

PROCESSING THE ABDOMINAL FETAL ECG USING A NEW METHOD

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INTRODUCTION

The excellent natural shielding of the fetus from the outside world prevents much of the information concerning its physical condition being obtained. Using non-invasive methods, all information has to be derived from physical and biochemical examination of the mother. Fetal heart action is the only vital function that can be recorded effectively without lesion.

Fetal heart action can be assessed using:

- the maternal abdominal measurement of the fetal electrocardiogram,
- the Doppler-shifted ultrasonic heart echo (ultrasonocardiography), and
- the recording of the heart sounds (phonocardiography).

After the rupture of the membranes, more information of a better quality can be obtained. The fetal ECG can be measured directly using an electrode attached to the presenting part, in most cases the scalp. There are no technical problems in monitoring this FECG signal. However, as it can only be used during birth, and as many physicians object in principle to using this method, it is necessary to employ the external monitoring methods.

Of the three possible methods the ECG can provide most information. However, the external measurement of the ECG is complicated by the interference of other signals, such as the maternal muscle action potentials, and by the significant attenuation of the ECG by the tissues between the fetal heart and the electrodes. The poor signal-to-noise ratio, and the similar frequency spectra of the signal and noise components, make the analysis of the ECG using conventional filtering techniques rarely possible.

The two main problems of ECG analysis are the elimination of the maternal ECG and the localisation of the fetal QRS complexes that are partly hidden by the maternal EMG (Figure 1). Figure 2 shows the performance of various methods used for the detection of the fetal ECG. In each case the abdominal signal is bandpass-filtered in order to reduce noise components which are outside the frequency band in which the fetal ECG has its main components. In most methods,

