abdominal fetal electrocardiogram
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COINCIDENCE OF MATERNAL AND FETAL QRS COMPLEXES IN VIEW OF FETAL HEART RATE DETERMINATION

Indirect fetal electrocardiography is a developing diagnostic method in perinatal medicine. Signals of electrical activity being recorded from maternal abdomen surface contain more information than in till now used method of mechanical heart activity measurement based on ultrasound signals. The main problem relies on separation of basic useful component from a signal containing also dominant maternal electrocardiogram and muscles activity artifacts. The algorithms of maternal electrocardiogram suppression via subtraction are commonly used. Although regarding their complexity, these algorithms have limited applicability in systems for long-term monitoring of fetal heart activity. Other solution relies on simple blanking of maternal QRS complexes. However, in case of coincidence of fetal and maternal QRS complexes, this leads to partial loss of information about fetal heart rate variability. For evaluation of how often such coincidence of both complexes takes place, the algorithm has been developed which is described in this paper.

1. INTRODUCTION

In 1906, the recording of electrical activity of fetal heart (FECG) has succeeded for the first time. The intravaginal and abdominal electrodes connected to simple string galvanometer were used for this aim. For many subsequent years, technical difficulties in recording and conversion of signals blocked the progress of studies on fetal electrocardiography. Rapid development of electronics, application of new materials in electrode production and first of all introduction of computers together with digital signals processing allowed researchers to improve a quality of the obtained signals. The main advantage of methods based on signal recording from electrodes placed on maternal abdomen is their non-invasiveness. This method can be practically applied already since 11-th week of gestation [3], but the signals quality depends on recording period [5]. Between 26 and 36-th week of gestation, the acquisition of signals is considerably hindered with regard to poor conducting properties of amniotic fluid.

Ultrasound Doppler method used in conventional fetal heart activity monitoring enables only the determination of T_{R-R} intervals, and thereby the trace of fetal heart rate (FHR) variability. Determination of T_{R-R} intervals between consecutive cardiac cycles relies on detection of cardiac

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systoles and diastoles basing on analysis of Doppler shift effect of ultrasound beam reflected usually from moving valves of a fetal heart [4].

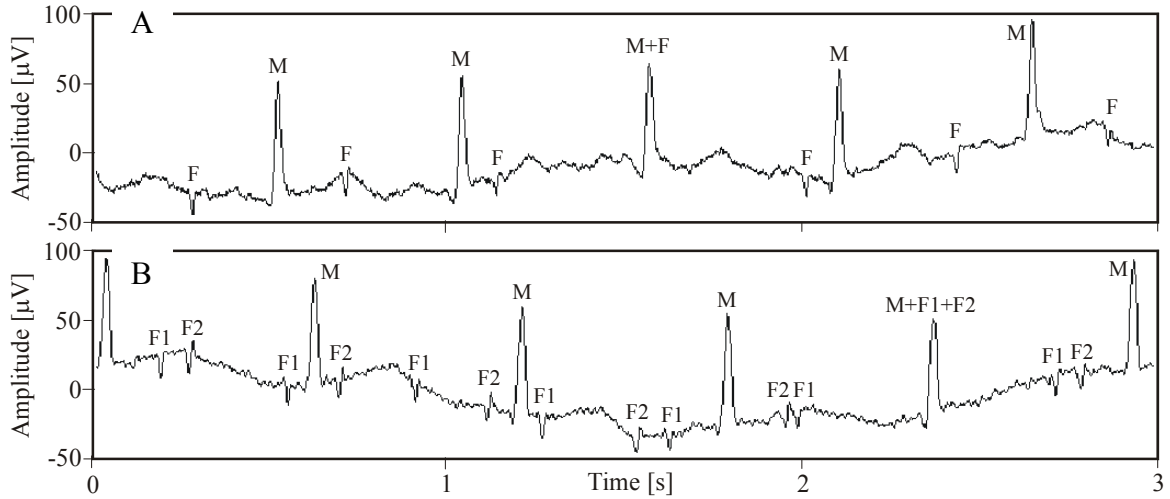

Fig.1. Fragments of electrocardiographic signal recorded from mother's abdomen A – single pregnancy, B – twin pregnancy.

