fetal electrocardiography,
fetal monitoring

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SIMULTANEOUS RECORDING AND ANALYSIS OF DIRECT AND INDIRECT FETAL ELECTROCARDIOGRAPHY

Recording and analysis of fetal heart rate variability is still the most common method for detection of early symptoms of fetal hypoxia. However, fetal heart rate obtained via ultrasound describes only mechanical activity of fetus heart. Limitations of this technique have stimulated the development of fetal electrocardiography. It ensures more precise determination of fetal heart rate and, which is more important, enables assessment of the morphology of the fetal QRS complexes. In this paper two techniques of obtaining the fetal electrocardiogram are described and their comparative study is presented.

1. INTRODUCTION

Present-day perinatology is aimed at detection of early symptoms of fetal hypoxia. This is still accomplished by analysis of fetal heart mechanical activity characterized by fetal heart rate (FHR) variability. Ultrasound Doppler method detects heart beats on the basis of the movement of valves and walls of the fetal heart. This enables determination of FHR expressed in beats per minute (bpm) according to the formula FHR [bpm] = $60000/T_{RR}$ [msec], where T_{RR} is an interval between two consecutive heart beats. However complex structure of Doppler signal envelope causes difficulties in precise recognition of R wave equivalents in the ultrasound signal. Evaluation of fetal state basing on analysis of fetal heart rate only is characterized by low sensitivity and positive predictive value, and thus it should be considered rather as a screening than diagnostic method [1].

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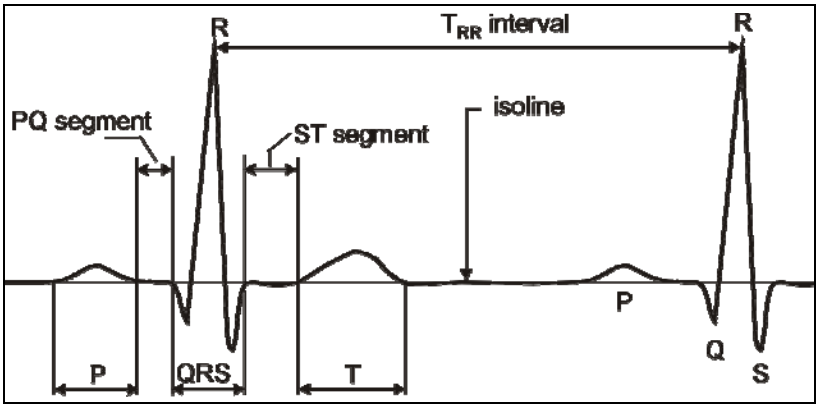

Fig. 1. Timing parameters of the fetal ECG complex

On the basis of fetal electrocardiogram (FECG) the fetal heart rate can be more precisely determined through location of consecutive heart beats - R waves. However much more important is that measurement of electrical activity of fetal heart enables to carry out assessment of the morphology of the fetal QRS complexes [2]. This comprises measurement of amplitude and time dependences between individual waves (Fig. 1): mainly analysis of the ST segment, determining of the ratio of T wave amplitude to the QRS complex amplitude as well as the correlation of the PR segment with the value of the FHR signal. Biphasic ST segments could be noted during the initial phase of hypoxia, when the fetal heart not yet had time to respond to an acute hypoxic event, or it may appear if for different reasons the fetus is not capable of responding to hypoxia.

2. THE BACKGROUND OF FETAL ECG ACQUISITION

Recording of fetal electrocardiogram can be accomplished by two methods: a direct – possible only during labour, where the spiral electrode is placed on the head of the fetus and an indirect – where measuring electrodes are placed on maternal abdomen. The first method provides in fact pure FECG signal – low frequency interferences can be easily filtered out. Unfortunately, this method is invasive. The abdominal method is completely noninvasive and it may be applied both during pregnancy and labour. The measurements are performed using abdominal electrodes placed around navel and a reference electrode placed above the symphysis pubis [3].

Since abdominal electrocardiography seems to be the most suitable method the following question has to be answered: Is it possible to obtain from abdominal signal the fetal electrocardiogram of a quality comparable with direct FECG, which will enable to perform assessment of the morphology of the fetal QRS complexes. There are two serious problems related to abdominal electrocardiography application. For the first, fetal electrocardiogram recorded from the maternal abdomen is usually highly disturbed – mainly by maternal electrocardiogram (MECG) and muscular interferences (Fig. 2).

