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Biophysical and Biochemical Assessment of Fetal Perinatal Hypoxia

Biofizyczne i biochemiczne metody oceny okołoporodowego niedotlenienia płodu

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Abstract

Background. Fetal monitoring based only on cardiotocography has caused an increase in the number of caesarian sections and vaginal procedures (vacuum, forceps). This raises the need of verifying cardiotocographic patterns and fetal monitoring during labor by means of fetal pulse oximetry. Reliable neonatal assessment after labor, including verification of the commonly used Apgar score, by measuring acid-base parameters (pH, pCO_2, pO_2, BE) and biochemical markers for hypoxia (troponin I) in umbilical cord blood is extremely important from both a medical and a legal point of view.

Objectives. The aim was to evaluate the simultaneous application of fetal pulse oximetry and cardiotocography in fetal monitoring during labor and to verify neonatal assessment according to the Apgar scale by means of acid-base parameter analysis and troponin I assay in umbilical cord blood.

Material and Methods. In 21 women in labor, fetal oxygen saturation ($FSpO_2$) was measured using the Nellcor Puritan N-400 pulse oximeter. Fetal heart rate, uterine contractile activity, and fetal oxygen saturation were simultaneously recorded using the MONAKO computer system for fetal monitoring. The cardiotocographic patterns were analyzed according to Melchior's classification. After labor, blood samples from umbilical vessels were collected and acid-base parameters and troponin I were assayed. Clinical neonatal assessment according to the Apgar scale was performed.

Results. Correlation between fetal blood oxygen saturation and the acid-base parameters of umbilical cord blood was not observed except for the base-excess value in the umbilical artery blood, which demonstrated a positive trend towards statistical significance ($r = 0.44$, $p = 0.0513$). The normal $FSpO_2$ values recorded in this study correlated with acid-base parameters values, not indicating hypoxia. Correlation between mean fetal blood oxygen saturation and Apgar score and troponin I concentration in umbilical vein blood was not observed. Worth noting is that the normal $FSpO_2$ values corresponded with a very good clinical condition of the neonate and troponin I values below the reference line (< 0.35 ng/ml) for fetal hypoxia. Moreover, correlation between troponin I concentrations and pH values in umbilical cord blood, which in this study did not indicate hypoxia, was not observed. No correlation was found between $FSpO_2$ values, acid-base parameters, and the chosen types of cardiotocographic patterns according to Melchior's classification.

Conclusions. Application of fetal pulse oximetry together with cardiotopographic pattern analysis in assessing fetal hypoxia during labor should become a standard of obstetric care. Clinical neonatal assessment according to the Apgar scale should by verified by means of acid-base parameters and troponin I measurement in the umbilical cord blood (**Adv Clin Exp Med 2007, 16, 2, 249–255**).

Key words: fetal pulse oximetry, fetal hypoxia, acid base balance, Apgar score.

Streszczenie

Wprowadzenie. Ocena dobrostanu płodu za pomocą zapisu kardiotokograficznego przyczyniła się do zwiększenia liczby wykonywanych cięć cesarskich oraz zabiegów pochwowych (próżniociąg, kleszcze). W związku z tym jest konieczna weryfikacja zapisów KTG oraz monitorowanie stanu płodu podczas porodu za pomocą pulsoksymetrii. Niezwykle istotna zarówno ze względów medycznych, jak i prawnych jest wiarygodna ocena stanu noworodka po przebytym porodzie i weryfikacja powszechnie stosowanej skali Apgar za pomocą wskaźników równowagi kwasowo-zasadowej (pH, pO_2, pCO_2, BE) oraz biochemicznych markerów niedotlenienia płodu (troponina I) we krwi pobranej z naczyń pępowinowych.