Indirect electrocardiography additionally allows an observation of complete morphology of FECG signal thus improving the effectiveness of diagnosis being established [1]. Signal of electrical activity recorded from maternal abdomen (Fig. 1) besides a useful component contains also artifacts coming from the maternal electrocardiogram (MECG), mother's muscles activity and from fetal movements. Essential problem is the effective suppression of maternal electrocardiogram, which amplitude many times exceeds the level of useful signal. In the studies carried out, the averaged MECG amplitude was approximately 300 μV whereas the FECG amplitude of 10÷20 μV was comparable to muscular artifacts in some cases. In addition, the frequency bands of maternal and fetal electrocardiographic signals are overlapping making thus impossible the application of traditional filtration methods. Therefore, for separation of FECG signal, the sophisticated algorithms using adaptative filtration, weighted summation of signals [2, 6] as well as the methods based on orthogonal transformations (e.g. SVD) [7] are applied.

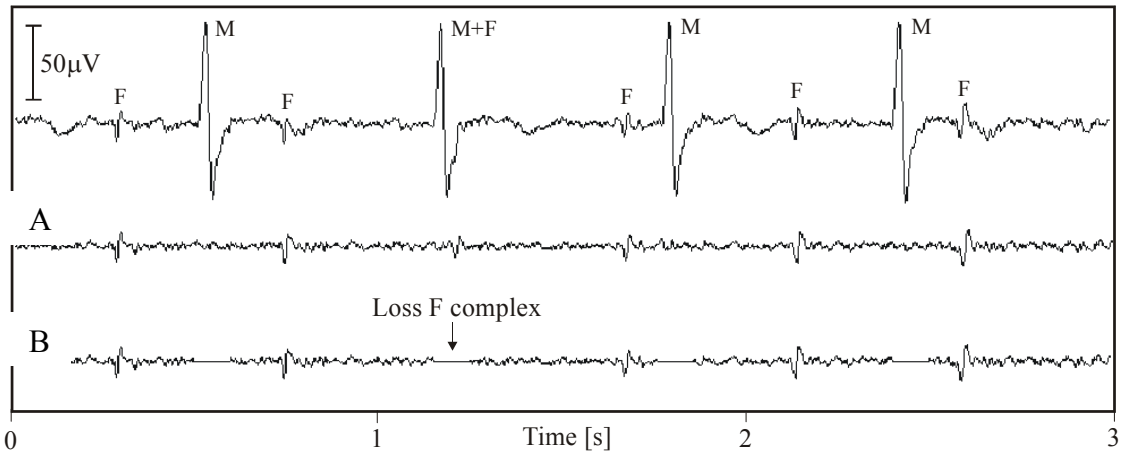

Fig.2. Example of signal with suppression of maternal ECG via subtraction (A) in comparison with simple blanking of maternal QRS complexes – B.

Their basic shortcoming is the necessity of recording of relatively large number of abdominal signals and sometimes also signals from chest leads. They very often require also application of strictly determined configuration of electrodes on maternal body that is usually difficult to accomplish during the labour. The developed method based on precise subtraction of averaged maternal PQRST complex has not the above mentioned shortcomings. However the algorithms used in this method require a large computational time, thus making impossible the use of this method in instrumentation for long-term monitoring of fetal heart rate. The simplest solution of the problem could be the blanking of interfering maternal QRS complexes. Unfortunately, in case of superposition of maternal and fetal QRS complexes, this solution leads to partial information loss in FECG signal (Fig. 2). For assessment of occurrence rate of these coincidence episodes, and thereby deciding as to application of the blanking method, here described algorithm has been developed.

2. METHODS

The algorithm described here has been developed with the use of simplified, virtual generator of electrocardiographic signals containing the maternal and fetal components (Fig. 3). Sampling frequency has been set up at a level of 500 Hz corresponding to a frequency used in the system developed for acquisition of signals from maternal abdominal wall. The proper length of generated signals was assumed in order to ensure a maximum repeatability of results. The length of 5 hours was chosen in connection with the size of accessible computer memory used for simulation of the algorithm operation and regarding the software environment LabView.

