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An Analysis of the ST Segment, QRS Complex, and R-R Intervals of Transabdominal Fetal Electrocardiograms in Diabetic Pregnancies*

Analiza fragmentu ST, kompleksu QRS i przedziałów R-R przezbrzusznych elektrokardiogramów płodu u ciężarnych chorych na cukrzycę

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Abstract

Background. Transabdominal fetal electrocardiograms have the same parameters in diabetic and non-diabetic pregnancies if there is no intrauterine growth retardation or congenital heart defects.
Objectives. Many caesarean sections were carried out in the authors' hospital because of unconfirmed non-reassuring fetal heart rate and diabetes mellitus of the mother. To change this they sought a simple, noninvasive, and inexpensive method of verifying fetal well-being.
Material and Methods. Fetal ECG studies of beat-to-beat variability (the exact time intervals between fetal R waves, R-R intervals), ST segment, and QRS complex were carried out in 51 diabetic and 50 healthy pregnant women at the same stage of gestation. The diabetic pregnant women were classified with diabetes class B or C according to White. Fifteen pregnancies were complicated by intrauterine growth retardation syndrome (IUGR). Heart rate dynamics was analyzed by nonlinear mathematics.
Results. Short-time variability of FHR in weeks 34–40 was the same in the diabetic and non-diabetic women (mean: 1.4708 vs. 1.4790) but was lower in diabetic women with IUGR (mean: 1.25213). The transabdominal fetal electrocardiograms performed before labor were normal in the diabetic pregnancies without IUGR and the percentage of caesarean sections performed as a consequence of non-reassuring fetal heart rate in that group (42%) was lower than in the diabetic pregnancies complicated by IUGR (68%) but higher than in the control group (28%).
Conclusions. Nonlinear methods of ECG signal filtration provide a non-invasive method for obtaining the fetal ECG. Careful detection and analysis of an fECG makes it possible to detect threats to the fetus and reduce the number of caesarean sections and premature deliveries in cases of diabetes mellitus class B and C if they are not complicated by IUGR. The transabdominal fECG can also be useful in diagnosing fetal heart diseases (**Adv Clin Exp Med 2008, 17, 6, 643–647**).

Key words: electrocardiogram (ECG), fetal electrocardiogram (fECG), electronic fetal monitoring (EFM), fetal heart rate (FHR), diabetes mellitus, intrauterine growth restriction (IUGR).

Streszczenie

Wprowadzenie. Elektrokardiografia przezbrzuszna u płodu (elektrody umieszczone na brzuchu ciężarnej) po wyizolowaniu sygnału płodu z szumów i zakłóceń pozwala uzyskać zapis płodowego EKG (fECG). Jest to więc metoda nieinwazyjna, która może być stosowana na dowolnym etapie ciąży oraz w czasie trwania ciąży, a nie tylko w czasie porodu. Dzięki zapisowi fEKG można nie tylko wykryć choroby serca płodu, ale również ocenić dobrostan płodu – na podstawie *beat-to-beat variability* (krótkotrwałych zmienności w akcji serca płodu mierzonych jako dokładne odstępy czasowe między kolejnymi załamkami R-R).

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Materiał i metody. Przezbrzuszne fEKG wykonano u 51 ciężarnych chorych na cukrzycę klasy B i C wg White i u 50 zdrowych ciężarnych w tym samym wieku ciążowym, tj. między 34. a 40. tygodniem ciąży.
Wyniki. *Short time variability* było takie samo zarówno u ciężarnych chorych na cukrzycę, jak i ciężarnych zdrowych (średnia 1,4708 i 1,4790), gdy cukrzycy nie towarzyszyło zahamowanie wewnątrzmacicznego wzrostu płodu (IUGR). Jeśli cukrzyca była powikłana IUGR, to *short time variability* było statystycznie niższe (średnia 1,25213; $p < 0,0001$). Ciąże z cukrzycą powikłaną IUGR trwały statystycznie krócej o 11 dni niż ciąże z cukrzycą niepowikłaną IUGR, a wskaźnik cięć cesarskich wykonanych w tej grupie z powodu cukrzycy i wątpliwych zapisów KTG wynosił 68%, w porównaniu z 42% w grupie chorych na cukrzycę bez IUGR i 28% w grupie kontrolnej.
Wnioski. Liczba cięć cesarskich wykonywanych w klinice autorów ze wskazań niepotwierdzonych, wątpliwych zapisów KTG (*unconfirmed nonreassuring fetal heart rate*), zwłaszcza u ciężarnych chorych na cukrzycę klasy B i C, jest bardzo duża. Zastosowanie przezbrzusznego EKG i obliczanie krótkotrwałych zmienności świadczących o dobrostanie płodu pozwoliłyby zmniejszyć liczbę cięć cesarskich w grupie chorych na cukrzycę bez IUGR do podobnego odsetka jak w grupie kontrolnej. Innymi słowy, skoro w grupie kontrolnej liczba cięć cesarskich ze wskazań wynikających z wątpliwych zapisów KTG wynosiła 28%, a w grupie tej krótkotrwałe zmienności były takie same jak w grupie chorych na cukrzycę bez IUGR, to jest prawdopodobne, że z zastosowaniem przezbrzusznego fEKG liczba cięć cesarskich w grupie chorych na cukrzycę bez IUGR mogłaby się zmniejszyć o kilkanaście punktów procentowych. Wszystkie noworodki urodzone w grupie kontrolnej i w grupie chorych na cukrzycę bez IUGR miały w piątej minucie życia więcej niż 8 pkt Apgar i żaden nie miał kwasicy. Przezbrzuszne płodowe EKG daje położnikowi dodatkową informację o stanie płodu i pozwala lepiej zdecydować o czasie i drodze zakończenia ciąży (**Adv Clin Exp Med 2008, 17, 6, 643–647**).