Cel pracy. Ocena jednoczesnego zastosowania pulsoksymetrii i kardiotokografii w monitorowaniu płodu podczas porodu oraz weryfikacja stanu noworodka ocenianego wg skali Apgar za pomocą analizy wskaźników równowagi kwasowo-zasadowej oraz stężenia troponiny I we krwi pobranej z naczyń pępowinowych
Materiał i metody. Analizę utlenowania krwi płodowej u 21 rodzących przeprowadzono za pomocą pulsoskymetru firmy Nellcor Puritan N-400. Akcję serca płodu, czynność skurczową macicy, wysycenie tlenem krwi płodowej analizowano jednocześnie z zastosowaniem komputerowego systemu nadzoru okołoporodowego – MONAKO. Analiza zapisu kardiotokograficznego została przeprowadzona wg klasyfikacji Melchiora. Po porodzie pobierano krew z naczyń pępowinowych w celu oznaczenia wskaźników równowagi kwasowo-zasadowej i stężenia troponiny I oraz oceniano stan kliniczny noworodków za pomocą skali Apgar.
Wyniki. Nie zaobserwowano korelacji między wysyceniem tlenem krwi płodowej a wskaźnikami równowagi kwasowo-zasadowej we krwi pobranej z naczyń pępowinowych z wyjątkiem niedoboru zasad w tętnicy pępowinowej, gdzie istniał trend dodatni ($r = 0,44$; $p = 0,0513$). Otrzymane prawidłowe wysycenie tlenem krwi płodowej odpowiadało wskaźnikom równowagi kwasowo-zasadowej, które nie wskazywały na niedotlenienie. Nie zaobserwowano korelacji między średnią wartością saturacji a stanem noworodka wg skali Apgar oraz stężeniem troponiny I we krwi pobranej z żyły pępowinowej. Należy jednak podkreślić, że prawidłowe wysycenie tlenem krwi płodowej odpowiadało bardzo dobremu stanowi klinicznemu noworodka oraz wartościom troponiny poniżej linii odcięcia charakterystycznej dla niedotlenienia płodu (< 0,35 ng/ml). Podobnie nie stwierdzono korelacji między stężeniem troponiny a wartościami pH we krwi z naczyń pępowinowych, które w badaniach własnych nie wskazywały na niedotlenienie. Nie wykazano korelacji między wysyceniem tlenem krwi płodowej oraz wskaźnikami równowagi kwasowo-zasadowej a wybranymi typami zapisu KTG wg Melchiora.
Wnioski. Ocena niedotlenienia płodu podczas porodu za pomocą pulsoksymetrii połączonej z jednoczesną analizą zapisu kardiotokograficznego powinna być standardem postępowania położniczego. Ocena stanu klinicznego noworodka za pomocą skali Apgar wymaga weryfikacji z zastosowaniem wskaźników równowagi kwasowo-zasadowej oraz stężenia troponiny I we krwi pobranej z naczyń pępowinowych (**Adv Clin Exp Med 2007, 16, 2, 249–255**).

Słowa kluczowe: pulsoksymetria płodowa, niedotlenienie płodu, równowaga kwasowo-zasadowa, skala Apgar.

Despite the huge recent progress in perinatal medicine, finding objective methods of fetal monitoring during labor and establishing credible criteria for hypoxia assessment in the neonate remain major problems of obstetrics. Cardiotocography, commonly used in Poland, has contributed only to a reduction in the infant mortality and morbidity in a narrow group of monitored women in labor. Fetal condition assessment based only on cardiotocography has caused an increase in the number of Caesarian sections and vaginal procedures dangerous both for mother and child due to incorrect diagnosis of intrauterine fetal asphyxia. Normal cardiotocographic patterns confirm fetal well-being; however, in the event of pathological patterns the probability of fetal hypoxia is below 50% [1].

Fetal pulse oximetry, based on the measurement of oxygen saturation in fetal blood, is a non-invasive method allowing, among others, verification of pathological cardiotocographic patterns. An undeniable advantage of pulse oximetry is the detection of fetal hypoxia at a very early stage, before anaerobic metabolism appears, i.e. before the formation of organic acids and before central nervous system and myocardial damage begins.