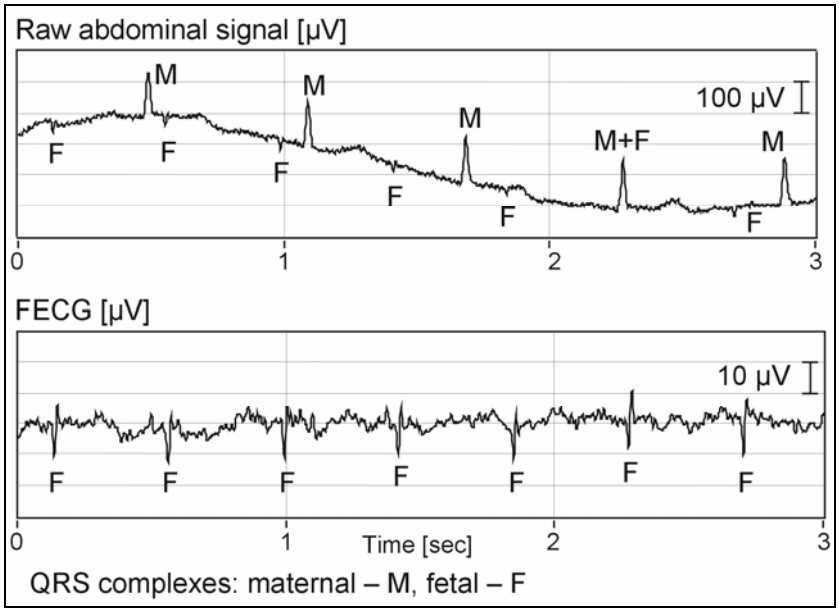

Fig. 2. Raw abdominal signal and fetal electrocardiogram using the developed algorithm for maternal ECG suppression

Simple frequency filtration cannot be applied as the frequency band of both ECG signals overlap. For the second, FECG has relatively low amplitude of 1÷50 μV, whereas amplitude of MECG is between 100 and 1000 μV. Thus, development of recording unit of a very low noise level and effective method of maternal ECG suppression are essential for obtaining fetal electrocardiogram from abdominal signals [4].

3. METHODOLOGY

We have developed a computer-aided instrumentation for simultaneous recording and analysis of FECG signals both from the pregnant maternal abdominal surface and directly from the fetal head. The system generally consists of two separate parts: the microcontroller-based recorder of bioelectric signals and external computer. Application of the fiber-optic link and battery power supply of the recorder ensures full safety of a mother and baby during monitoring.

The recorder is equipped with four differential channels for measurement of abdominal signals as well as the channel for connecting electrode attached to fetus head. Typical configuration of the abdominal electrodes comprises four electrodes placed around the navel and the reference electrode placed above the pubic symphysis. Additionally on the left leg, the common mode reference electrode is placed. The necessity of using four abdominal leads results from the fact that very often the FECG signal of a good quality is present only in one lead, whereas in the others it is not observed. Considering abdominal FECG, the basic merit of the presented recording unit is a very low level of its own noise not exceeding 2 μV (peak-to-peak), measured with reference to input, and a high value of CMRR (120 dB). These parameters have been obtained thanks to novel recorder structure

including complete separation of analog part from a digital part. Each channel is equipped with an amplifier with gain control that allows the amplification of recorded signals from the tens of microvolts up to the level of several volts. The band-pass filter in each channel removes low frequency components and thus prevents the reaching of saturation state by amplifiers in case of strong isoline drift. The system software has been developed using LabView (National Instruments) graphical environment for building signal processing applications. The program enables the appropriate control of recording of bioelectric signals and their analysis (Fig. 3).

Suppression of the dominating component on the abdominal signal – maternal electrocardiogram – is the first, and at the same time, the decisive step in abdominal fetal electrocardiography [5, 6]. The method of MECG suppression has proposed by us is a result of our previous research work [7, 8]. It is based on precise subtraction of averaged maternal QRS complex in each abdominal channel. Reference QRS complexes of maternal electrocardiogram are created and then after scaling they are subtracted from successive maternal QRS complexes in each abdominal signal (Fig. 4). The phenomenon of inaccurate pattern synchronization can be eliminated by subtraction of the first derivative of maternal QRS complex pattern. This leads to full suppression of MECG and does not influence FECG component (see FECG in Fig. 2). The detection and the exact location of the consecutive QRS complexes in FECG have the main influence on determination of the FHR signal [9]. The decision-making algorithm is used, whose task is to detect the peaks of the detection function which are responses to the occurrences of the QRS complexes.

