregnancies										
b_0	0.201213	0.025985	7.74342	0.000000	0.150170	0.252255				
b_{GA}	-0.001292	0.000736	-1.75560	0.079717	-0.002738	0.000154	-0.075	0.043	-0.159	0.009
Median values of T/QRS ratio										
IUGR pregnancies with normal CPR										
b_0	0.143089	0.088628	1.614476	0.109342	-0.032588	0.318766				
b_{GA}	0.000446	0.002559	0.174211	0.862026	-0.004627	0.005518	0.017	0.096	-0.174	0.207
IUGR pregnancies with reduced CPR										
b_0	0.077689	0.117864	0.659146	0.515385	-0.164147	0.319526				
b_{GA}	0.002745	0.003425	0.801553	0.429810	-0.004282	0.009773	0.152	0.190	-0.238	0.543
Normal pregnancies										
b_0	0.186690	0.025759	7.24743	0.000000	0.136090	0.237289				
b_{GA}	-0.001041	0.000730	-1.42648	0.154300	-0.002474	0.000392	-0.061	0.042	-0.145	0.023
Minimal values of T/QRS ratio										
IUGR pregnancies with normal CPR										
b_0	0.078267	0.070532	1.109672	0.269605	-0.061539	0.218074				
b_{GA}	0.000459	0.002037	0.225351	0.822132	-0.003578	0.004496	0.022	0.096	-0.169	0.212
IUGR pregnancies with reduced CPR										
b_0	-0.017481	0.095039	-0.183932	0.855441	-0.212485	0.177523				
b_{GA}	0.003115	0.002762	1.127807	0.269324	-0.002552	0.008781	0.212	0.188	-0.174	0.598
Normal pregnancies										
b_0	0.082207	0.019645	4.184648	0.000033	0.043618	0.120796				
b_{GA}	0.000118	0.000556	0.211358	0.832687	-0.000975	0.001211	0.009	0.042	-0.075	0.093
Maximum values of T/QRS ratio										
IUGR pregnancies with normal CPR										
b_0	0.404799	0.119113	3.39846	0.000950	0.168697	0.640901				
b_{GA}	-0.003554	0.003439	-1.03332	0.303764	-0.010371	0.003263	-0.099	0.096	-0.289	0.090
IUGR pregnancies with reduced CPR										
b_0	-0.100127	0.246104	-0.406849	0.687326	-0.605090	0.404836				
b_{GA}	0.013189	0.007151	1.844226	0.076150	-0.001485	0.027862	0.334	0.181	-0.038	0.707
Normal pregnancies										
b_0	0.435131	0.037604	11.57135	0.000000	0.361265	0.508998				
b_{GA}	-0.004531	0.001065	-4.25380	0.000025	-0.006624	-0.002439	-0.179	0.042	-0.262	-0.096
Difference between maximum and minimal values of T/QRS ratio										
IUGR pregnancies with normal CPR										
b_0	0.326532	0.089282	3.65730	0.000396	0.149559	0.503504				
b_{GA}	-0.004013	0.002578	-1.55659	0.122494	-0.009123	0.001097	-0.148	0.095	-0.337	0.041
IUGR pregnancies with reduced CPR										
b_0	-0.082646	0.269776	-0.306352	0.761687	-0.636180	0.470888				
b_{GA}	0.010074	0.007839	1.285087	0.209677	-0.006011	0.026159	0.240	0.187	-0.143	0.623
Normal pregnancies										
b_0	0.352924	0.029038	12.15385	0.000000	0.295884	0.409964				
b_{GA}	-0.004649	0.000823	-5.65165	0.000000	-0.006265	-0.003033	-0.235	0.042	-0.317	-0.153

SE=standard error, t=test value, P=probability, CI=confidence interval, β =standardized coefficient, -95%/+95%=confidence borders, IUGR=intrauterine growth restriction, CPR=cerebroplacental ratio. b_0 , b_{GA} =regression coefficients. P-values <0.05 are statistically significant and they are marked in bold.

addressing this problem in pregnancies complicated by IUGR. The decisions are made individually mostly based on changes observed in fetal heart rate recordings and flow measurement in fetal vessels. Ferrazzi et al. showed that worsened flow in the UA and persistent dilatation of the MCA are present in more than 50% of fetuses 2–3 weeks prior to any changes in the fetal heart rate tracings [9]. In view of this fact, searching for additional non-invasive methods of assessment of fetal well-being in pregnancies complicated by IUGR is important. The present study of fetal ECG changes and variability in T/QRS ratios provides insight into abnormalities that occur in fetal compartment during chronic hypoxia. To my knowledge, there is no analysis of T/QRS ratio variations in pregnancies complicated by IUGR in the studies performed by other researchers.