A reliable assessment of the neonatal condition is extremely important and it summarizes the obstetric conduct during labor. The Apgar scale, commonly used for this purpose, is a quick and simple method of neonatal clinical assessment, although despite its numerous practical advantages there are many studies critically appraising its value regarding the detection of anoxia and acidosis [2]. Therefore it seems worthwhile to measure acid-base parameters in umbilical cord blood and biochemical markers for hypoxia of individual fetal organs, i.e. troponin I, troponin T, endothelin, S-100 protein, creatine kinase (CK) and its isoenzymes (CK-MB, CK-BB), alanine and aspartate aminotraspherase, lactate dehydrogenase, and creatinine [3–9].

Material and Methods

The study was carried out in 2006 at the Department of Human Reproduction and Obstetrics of Silesian Piasts University of Medicine in Wrocław and covered 21 women in labor (between the 38th and 42nd pregnancy week). Fetal oxygen saturation was measured using the Nellcor Puritan N-400 pulse oximeter and the FS-14 C fetal oxisensor placed on the fetal cheek area. Analysis of the mean fetal blood oxygen saturation ($FSpO_2$) was performed during the last 30 min of the second stage of labor. The women included in the study were diagnosed as not having any contraindications for this kind of monitoring, i.e. abnormal fetal presentation, uterine malformation, threat of intrauterine infection, vaginal bleeding due to placental pathology (placenta praevia, premature detachment of the placenta), placenta praevia without clinical symptoms, or lack of patient

consent. The main criteria for placing the fetal oxisensor included: ruptured membranes – lack of the inferior pole of the amniotic sac, complete cervical dilation, cephalic presentation in single pregnancy, and fixation of the fetal head in the pelvic inlet.

Fetal heart rate, contractile activity of the uterus, and fetal oxygen saturation were simultaneously recorded using a Hewlett-Packard Cardiotocograph and the MONAKO computer system for fetal monitoring. The cardiotocographic patterns were analyzed according to the five types of fetal heart rate patterns in the second stage of labor derived from Melchior [10], these being type 0: normal pattern of fetal heart rate (FHR), type 1: normal baseline FHR with decelerations and subsequent return to baseline level, type 2: rapid decrease in the baseline FHR resulting in prolonged bradycardia, type 3: onset of accelerations during each contraction while the baseline FHR is decreased to the level of bradycardia, and type 4: initially, the FHR remains normal (single decelerations may occur) and later FHR decreases, resulting in prolonged bradycardia.

After the birth, blood samples from the umbilical vessels (artery, vein) were collected at omphalotomy via puncture and spontaneous suction using standard heparinized capillaries. The gasometric measurements were carried out indirectly after blood sample collection using a Ciba Corning 248 Blood Gas Analyzer. Moreover, in the blood samples collected from the umbilical vein after omphalotomy the troponion I concentration was assayed by the immunoenzymatic method at the Laboratory of Biochemistry of Public Clinical Hospital No. 1 in Wroclaw. The neonates' conditions were assessed clinically according to the Apgar score in the first and fifth minutes after birth.

The results of the study underwent statistical analysis. For each parameter the mean, median, and standard deviation were calculated. Statistical significance between the means for different groups was calculated by the non-parametrical Wilcoxon signed rank test (because the number of cases was too small to use parametrical tests). Analysis of $FSpO_2$% in relation to other parameters was undertaken using Spearman correlation. A p value of less than 0.05 was required to reject the null hypothesis. Statistical analysis was performed using the EPIINFO Ver. 3.2 (04-02-2004) software package.

Results

One woman whose second stage of labor lasted less than 30 min and who showed a significant loss of recorded signal was excluded from the studied group. The mean time of pregnancy duration among the remaining 20 women was (mean ± *SD*) 39.9 ± 0.1 weeks, their mean age was 29.6 ± 0.1 years, and the mean fetal weight was 3420 ± 289.7 g. Primiparas made up 35% and multiparas 65% of the studied group. Fourteen women delivered spontaneously and in 6 cases Cesarean section was performed.