Variable	Parameter	Value
$T_{RR}M$	Duration of maternal T_{RR} interval [msec]	545÷1000
$\Delta T_{RR}M$	Variation range of maternal T_{RR} interval duration [%]	20
QRSM	Width of maternal QRS complex [msec]	70÷90
$T_{RR}F$	Duration of fetal T_{RR} interval [msec]	300÷600
$\Delta T_{RR}F$	Variation range of fetal T_{RR} interval duration [%]	20
QRSF	Width of fetal QRS complex [msec]	20÷40

Tab.1. Trace parameters having influence on coincidence episodes of maternal and fetal QRS complexes.

Detailed list of electrocardiographic trace parameters having direct influence on the episodes of maternal and fetal QRS complexes coincidence together with their assigned values is presented in Table 1. Very important feature of heart rhythm is his beat-to-beat variability. It has been simulated with the use of pseudo-random numbers generator. Maximum variation range resulting from physiology of a heart activity is determined by the variables $\Delta T_{RR}M$ and $\Delta T_{RR}F$. Due to variability of heart rate, the phase shift between signals of mother and fetus is not essential, hence it has not been regarded in our algorithm. The term of QRS complexes coincidence factor (CF_i) has been defined for the algorithm purposes as a common part of maternal and fetal complexes, having determined duration „t_i" expressed in relation to width of fetal complex $QRSF_i$:

$$CF_i = \frac{t_i[msec]}{QRSF_i[msec]} \cdot 100\% \qquad (1)$$

Four thresholds of minimum superposition: 25, 50, 75 and 100 % have been established. For instance, the threshold of CF_i equal to 50% value comprises fetal QRS complexes that were overlapped in the limits 50%÷100% of their width.

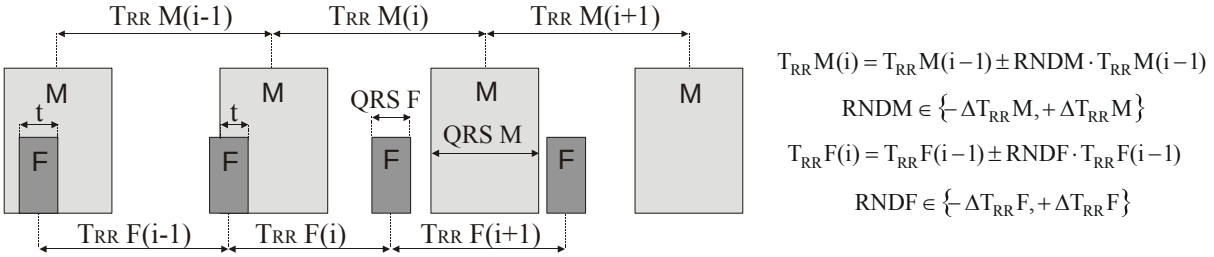

Fig.3. Fragments of generated electrocardiographic signal together with its descripting parameters. RNDM and RNDF – generation of pseudo-random numbers descripting the variability of maternal and fetal heart rhythm respectively.

The quantitative evaluation of occurrence rate of coincidence episodes in electrocardiogram record was effected by determination of coincidence factor which specifies the number of fetal QRS complexes having common part corresponding to preset threshold. This quantity is being expressed as a percentage of all occurring fetal complexes in the record:

$$CF(T) = \frac{\sum_{i=1}^{N} marker_i}{N} \cdot 100\% \qquad (2)$$

where: T – threshold value (25, 50, 75, 100%)

N – number of all fetal QRS comlexes

$$marker_i = \begin{cases} 1 & for \quad CF_i \geq T \\ 0 & for \quad CF_i < T \end{cases}$$