Słowa kluczowe: elektrokardiogram, elektrokardiogram płodu, elektroniczne monitorowanie płodu, częstość rytmu serca płodu, cukrzyca, wewnątrzmaciczne zahamowanie wzrostu płodu.

The fetal electrocardiogram (fECG) has proved to be a promising tool for the detection of fetal heart electrical activity, thus providing obstetricians with tracings that can be useful in the diagnosis of abnormal fetal electric heart activity and, indirectly, fetal well-being [1–3]. There are many studies on acquiring the fetal cardiac signal directly from the fetus (with the electrode attached to the baby's head) and fewer that reconstruct the fetal signal from electrocardiograms which include signals both from the fetus and the mother [4, 5]. The advantage of direct fECG is that it gives a precise quantification of fetal heart rate (FHR) variability as the exact time intervals between fetal R waves (R-R intervals) are easily measured. However, direct monitoring requires special conditions: dilatation of the cervix, vertex presentation, and lack of an amnion, which make this tool of little use during the antepartum period. Indirect fECG (transabdominal fECG), in contrast, is a noninvasive method, safer and less expensive, and may be used at any time during the pregnancy [4, 5]. The difficulty is that the transabdominal fetal heart signal is very weak compared with the maternal signal and there are many sources of interference, noise, and baseline fluctuation. Consequently, the main problem with this method is how to remove noise, level the baseline fluctuation, and isolate the fetal signal from the mother's waveforms. The aim of the current study was to estimate fetal heart rate variability, the ST segment, and the QRS complex in diabetic and healthy pregnancies and to establish their importance in obstetricians' decision making. The caesarean section (CS) ratio is very high in this hospital, which manages pregnancies complicated by diabetes mellitus from the whole region of Lower Silesia.

Material and Methods

Transabdominal fECG tracings from 51 singleton diabetic pregnancies between the 34 and 40 gestational weeks were selected. According to the White classification there were 31 pregnancies with class B and 20 with class C diabetes (class B: insulin dependent before pregnancy, onset after the age of 20 years, duration less than 10 years; class C: insulin dependent before pregnancy, age of onset 10–20 years, duration 10–20 years). Of these, 50 fetuses were in cephalic presentation and only 1 was in pelvic presentation. Of the 51 diabetic pregnancies, 15 were complicated by IUGR. The control group consisted of 50 uncomplicated (healthy) singleton pregnancies of the same gestational age (women who reported for routine periodic obstetric control). For both groups, only pregnant women without heart disease were selected.

An As Card B56 Aspel (Poland) device, modified with the permission of the producer, was used to record the ECG signal. The signal came from electrodes placed on the mother's abdomen (at the level of fundus uteri on the side of the fetal vertebral column) and limbs. The recording was carried out for 60 minutes and the results were saved on disk. The recording time had to be so long so that a sufficient number of QRS complexes, necessary for checking the validity of the mathematical method, could be obtained. Obtaining a clear fECG is complicated by non-cardiological noise from the maternal signal and by the disproportion between the amplitudes and frequencies of the maternal and fetal signals. Consequently, filtration must proceed in steps. As the first step, the fECG signal is treated as a factor distorting the maternal