The mean fetal blood oxygen saturation ($FSpO_2$) during the last 30 min of the second stage was 43.6% and the mean loss of signal was 40.1 ± 19.3%. The smallest $FSpO_2$ value was 31.5% and the largest 57.2%. The mean value of troponin I concentration in umbilical vein blood was 0.06 ±

Table 1. Characteristics of the studied group

Tabela 1. Charakterystyka badanej grupy

		Mean (Średnia)	*SD*	Range (Zakres)
Age – years (Wiek – lata)		29.55	5.443248	19–41
Pregnancy duration – weeks (Czas trwania ciąży – tygodnie)		39.95	0.998683	38–42
Parity (Rództwo)	*primigravida*	13	–	–
	multigravida	7	–	–
$FSpO_2$		43.575	8.586089	31.5–57.2
Loss of signal – % (Utrata sygnału – %)		40.13	19.32778	9.1–70.6
Troponin I concentration – ng/ml (Stężenie troponiny I – ng/ml)		0.0565	0.171841	0.01–0.78
Fetal weight – g (Masa urodzeniowa płodu – g)		3420.5	289.6727	2950–4040

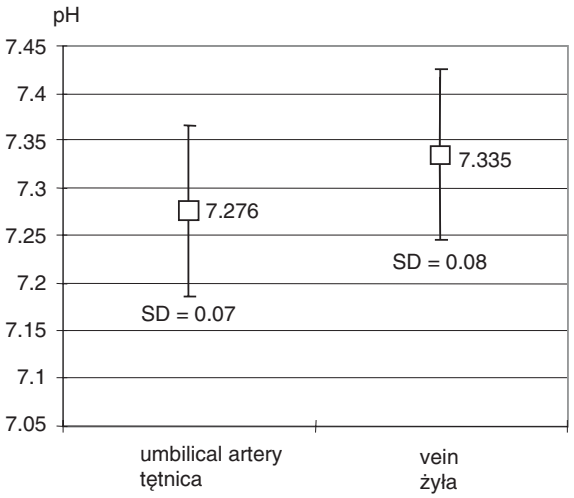

Fig. 1. The mean pH values in the umbilical artery and vein

Ryc. 1. Średnie wartości pH w tętnicy i żyle pępowinowej

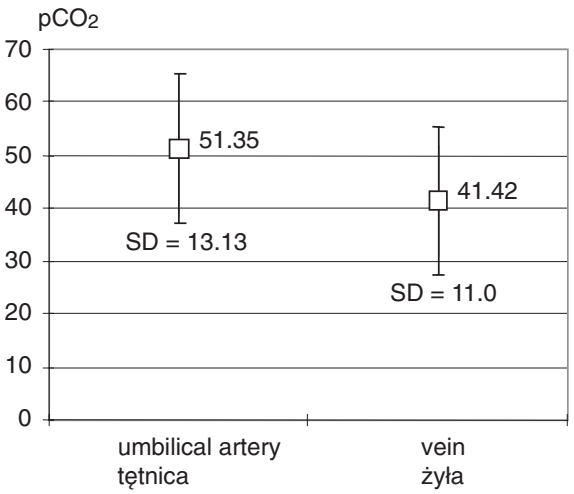

Fig. 2. The mean pCO_2 values in the umbilical artery and vein

Ryc. 2. Średnie wartości pCO_2 w tętnicy i żyle pępowinowej

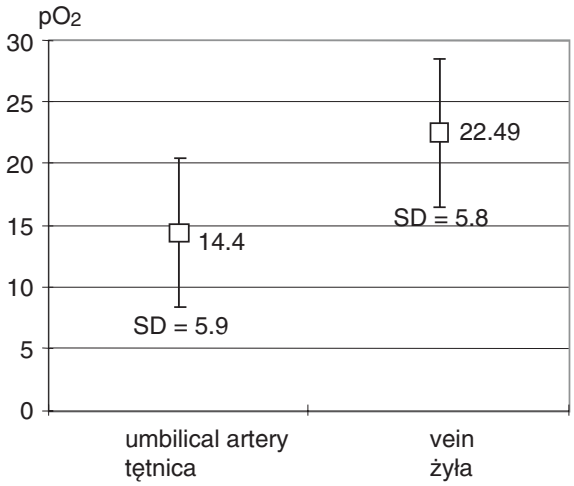

Fig. 3. The mean pO_2 values in the umbilical artery and vein

Ryc. 3. Średnie wartości pO_2 w tętnicy i żyle pępowinowej

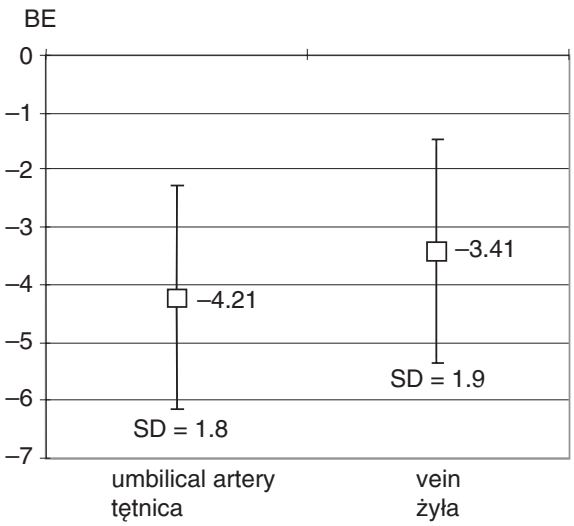

Fig. 4. The mean BE values in the umbilical artery and vein

Ryc. 4. Średnie wartości BE w tętnicy i żyle pępowinowej

0.2 ng/ml (Tab. 1). Figs. 1–4 show the selected acid-base parameters (pH, pCO_2, pO_2, BE) measured in venous blood collected from the umbilical artery and arterial blood collected from the umbilical vein.