According to the results obtained by Rizzo et al. in pregnancies complicated by IUGR, the flow of correctly oxygenated blood to the fetus is impaired. Chronic fetal exposure to stress and hypoxia causes blood redistribution in the vascular bed of the affected fetus, abnormal filling of the chambers of the heart, as well as changes in the atrio-ventricular gradient. In addition, polycythemia, which often occurs in IUGR fetuses, causes an additional increase in cardiac preload due to increased blood viscosity [26]. All being said, the factors are in line with research results that may indicate an increase in the oxygen deficit in the heart muscle of the IUGR fetuses with reduced CRPs. The increase in the maximum values of the T/QRS ratio with advancement of pregnancy indicated deterioration of intrauterine environment and fetal well-being.

In addition, as shown by the studies on the fetal heart physiology, the fetal heart muscle consumes much less oxygen than the adult heart muscle to cause contraction of the same strength [27]. Fetal myocardial cells are immature and have better tolerance to hypoxia [28]. Moreover, it was proved on animal models that in cases of acute hypoxemia, oxygen consumption decreased by 10%, and during chronic hypoxia as well as IUGR, the decrease is even greater, dropping by 20% [8, 11]. This reflects fetus transition to the so-called energy saving status. Studies on the animal model have shown that in such cases various degrees of hypoxia occur with or without the presence of mild metabolic acidosis [29]. Moreover, the fetus reduces the consumption of oxygen by decreasing breathing activity and body movements [12, 30]. The degree of reduction of the above variables is related to the severity of IUGR.

All the mentioned factors make it difficult to analyze and differentiate the groups of IUGR pregnancies according to weeks of pregnancy. Many studies include cases with growth retardation with a slightly reduced amount

of amniotic fluid and a brain sparing effect, as well as cases with oligohydramnion, extreme growth retardation, and the beginnings of fetal cardiac decompensation. A strength of the present study is the well-defined criteria used for diagnosis of IUGR. The study group included patients with asymmetric fetal growth type 2 as a result of impaired function of the placenta. Fetuses included in the study weighed less than the fifth percentile of the normal population. These criteria gave a fairly homogeneous group of IUGR fetuses. Moreover, the IUGR group was divided into two subgroups: IUGR fetuses without selective redistribution of blood flow (normal CPR) and IUGR fetuses with brain sparing effect (reduced CPR). However, in the published literature there is no data regarding potential differences between the two groups of IUGR fetuses.

Results of the present study show that in pregnancies complicated by IUGR with reduced CPRs, the T/QRS ratio had higher maximum values compared to physiological pregnancies and early stages of IUGR. The obtained results confirm that in the IUGR group of fetuses with reduced CPRs, a large reduction of oxygen blood concentration occurs that results in increased values of the T/QRS ratio worsening with advancement of pregnancy. This is in line with the conclusions of a study conducted by Rosen et al. that revealed the relationship between T/QRS values and the pH of umbilical blood sampled during labor [15]. The increased T/QRS ratio in IUGR fetuses can be an additional non-invasive parameter describing intrauterine fetal well-being, especially in cases in which abilities of reducing oxygen consumption by the fetal heart muscle are close to its limit.

A limitation of this study is that the number of IUGR pregnancies was relatively small in comparison to the healthy control group.

Future studies are needed to determine typical ranges for physiological pregnancies and pregnancies complicated by IUGR as well as for different stages of IUGR. In conclusion, T/QRS ratio in IUGR fetuses can be an additional non-invasive parameter describing intrauterine fetal well-being.

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