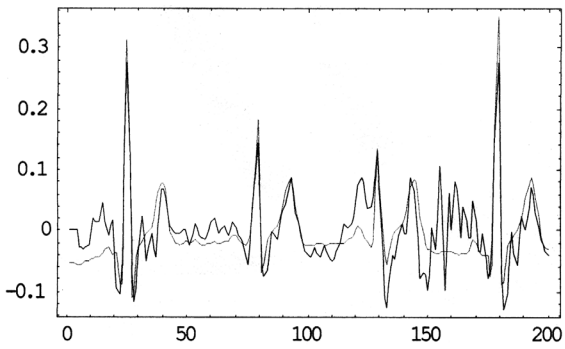

Fig. 1. Fetal ECG signal before and after filtering (according to K. Wilińska)

Ryc. 1. Zapis płodowego EKG przed i po przefiltrowaniu (wg K. Wilińskiej)

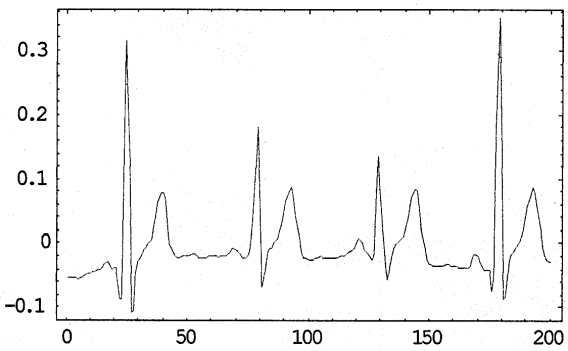

Fig. 3. Fetal signal (according to K. Wilińska)

Ryc. 3. Zapis sygnału pochodzącego od płodu (wg K. Wilińskiej)

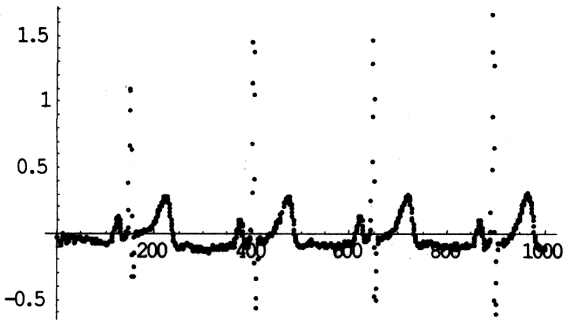

Fig. 2. Maternal signal (according to K. Wilińska)

Ryc. 2. Zapis sygnału pochodzącego od matki (wg K. Wilińskiej)

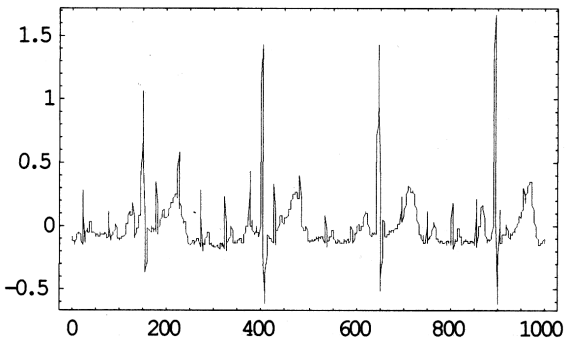

Fig. 4. A synthetic combination of the maternal and fetal signals (according to K. Wilińska)

Ryc. 4. Nałożenie sygnału pochodzącego od matki i płodu (wg K. Wilińskiej)

ECG signal. To level the baseline fluctuation and remove noise, wavelet-based multiresolution analysis (MRA) was used. Identification of the observed waveforms as coming from the fetus was done with the Lipschitz exponential method [6]. Beat-to-beat or short-term variability represents fast changes in heart rate. Variability in beats per minute is defined as the absolute value of the difference between two successive beat-to-beat heart rate determinations (R-R) [7].

Results

A total of 101 antepartum transabdominal fECG studies were used for the analysis of short-term variability (R-R intervals), the ST segment, and the QRS complex. In this study, the ST segment was unchanged in all pregnancies in the "diabetic without IUGR" group (n = 36) and in the non-diabetic control group (n = 50). There was no elevation of the ST segment. There were no differences (neither in duration nor amplitude) between the QRS complexes in the two groups. In the "diabetic with IUGR" group (n = 15), the ST segment was elevated in two cases, but the amplitudes and durations of the QRS complexes did not change compared with the control group. The variability in the non-IUGR diabetic group (mean ± *SD*) was 1.4708 ± 0.0895 and in the control group 1.4790 ± 0.0509 (p = = 0.5930, i.e. not statistically significant). All 86 (36 + 50) women delivered children in good condition. All the newborns had an Apgar score in 5 minutes of no less than 8 and none had metabolic acidosis. The variability of the fetal heart rate in the diabetic pregnancies with IUGR was lower than in diabetic pregnancies without IUGR (mean: 1.25213 ± ± 0.08949, $p < 0.0001$, i.e. statistically significant). The pregnancies with diabetes mellitus complicated by IUGR terminated on average 11 days earlier than the non-IUGR diabetic pregnancies and in 6 of them the children had less than 8 points in 5 minutes. The incidence of CS performed as a result of non-reassuring fetal heart rate in the non-IUGR diabetic group was 42%, in the IUGR diabetic group 68%, and in the control group 28%.