The statistical analysis revealed no correlation between $FSpO_2$ values recorded during the last 30 min of the second stage of labor and the acid-base parameters values (pH, pCO_2, pO_2, BE) in the umbilical vein blood. Similarly, no statistical correlation was noted between the acid-base parameter values in the umbilical artery blood (pH, pCO_2, pO_2) and the mean $FSpO_2$ values except for base excess (BE), which revealed a positive trend towards statistical significance (r = 0.44, p = 0.0513). The normal mean $FSpO_2$ values in the last 30 min of the second stage of labor recorded in this study corresponded with the normal acid-base parameter values in venous (umbilical artery) and arterial (umbilical vein) blood, both those recorded in this study and those presented in literature.

Tab. 2 shows the mean values of pH, pCO_2, pO_2, and BE in the blood from the umbilical artery and vein, the mean fetal blood oxygen saturation ($FSpO_2$), the mean troponin I concentration in the umbilical vein blood, and the neonatal clinical assessment in the first and fifth minutes after birth according to the Apgar scale in relation to Melchior's classification of cardiotocographic patterns. This study revealed no correlation between

Table 2. The mean values of pH, pCO_2, pO_2, BE in the umbilical artery (UA) and vein (UV), mean fetal blood oxygen saturation ($FSpO_2$), mean troponin I concentration in the umbilical vein blood, and the neonatal clinical assessment according to the Apgar scale in relation to Melchior's classification of cardiotocographic patterns

Tabela 2. Odniesienie średnich wartości pH, pO_2, pCO_2, BE w tętnicy (UA) i żyle (UV) pępowinowej, wysycenia tlenem krwi płodowej (FSpO2), stężenia troponiny I w żyle pępowinowej oraz stanu noworodka wg skali Apgar do klasyfikacji zapisu kardiotokograficznego wg Melchiora