At first, the influence of width of maternal and fetal QRS complexes on the coincidence episode rate has been examined. Such sequence of examinations was resulting from invariability of these parameters within the electrocardiographic record. Maternal and fetal T_{RR} interval lengths have been assumed at the levels of 700 and 444 msec representing the most frequent values occurring, and corresponding to heart rates: 85 bpm (beat per minute) for mother and 135 bpm for fetus. Obtained results showed a tendency according to which the coincidence factor decreases with increase of fetal QRS width along with decrease of maternal QRS width. For further analysis, the electrocardiograms were used with minimum and maximum value of *CF* factor, that is to say, the cases where *QRSM* = 70 msec and *QRSF* = 40 msec as well as *QRSM* = 90 msec and *QRSF* = 20 msec. For such combinations of widths of maternal and fetal QRS complexes, the parameters $T_{RR}M$ and $T_{RR}F$ had then been changed and their influence on *CF* factor value was studied. It appeared that for selected width of maternal and fetal QRS complexes as well as for selected length of

maternal T_{RR} interval the change of fetal T_{RR} interval does not influence the value of coincidence factor. This is a consequence of the fact that change of fetal T_{RR} interval length influences both the number of these intervals in the record and the probability of occurrence of complexes coincidence. According to expectations, the value of coincidence factor *CF* was arising along with shortening of the maternal T_{RR} interval. Maximum value of this factor was achieved for $T_{RR}M$ = 545 msec. For each threshold value the range had been estimated in which the *CF* factor will be contained in electrocardiographic records (Fig. 4). Additionally in the Figure, the value of the coincidence factor for mean value parameters ($T_{RR}M$=700 msec, *QRSM*=80 msec, *QRSF*=30 msec) have been marked.

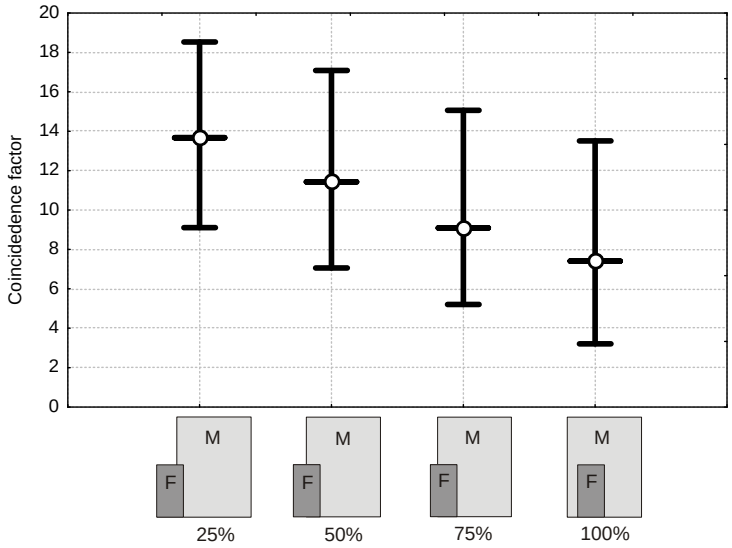

Fig.4. Relation of percentage content of superposed maternal and fetal QRS complexes to superposition threshold.

When analysing the results for the lowest threshold of 25 % value comprising cases of significant fetal QRS coincidence ($CF_i \geq 25$ %) disabling its correct detection, the range of coincidence factor value for the record being equal to 9,11÷18,53% is obtained. This means 18 % loss in FECG signal in the pessimistic variant. It should be noted that the loss episode is not continuous but occurs randomly and lost T_{RR} intervals can be determined by interpolation of several values correctly calculated earlier. Fig. 5 presents FHR signal determined on a basis of FECG record with lost values and the same signal supplemented with interpolated values, in coparison to signal obtained from complete FECG record and signal provided by ultrasound method. Sampling frequency equals 4 Hz that corresponds to a frequency used in monitoring equipment. FHR signal determined with the use of interpolated values slightly differs from the remaining signals although the general trend is maintained. This signal cannot be used for evaluation of short-term variability because through interpolation the real information about beat-to-beat changes of FHR is being lost. Nevertheless, such a signal can be used in classical FHR analysis requiring an averaged signal for a period of 2.5 seconds. While slight differences are visible on signals in Fig. 5, the averaged signals looks identically (Fig. 6). The difference between FHR signal determined by ultrasound and electrocardiographic methods appearing in the fourth minute is caused by large interference present in ECG signal.