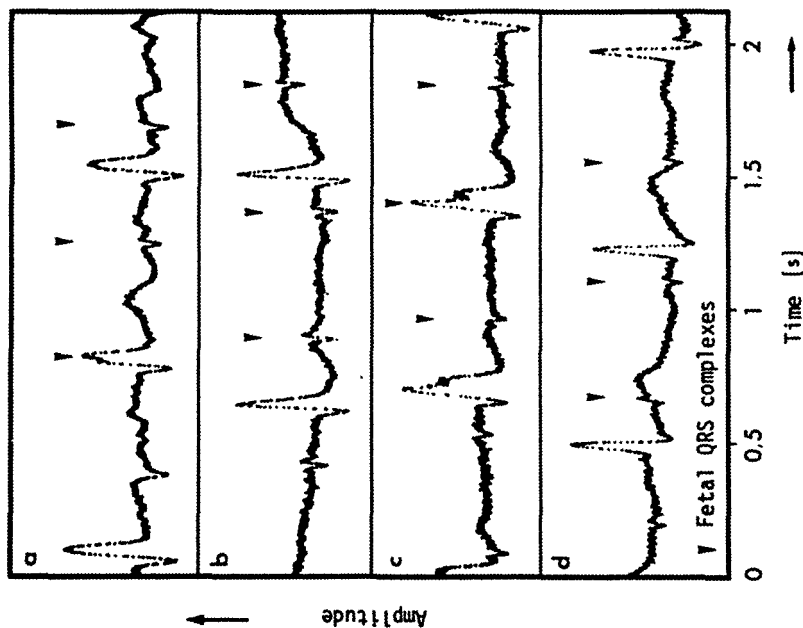


Figure 1. Four different abdominal lead fetomaternal ECGs

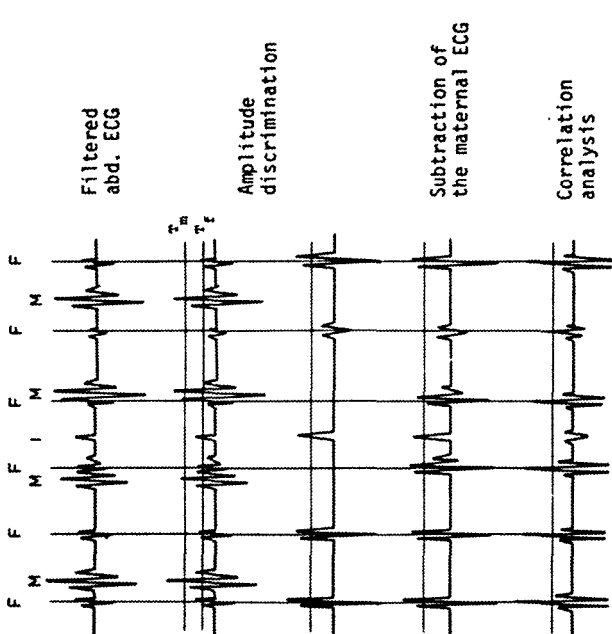


Figure 2. Illustration of different methods for the fetal ECG detection

after filtering, the separation of maternal and fetal ECG is achieved by using some form of amplitude discrimination. There are two triggering levels, one for the detection of the maternal QRS complexes and a lower one for localising those of the fetus. The disadvantage of this method can easily be seen. Each time a maternal QRS complex is detected the signal is completely suppressed, and coincident fetal complexes are lost. Moreover, there is no easy way of deciding whether the lower triggering level has been crossed by the fetal ECG or by signal disturbances. Thus, because of the poor signal-to-noise ratio and the high rate of coincidence between maternal and fetal ECG, the detection rate for the fetal QRS complexes is no better on the average than about 60%. Consequently, it is evident that a reliable FECG analysis firstly requires the maternal ECG to be subtracted in such a way that the remaining FECG is not affected. The resulting fetal QRS complexes may then be detected by means of a correlation analysis which is able to distinguish between them and the interfering noise.

SUBTRACTION OF THE MATERNAL ECG

The maternal ECG is additively superimposed upon the fetal ECG, and multiplicative distortions that result mainly from movements can be disregarded. So, theoretically, it is possible to separate the MECG from the abdominal signal by subtraction if its waveform is known. In practice it is rather difficult to perform the subtraction since the waveform of the MECG is not known in advance and is often subject to fluctuations within the time interval in which the signals are being processed. In some studies other groups tried to solve this problem by means of an additional MECG lead, the elimination of the MECG from the abdominal signal then being achieved by subtracting the two ECGs. This method is fraught with problems since it is practically impossible to bring the two maternal ECGs into coincidence with respect to amplitude and phase. The method is therefore unsuitable, particularly for routine examinations.

A much better solution to the problem is the use of an averaging technique to extract the waveform of the MECG using only the abdominal lead. The R-waves of the MECG are easily detectable by means of threshold detectors because of their large amplitude in the abdominal signal. By running averaging of succeeding intervals of the abdominal signal, all containing the maternal QRS complex in the same phase position, a reference signal corresponding to one interval of the MECG is obtained. The FECG and the EMG are suppressed in the reference since they are statistically independent from the MECG. Subtraction of the reference from the abdominal signal then results in the complete elimination of the MECG. Amplitude variations of the MECG which would result in non-zero differences require the reference signal to be scaled to the actual MECG amplitude before each subtraction. Running averaging guarantees the adaptation of the reference signal to varying waveforms of the MECG, thus it is possible to detect all the fetal QRS complexes in spite of their coincidence with the MECG. Figure 3 shows an example of the subtraction of the MECG.

For the exact subtraction of the MECG it is necessary that both phase and amplitude are known for the template and the actual R-wave. This condition cannot be satisfied in all cases by simple threshold logic. The superposition of