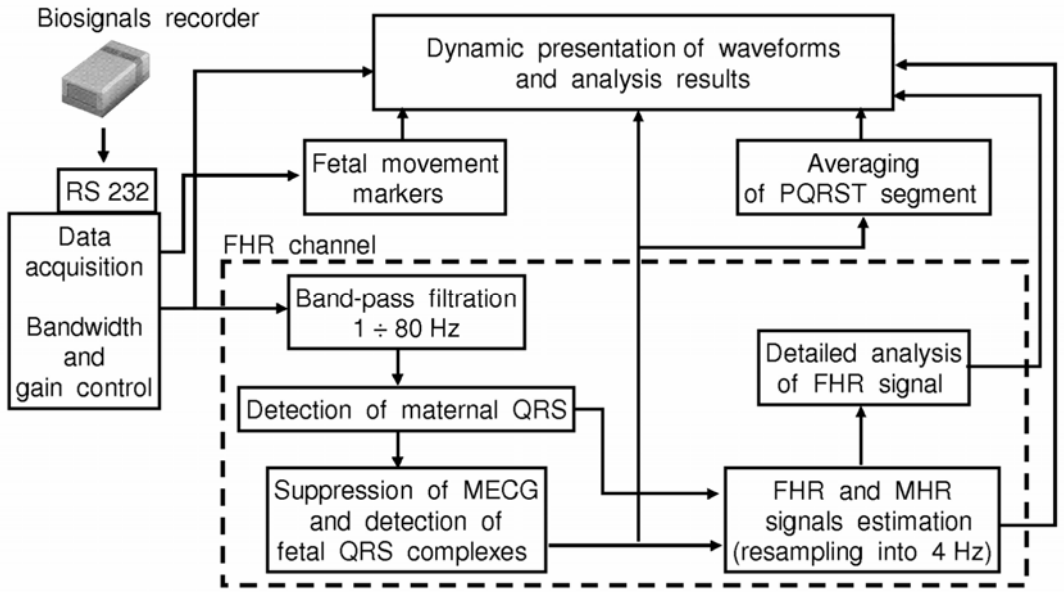

Fig. 3. Structure of the system for recording and analysis of fetal abdominal electrocardiogram

When the locations of the consecutive occurrences of the QRS complexes are known, it is possible to determine the duration of individual cardiac intervals and to calculate the corresponding instantaneous values of the FHR signal. Considering analysis of ECG morphology the P-QRS-T complexes have been averaged over 50 consecutive cycles. Then the time parameters and T/QRS ratio (relating to amplitudes) of averaged complexes are

calculated. For the aim of presented work complete analysis has been carried out both in direct and abdominal channel.