3. CONCLUSIONS

Indirect fetal electrocardiography is a developing diagnostic method that can revolutionize the perinatal medicine in future. At present, the main problem is a separation of useful component – the FECG signal from the signal containing maternal ECG and muscle activity artifacts. Blanking of the maternal QRS complexes is a relatively simple method usable in long-term monitoring of fetal heart activity systems. Although, in case of superposition of maternal and fetal QRS complexes, the method causes losses in FECG signal, but as was shown in the paper, this coincidence episode occurs so rarely that does not influence significantly the accuracy of FHR trace determination.

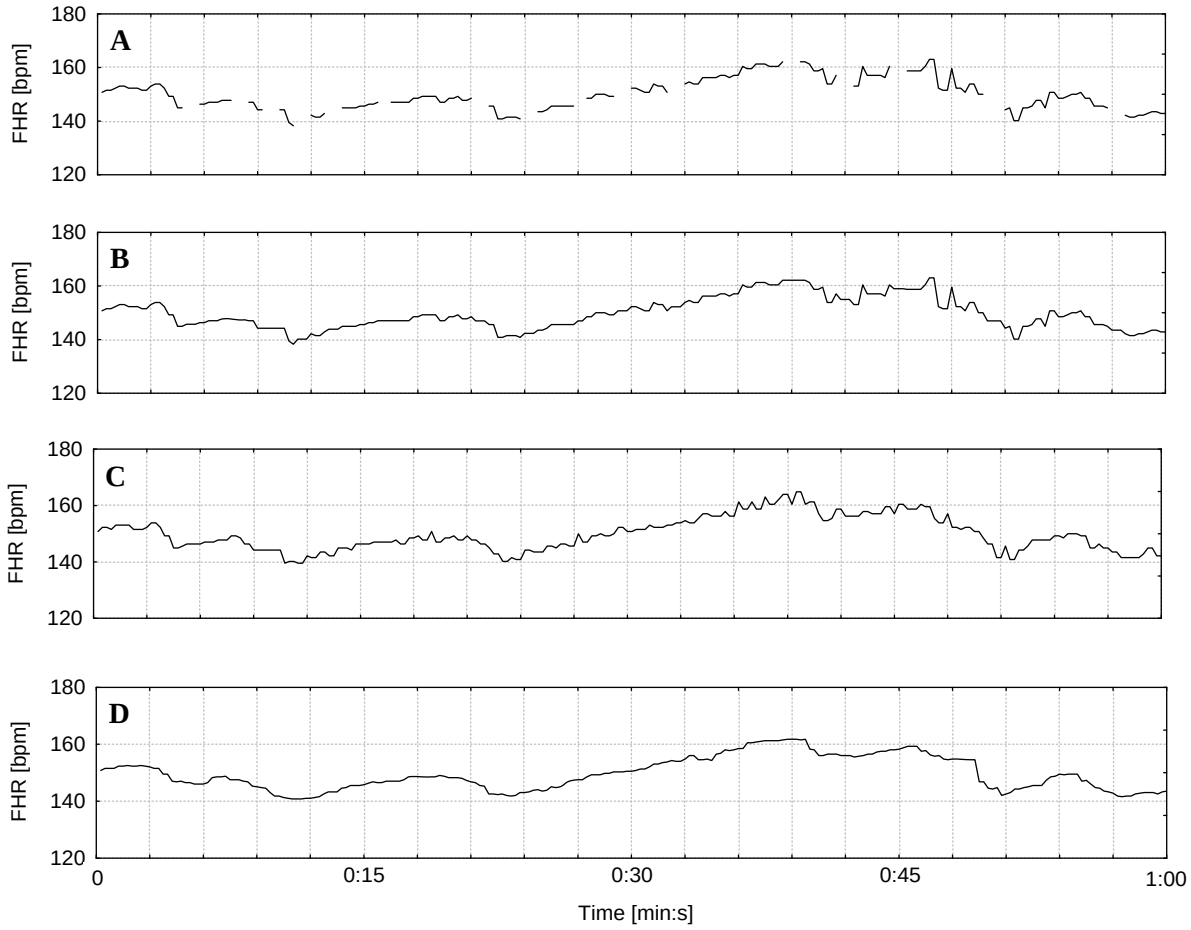

Fig.5. One-minute FHR segment determined from: A – FECG signal with losses, B – FECG signal with losses supplemented by linear interpolation of neighbouring values, C – FECG signal without losses obtained after application of developed method of maternal ECG suppression, D – signal of Doppler envelope.