Many caesarean sections in the present

authors' hospital are carried out as a result of unconfirmed non-reassuring fetal heart rate (FHR) tracings in electronic fetal monitoring (EFM). Many hospitals in Poland do not have any other diagnostic means apart from standard CTG and USG. Diabetic pregnancies of classes B and C are terminated by caesarean section 2–4 weeks before the expected time of delivery. The fECG gives the obstetrician additional information about fetal well-being and enables making a more informed decision about the time and route of delivery.

Discussion

Visual interpretation of electronic fetal heart rate monitoring (EFM) is often inaccurate due to differences between observers and between the readings of the same observer on different occasions. This may lead to unnecessary surgical interventions or to children being born with a low Apgar score [8, 9]. This is why obstetricians are still looking for a tool allowing them to assess with greater precision the well-being of the fetus during labor and pregnancy. Fetal ECG assessment has become such a new tool. The method used most often consists of assessing the ST segment of the fetal ECG. Automatic ST analysis (STAN) has improved perinatal outcomes, reduced the incidence of metabolic acidosis in newborns, and even reduced the number of neonatal encephalopathies [10–14]. However, there are also reports of a poor positive value of ST segment analysis [15]. In spite of this, the data related to ST segment analysis seem promising. It has also been shown that short-term variability is important for the assessment of fetal well-being [12, 16, 17]. Especially important for obstetrics is the transabdominal fECG because it is safer and can be carried out when the amniotic fluid is still present.

In the present study the QRS complex, ST segment, and R-R intervals were observed. The lower variability in diabetic pregnancies with IUGR is probably connected not only with oxygenation, but may also depend on serum leptin levels or general hormonal status [18]. It is not certain if it was fECG monitoring alone that was behind many obstetricians' decisions not to perform CS, because the percentage of CSs in diabetic pregnancies in this hospital is generally higher than in the group of the present study. The additional fECG monitoring made it possible to reduce the number of CSs in the diabetic group.

The excessive number of CSs in pregnancies complicated by class B and C diabetes results from over-caution on the part of obstetricians concerned with the well-being of the fetus in the absence of more precise diagnostic methods. The dramatic increase in the CS rate in Poland is also due to the lack of proper legal regulations protecting obstetricians from malpractice charges whenever they refuse to carry out a CS at the patient's request. Most patients and, interestingly, most obstetricians serving as expert witnesses (often not actively involved in treating diabetes in pregnancy) believe that diabetes is in itself an indication for caesarean section. The results of the present study suggest that short-time variability in normal fetal heart rate may mean that the risk of fetal distress syndrome is low, regardless of whether the pregnant woman is diabetic or not. The transabdominal fECG is a non-invasive method which may be performed at any stage of pregnancy and which allows obstetricians to alter their decision about a caesarean section in case of unconfirmed non-reassuring fetal heart rate.

The authors concluded that transabdominal fECG in diabetic pregnant women makes it possible to reduce the number of caesarean sections with no harm to newborns. Normal short-time variability in fetal heart rate obtained from an fECG, an unchanged ST segment, and regularity of the QRS complex in diabetic pregnant women allow the obstetrician to decide on natural labor (in the absence of other contraindications). The analysis of fECGs in pregnancies with IUGR should make it possible to establish a connection between the changes in fECG and this type of pathology. The rapid development of new methods of signal transformation allows for a more efficient analysis of fECGs. It should be noted that it is possible to analyze the signal in a noninvasive way from electrodes placed on the mother's abdomen. These particular conditions of signal acquisition require transformation methods insensitive to disturbances, fluctuations, and noise coming from the equipment or the mother. At the same time they must be sensitive enough to allow for the extraction of the very weak fECG against the background of the strong maternal signal. Nonlinear filtration of ECG signals makes it possible to obtain a complete picture of the fECG. The methods used until recently allowed for only a partial view of the fECG, reducing its detection to the QRS complex. The methods described above also allow observation of waves, segments, and intervals. The results of this study indicate that diabetes of classes B and C uncomplicated by IUGR does not affect beat-to-beat variability, ST segment, and the QRS complex. In spite of this, the number of CSs performed as a result of non-reassuring fetal heart rate was higher in this group than in the control group. More experience in applying transabdominal fECG may result in a reduction in the number of CSs in diabetic pregnancies without IUGR, even to the level of the group of healthy mothers.

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