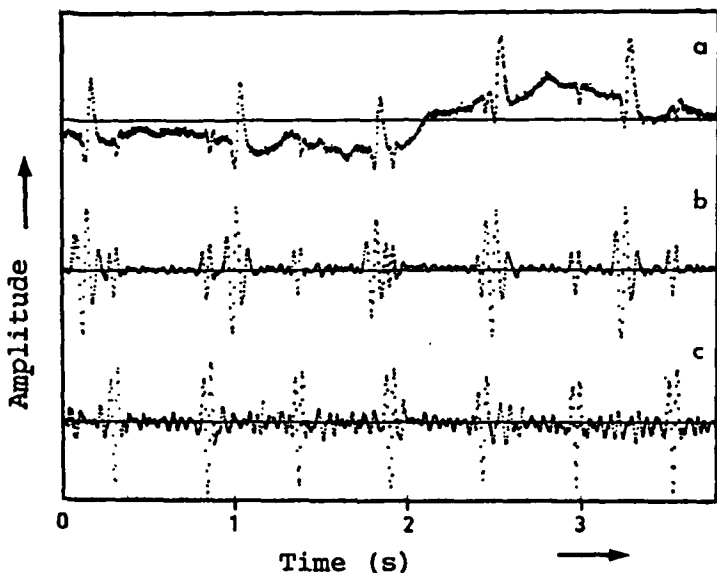


Figure 3. Subtraction of the maternal ECG from the abdominally measured signal

the fetal ECG and the EMG sometimes leads to jitter in the R-wave detection and consequently to a faulty determination of the amplitude and phase of the actual maternal R-wave. In order to prevent these errors the maternal ECG is analysed using a cross-correlation algorithm.

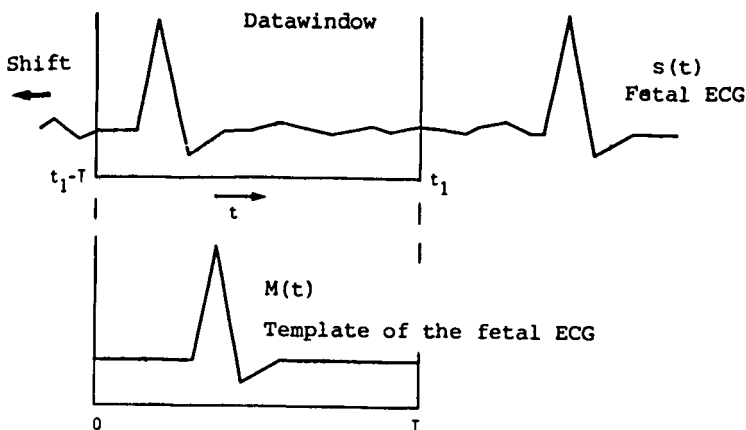
The maximum of the cross-correlation function between the abdominal signal and the maternal ECG template localises the peak of the MECC R-wave with greater precision than the simple threshold detector. It can be shown that the cross-correlation between MECC and FECC or EMG equals zero if the signal components are statistically independent. It follows that the scaling factor needed for the matching of the template and the actual MECC is found as the quotient of the cross-correlation function and the auto-correlation function of the template, both for the delay time equal to zero.

DETECTION OF THE FETAL ECG

The remaining signal disturbances, which are mostly caused by the maternal EMG, prevent the fetal QRS complexes from being detected with the necessary accuracy using simple threshold logic. It can be shown that, because of the poor signal-to-noise ratio, the expected error using the threshold detection of the fetal ECG is on average greater than 25%.

Therefore the signal is also subjected to correlation analysis similar to the processing of the MECC. Thus a reference of the FECC is extracted.

The cross-correlation function between the fetal reference and the signal is



$$R_{SN}(0) \Big|_{t=t_1} = \frac{1}{T} \int_0^T S(t+t_1-T) \cdot M(t) dt$$

Figure 4. Cross-correlation scheme for the fetal ECG

computed with an integration time of slightly less than one FECC interval (Figure 4). This time is sufficient because of the prior subtraction of the maternal ECG. Using integration times greater than one signal cycle would prevent the detection of one single R-peak, and it would only be possible to gain knowledge about the mean interval between succeeding R-peaks. The maxima of the cross-correlation function mark precisely the position of the fetal QRS complexes. The two main advantages of correlation analysis are that:

the fetal electrocardiogram is detected even if its amplitude is smaller than that of the superimposed noise and,

the jitter of the trigger point on the R-wave due to signal disturbances, such as appears when performing simple threshold detection, is substantially reduced. Thus the reliability of the measurement of heart rate is increased significantly, and the occurrence of non-existent heart rate oscillations is excluded.