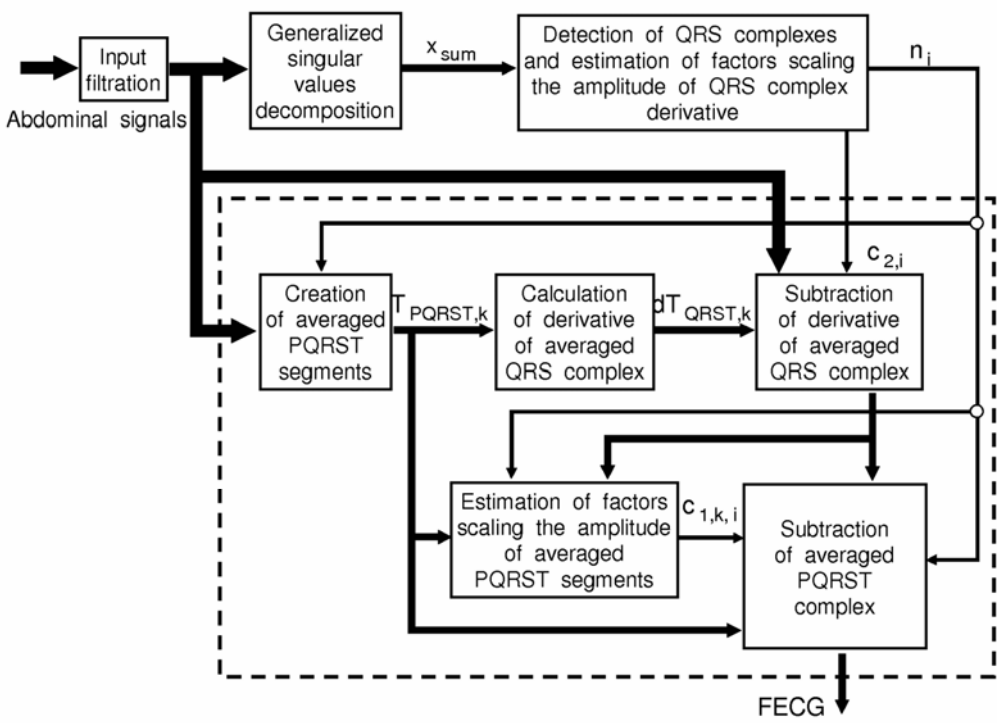

Fig. 4. The scheme of procedure for suppression of maternal ECG component from abdominal signals

4. RESULTS AND DISCUSSION

We have performed our preliminary comparative study on the basis of 20 traces comprising direct and abdominal FECG signals. Those traces were recorded during labour between 36th and 41st week of pregnancy. As a result of visual assessment we noted that the shape of corresponding FHR waveforms determined on the basis of the FECG recorded directly and indirectly were very similar (Fig. 5). From the other hand the shapes of corresponding P-QRS-T complexes were slightly different. This results most probably from different location of fetal heart in relation to measurements electrodes in both methods. However, this does not impact the FECG morphology interpretation, which has been confirmed by statistical analysis.

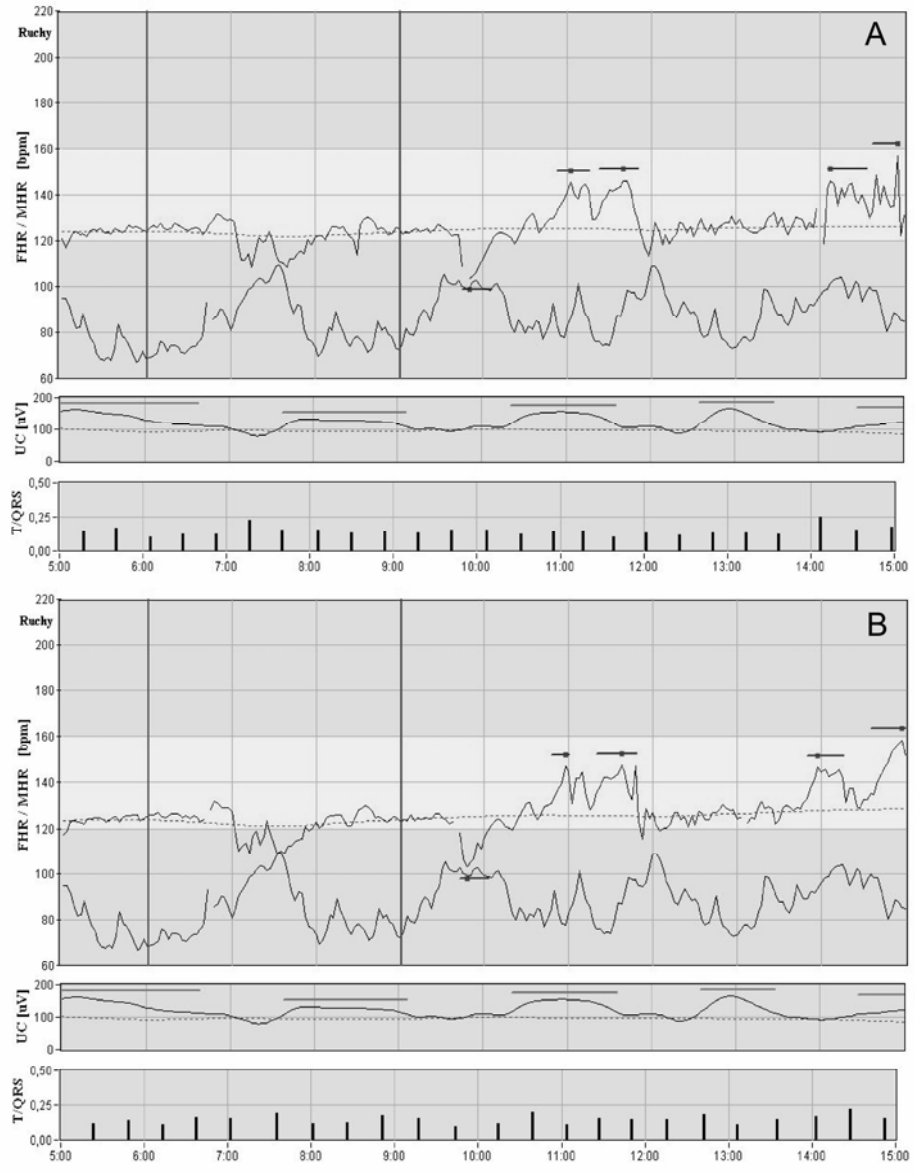

Fig. 5. Example of intrapartum fetal heart rate (FHR) trace registered simultaneously using direct (A) and abdominal (B) electrocardiography. Below there are traces of the maternal heart rate and uterine contraction activity.