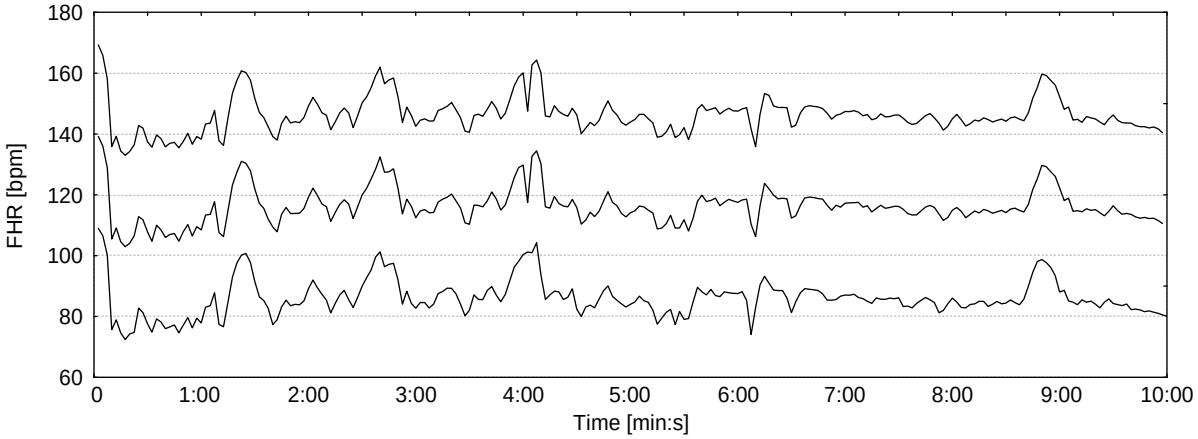

Fig.6. Ten-minutes FHR signals from Fig.5 (B, C, D) averaged over period of 2.5 seconds.

The more serious problem is connected with existence of a period of poor signal recording between 26 and 36-th week of gestation due to change of conduction properties of amniotic fluid and the high level of muscular artifacts in some cases.

BIBLIOGRAPHY

[1] ABBOUD S., BARKAI G., MASHIACH S., SADEH D.: Quantification of the Fetal Electrocardiogram Using Averaging Technique, Comput. Biol. Med., vol. 20, no. 3, pp. 147-155, 1990.
[2] BERGVELD P., MEIJER W.J.H.: A New Technique for the Suppression of the MECG, IEEE Trans. Biomed. Eng., vol. BME-28, pp. 348-354, April 1981.
[3] CALLAERTS D., VANDEWALLE J., SANSEN W., JANSSENS J., VANTRAPPEN G.: Acquisition and processing of the antepartum, Elsevier Science B.V., pp. 371-380, 1994.
[4] JEŻEWSKI J., WRÓBEL J., HOROBA K., MOCZKO J., BRĘBOROWICZ G., GRACZYK S.: Advances in Doppler ultrasound FHR monitoring, Kliniczna Perinatologia i Ginekologia, Suppl.IX, pp. 241-251, 1995.
[5] MATONIA A., JEŻEWSKI J., WRÓBEL J., HOROBA K., KUPKA T.,: Application of spatial filtration in noninvasive fetal electrocardiography, VI International Conference SYMBIOSIS, pp. 116-120, Szczyrk 2001.
[6] MEIJER W.J.H, BERGVELD P.: The simulation of the Abdominal MECG, IEEE Trans. Biomed. Eng., vol. 37, no. 1, pp. 354-357, 1981.
[7] VAN OOSTEROM A.: Spatial filtering of the fetal electrocardiogram, J. Perinat. Med., vol. 14, pp. 411-419, 1986

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