CLINICAL RESULTS

The performance of the method described above has been assessed in clinical trials. Comparing the results with those obtained using the earlier techniques of abdominal ECG processing showed a mean increase in the detection rate of the fetal QRS complexes of about 60%. When compared to fetal heart frequency recordings using ultrasonocardiography or phonocardiography the new method shows an important improvement with respect to the evaluation of short term variations of heart frequency.

Figure 5 shows the fetal heart frequency (FHF) curve as obtained from the

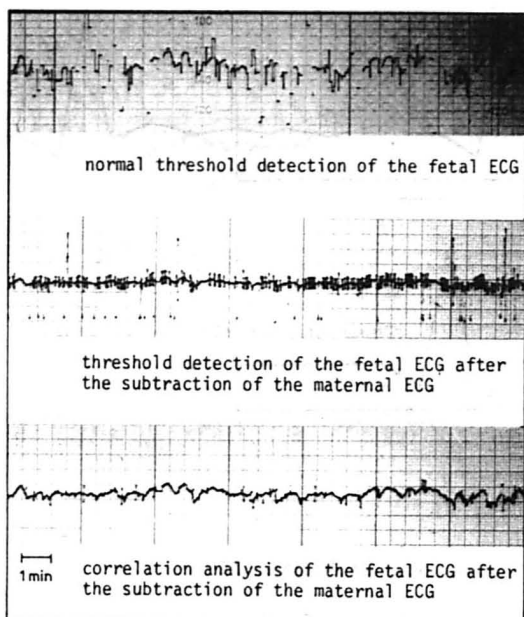


Figure 5. Fetal heart frequency computed from the same abdominal ECG using different processing methods

same abdominal ECG using different methods. In addition to a bad signal to noise ratio the analysed abdominal signal showed a high rate of coincidence between maternal and fetal QRS complexes. Using simple threshold logic the resulting FHF curve cannot be employed clinically. An improvement of the

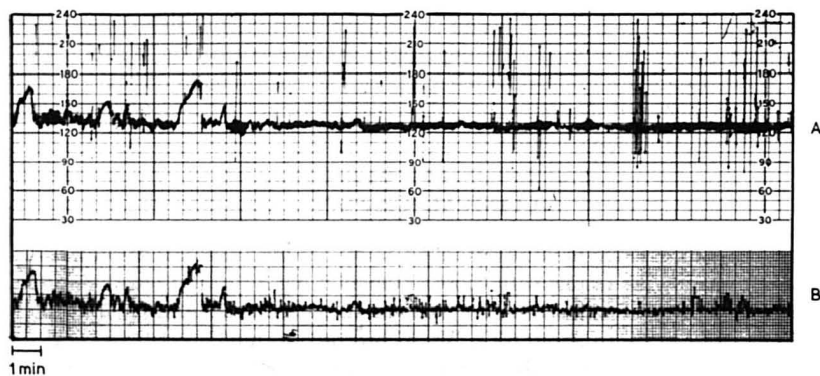


Figure 6. Fetal heart frequency, computed using a scalp electrode (A), and maternal abdominal electrodes (B)

measurement is obtained if the maternal ECG is subtracted prior to the threshold analysis of the signal. However, the necessary reliability is only achieved when both the maternal ECG is eliminated and a correlation analysis of the residual signal is performed.

Comparing the FHF computed simultaneously from the scalp-lead ECG (A) and the abdominal ECG (B) shows that in most cases there is no loss of information when using the new non-invasive technique (Figure 6).

In conclusion, it can be stated that the reliability of 'beat-to-beat' measurement of the fetal heart frequency could be significantly improved by employing the new analysis procedure.

Acknowledgment

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