Mean values (Wartości średnie)		Type 0 (Melchior) n = 7	Type 1 (Melchior) n = 9	Type 2 (Melchior) n = 4
UA pH		7.27 ± 0.08	7.27 ± 0.08	7.29 ± 0.03
UA pCO_2		53.68 ± 8.43	51.14 ± 17.56	47.72 ± 9.83
UA pO_2		13.57 ± 2.57	14.44 ± 14.44	15.75 ± 4.78
UA BE		–3.54 ± 2.36	–3.36 ± 1.91	–3.3 ± 0.67
UV pH		7.319 ± 0.10	7.34 ± 0.07	7.35 ± 0.05
UV pCO_2		42.78 ± 11.8	42.39 ± 11.3	36.87 ± 7.42
UV pO_2		23.86 ± 2.26	20.75 ± 7.16	24 ± 7.16
UV BE		–5.18 ± 2.44	–3.73 ± 1.70	–3.6 ± 0.77
FSp O_2		41.77 ± 8.57	43.88 ± 8.99	46.05 ± 9.38
Troponin I (Troponina I)		0.12 ± 0.28	0.024 ± 0.03	0.01 ± 0
Apgar scale (Skala Apgar)	1st minute	9.14 ± 1.57	9.78 ± 0.44	9.75 ± 0.5
	5th minute	10 ± 0	10 ± 0	10 ± 0

the mean $FSpO_2$ value and the Apgar score and the troponin I concentration in the umbilical vein blood. However, it should be noted that the normal $FSpO_2$ values corresponded with very good clinical condition of neonates and troponin I values below the reference line (i.e. < 0.35 ng/ml) for fetal hypoxia. Similarly, no correlation was observed between troponin concentration in the umbilical vessels and both the arterial and the venous pH values, which did not indicate fetal hypoxia (pH > 7.2). Moreover, this study revealed no correlation between mean fetal blood oxygen saturation, the selected acid-base parameters, and the types of cardiotocographic patterns according to Melchior's classification.

Discussion

Perinatal fetal hypoxia is the main cause of infant morbidity and mortality and plays a significant role in the child's further development. In the event of hypoxia, the fetus activates compensation mechanisms in order to reduce oxygen consumption and protect important organs. This leads to increased blood flow in the brain, heart, and adrenal glands and to decreased pulmonary, renal, cutaneous, intestinal, splenic, and striated muscle blood supply. In the anaerobic conditions, intensification of glycogenlysis takes place, resulting in acidosis and leading to fetal central nervous system, cardiovascular system, intestinal, and pulmonary damage. Fetal pulse oximetry enables the detection of fetal hypoxia at a very early stage, before the compensation mechanisms appear, i.e. before the formation of organic acids and before central nervous system and myocardial damage begins. In all the cases monitored during the last 30 min of the second stage of labor in the present study, fetal oxygen blood saturation ($FSpO_2$) was more than 30%, which guarantees a sufficient oxygen supply and minimizes the risk of developing metabolic acidosis, according to available literature data [11].

The acid-base parameters in the umbilical artery blood (pH, pCO_2, pO_2, BE) confirm fetal well-being. The measurement of these parameters is generally accepted as the most objective method of postnatal condition assessment [12]. Considering the fact that the condition of the placenta and its ability of metabolic and gas exchange between the mother and fetus influences acid-base parameters in arterial blood from the umbilical vein, these parameters are not quite objective [3]. According to recommendations of the American Academy of Pediatrics, the normal pH value of the umbilical artery blood is 7.19; however, according to some authors, 7.1 is a limit value [13,14]. The mean pH values in arterial and venous blood recorded in the present study were within the normal limits given by Grudzińska et al. for venous blood (pH 7.29–7.43) and arterial blood (pH 7.35–7.45) [15].

According to literature data, in chronic hypoxia the pCO_2 values in the blood from both the

umbilical artery and vein remain within the normal limits or are slightly elevated, while in acute hypoxia they rise rapidly [15]. The mean pCO_2 values in the umbilical artery blood recorded in the present study were similar to those defined as normal by Graczyk et al. (47 ± 9.5) [16] and in the umbilical vein blood they were within the normal limits (40 ± 6.81) presented by other authors [15].

