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Perinatal intensive care is an urgent condition for the early detection and the prevention of risks for both mother and fetus. It is necessary to survey their physical condition, to detect changes and to analyse the influence of the maternal state on fetal development. Unfortunately the natural shielding of the fetus against external influences complicates the access to information about its physical condition. The heart action is the only fetal vital function that can be recorded using non-invasive methods. Hence cardiocography, i.e. the simultaneous registration of the beat-to-beat measured fetal heart rate (FHR) and uterine pressure (UP), has become the most important method of examination besides amniocopy and fetal blood analysis.

The evaluation of the FHR can be implemented by either analysing the fetal signals such as the ECG and the phonocardiogram (PCG), or by means of Doppler ultrasonics. Though the fetal ECG (FECG) is best suited for the exact interpretation of the heart activity, its abdominal recording is rarely used in clinical routine monitoring, as the reliability of available monitors has not yet been satisfactory. The most used methods are the ultrasonocardiography and, after the rupture of the fetal membranes, the direct recording of the FECG using scalp-electrodes. Ultrasonic and PCG measurements being rather inaccurate and internal derivation of the FECG being objected by many physicians, there has been a need for the improvement of abdominal lead FECG processing.

The external FECG derivation is complicated by the existence of severe signal disturbances such as the maternal electrocardiogram (MECG), the maternal electromyogram (EMG) and by the substantial attenuation of the FECG through the tissues between fetal heart and abdominal electrodes. The amplitudes of the interfering signal components are much higher than that of the FECG whose maximum amplitude when recorded by means of abdominal electrodes is 10 to 50 μV . In consequence of the unfavorable signal to noise ratio the discovery quota for the occurrence of fetal QRS complexes with the prior art filtering techniques is only about 50%. Since this quota is sufficient, at most, to indicate the average FHR, the physician has available to him neither sufficient data about the short time fluctuations in the heart rate, that are of greatest importance for his diagnosis, nor about

the wave shape of the fetal ECG. An essential improvement of monitoring equipment has been achieved in our institute through the implementation of averaging and correlation techniques. The two main problems in the evaluation of the fetal heart rate are:

- reliable detection of each heart action even during coincidence between the QRS complexes of the FECG and the MECG
- accurate triggering on each fetal QRS complex in order to achieve a precise determination of the R-R interval, excluding the simulation of non-existent heart rate oscillations by triggering errors.

Coincidence between maternal and fetal QRS complexes means that using conventional techniques fetal heart action is not detectable. This is a severe restriction as in many cases the coincidence rate amounts 50% and more. The solution for this problem has been found by the development of an algorithm that eliminates the MECG from the abdominal signal without any influence on the residual FECG and without the need for an additional lead of the MECG.

The R-peaks of the MECG are easily detectable by means of threshold detectors because of their outstanding amplitude in the abdominal signal. Through exponential 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. Herein the FECG and EMG are suppressed as they are statistically independent from the MECG. Subtraction of reference and abdominal signal results in the complete elimination of the MECG. Amplitude variations of the MECG that would result in non-zero differences request that the reference signal is scaled to the actual MECG amplitude before every subtraction. Exponential averaging guarantees the adaption of the reference signal to varying wave shapes of the MECG. Hence it is possible to detect all the fetal QRS complexes regardless to their coincidence with the MECG.

The remaining signal disturbances, caused by the maternal EMG prevent the fetal QRS complexes from being detected with the necessary accuracy by means of a simple threshold logic. Therefore the signal is additionally submitted to a correlation analysis. Similar to the processing of the MECG, a reference of the FECG is extracted.

The maxima of the crosscorrelation function that is computed between this reference and the signal with an integration time of slightly less than one FECG interval, mark precisely the position of the fetal QRS complexes. The two main advantages of the correlation analysis are that

- the fetal electrocardiogram is detected even if its amplitude is smaller than that of the superposed noise and
- the jitter of the trigger point on the QRS complex due to signal disturbances, as appearing when performing simple threshold detection, is reduced substantially.

Clinical tests of this new method showed a mean increase in the detection rate for the FECG of about 60% in relation to conventional techniques.

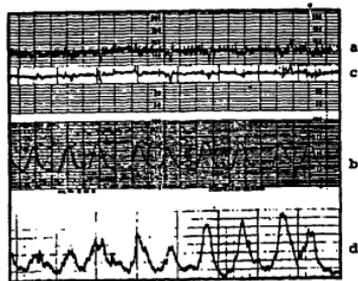


Fig. Cardiotocogram based on ultrasonics (a) and tocotransducer (b) compared to abdominal lead registered CTG (c) and (d).

Monitoring the uterine pressure is important in perinatal medicine for surveying the course of pregnancy and evaluating the state of the fetus. Essentially two methods, an internal and an external, are known for recording the tocogram. They have in common that the uterine pressure is measured at the body by means of pressure sensors. For internal tocography, the pressure is determined by introducing a fluid-filled open-ended catheter into the amniotic cavity. After zero matching, it is possible with this method to determine the absolute intra-uterine pressure. Before the rupture of the fetal membranes the pressure is approximated by measuring the stress of the abdominal wall, applying an external tocodynamometer. Both methods have significant drawbacks during routine-clinical use.

The analysis of the abdominally registered electrical signal showed, that the maternal EMG, though complicating the detection of the fetal ECG, and in opposition to the so far valid opinion, is not to be regarded only as an unprofitable signal disturbance. It contains all the information necessary to registrate the uterine activity.

Changes in intra-uterine pressure are produced directly by muscle contractions. The electrical fields connected with these contractions are registered on the surface of the skin as the EMG. The measured voltage curve is not a direct measure for the intensity of the contractions. But after the elimination of the maternal and fetal ECG from the abdominally derived EMG, rectifying and envelope detection results in the uterine activity curve. Besides the information of labor frequency and intensity this curve also shows the excitation and propagation of the contractions. By this method uterine activity can also be monitored in those cases where, due to an incoordination of the muscle activity, no pressure changes can be detected.

The particular advantages of the described methods become evident in the case where abdominally attached electrodes are used to obtain signals from the uterus as well as from fetal and maternal cardiac activity. This provides the possibility of obtaining extensive data in a perinatal examination from a single measurement which gives only little discomfort to the patient and which enables the physician to quickly obtain an accurate picture of the state of mother and fetus.

SUMMARY

A new method of continuous monitoring both fetal heart rate and uterine activity during pregnancy and birth is described in the paper. Electrodes, placed on the maternal abdomen are used to obtain signals from the uterus as well as from fetal and maternal cardiac activity. By means of averaging and correlation techniques the components of the registered signal are separated. The fetal electrocardiogram is used to compute the heart rate whereas the electrocardiogram is processed so as to result in the uterine activity curve. Besides a substantial improvement in the reliability of fetal heart rate monitoring, it is for the first time, that uterine activity could be registered other than by mechanical means and without any additional signal transducers.