There are no significant differences noted in case of statistical measures of timing parameters of corresponding fetal P-QRS-T complexes obtained using both methods (see Tab. 1). Both mean values and standard deviations of determined durations of particular events are comparable. Hence, using noninvasive and more convenient abdominal electrocardiography it is possible to monitor FECG morphological changes on a level comparable with direct method, additionally without limitation to labour.

Table 1. Statistical measures of the timing parameters of FECG complexes obtained form abdominal and direct ECG

Parameters	**Abdominal FECG** min-max, mean ± SD	**Direct FECG** min-max, mean ± SD
P [ms]	42 – 66, 53 ± 5,9	48 – 63, 57 ± 3,9
PQ [ms]	46 – 68, 58 ± 6,1	50 – 68, 60 ± 5,7
QRS [ms]	50 – 66, 58 ± 3,5	47 – 64, 55 ± 5,9
ST [ms]	40 – 86, 69 ± 13,8	55 – 85, 71 ± 8,1
T [ms]	124 – 208, 164 ± 25,8	144 – 187, 160 ± 13,3
RR [ms]	462 – 486, 474 ± 5,5	463 – 495, 476 ± 7,6

Tab. 2 presents results which are very important for classical analysis of fetal heart rate variability. Ultrasound-based fetal monitors provide FHR signal originally as 4 Hz samples, which are used to calculate both the long-term and the short-term variability indices describing instantaneous variability of fetal heart. Analysis of FHR comprises also detection of characteristic patterns: acceleration and deceleration events, tachycardia and bradycardia periods, which are carried out using FHR samples averaged over 2.5-second periods.

Table 2. Statistical measures of differences between corresponding FHR values determined using direct (D) and abdominal (A) electrocardiograms.

	$FHR_D - FHR_A$ (4 Hz samples)	$FHR_D - FHR_A$ (0.4 Hz samples)
$\overline{\Delta FHR}$	0,09 bpm	-0,05 bpm
$SD\_\Delta FHR$	1,93 bpm	0,56 bpm
$2 \cdot SD\_\Delta FHR$	3,86 bpm	1,12 bpm
$\overline{\lvert\Delta FHR\rvert}$	1,13 bpm	0,49 bpm
$Med.\lvert\Delta FHR\rvert$	1,01 bpm	0,28 bpm

$\overline{\Delta FHR}$ – mean value of differences of corresponding FHR samples

$SD\_\Delta FHR$ – standard deviation of differences; about 68% of differences in that range

$2 \cdot SD\_\Delta FHR$ – double SD; about 95% of differences in that range

$\overline{\lvert\Delta FHR\rvert}$ – mean absolute error

$Med.\lvert\Delta FHR\rvert$ – median value of differences

Tab. 2 shows that 95% of differences, between corresponding 4 Hz FHR samples do not exceed 1.12 bpm, and at the same time 50% of differences between 0.4 Hz samples are below the value of 0.28 bpm. These results confirm conclusions from visual assessment where we have noted that the shape of corresponding FHR waveforms determined on the basis of the FECG recorded directly and indirectly are very similar. However the more important is that a type of fetal ECG measurement method used has not considerable influence on conventional analysis of FHR variability.

5. CONCLUSION

Results of comparative studies of direct and abdominal fetal electrocardiography, confirmed the fact that the abdominal fetal electrocardiography may in the near future completely revolutionize the perinatal diagnostics. Contrary to traditional approach based on analysis of fetal heart rate variability only, this enables to obtain not only the fetal heart rate signal but also analysis of the P-QRS-T morphology. This provides completely new diagnostic information and allows making a correct decision as regards to the time and method of pregnancy termination.

Further research work should be focused on establishing of reference values for individual FECG parameters and evaluating of their prognostic values in prediction of fetal outcome.

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