Partial pressure of oxygen (pO_2) in the umbilical blood is 1/3–1/4 lower than in an adult's blood. Normal oxygen saturation in the fetal blood takes place under conditions of low oxygen pressure due to the mixing of oxygenated blood from the placenta and deoxygenated blood from tissues in the fetal circulation. In spite of the lower fetal oxygen saturation, the oxygen supply is sufficient because of the high affinity of fetal hemoglobin to oxygen and the high perfusion of individual organs in relation to their oxygen requirements [12, 16]. The normal pO_2 values in the blood from the umbilical artery and vein recorded in the present study were similar to those presented by Graczyk et al. (15.4 ± 4.4 and 24 ± 6.7 for artery and vein, respectively) [17].

Base excess (BE) is a very sensitive indicator of chronic fetal hypoxia and its assay, even several minutes after hypoxia subsides, indicates metabolic disorders, while pO_2 and pCO_2 values return to the range of normal values [15]. The mean BE values in the umbilical artery blood recorded in the present study were within the normal limits according to literature data, with the limit value below 10 mmol/l [13]. A positive trend was observed here towards statistical significance (r = 0.44, p = 0.0513) between fetal oxygen saturation in the second stage of labor and base excess in umbilical vessels, which might confirm applying BE for indicating fetal hypoxia.

The mean value of normal $FSpO_2$ during the second stage of labor closely corresponded with a high Apgar score, which confirms the usefulness of the Apgar scale in the studied group. However, some authors have drawn attention to some imperfections of this method in assessing the degree of fetal hypoxia during labor [18]. According to literature data, an Apgar score of 7 or more points in the first minute after birth is a generally accepted value indicating fetal well-being [19].

There are a lot of literature data in the field of pediatrics and cardiology concerning the application of troponin I measurement. Troponin I is a very sensitive and specific indicator of even very small areas of myocardial necrosis; however, some authors claim this is disputable, which raises the need for further investigations [20, 21]. Troponin I is not only a sensitive indicator of myocardial necrosis, but also has prognostic value of fetal central nervous system hypoxia. Thus a considerable rise in its concentration (> 4.6 ng/ml) in the umbilical cord blood is an early marker of hypoxic-ischemic encephalopathy and is prognostic for fetal death in full-term pregnancy [21]. Troponin I concentration in the umbilical cord blood rises in fetal hypoxia (the reference value for fetal hypoxia is 0.35 ng/ml) and correlates with the acid-base parameters in the blood from umbilical vessels [22]. The mean value of troponin I concentration of 0.0565 ± 0.17 ng/ml recorded in the present study confirmed the above reference value for fetal hypoxia. According to Trevisanuto et al., troponin I concentration in the umbilical vessels in neonates with an Apgar score of 10 remains equal to 0 ng/ml [23].

A considerable decrease in pH value in the blood from the umbilical vessels in type 1 of Melchior's classification of cardiotocographic patterns and pH decrease below 7.2 in type 2, as previously reported by Cardoso et al. [24], was not observed in the present study. In accordance with the results obtained by Langer et al., it was observed in the present study that in types 0, 1, and 2 of the cardiotocographic patterns in the second stage of labor both $FSpO_2$ (> 30%) and pH (> 7.2) in the umbilical cord blood were within the normal limits [25]. In the present study, neonatal condition assessed according to the Apgar scale in types 0, 1, and 2 of the cardiotocographic patterns was found to be very good (Apgar score of 9–10 points), which corresponds with the results obtained by other authors [25].

The authors conclude that application of fetal pulse oximetry together with cardiotopographic pattern analysis in assessing fetal hypoxia during labor should become a standard of obstetric care. Clinical neonatal assessment according to the Apgar scale should by verified by means of acid-base parameter and troponin I measurement in the umbilical cord blood.

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