uterine contraction activity,
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ANALYSIS OF UTERINE CONTRACTION ACTIVITY USING TWO WAYS OF SIGNAL ACQUISITION

The presented data acquisition system allows recording of electrohysterographic signals from maternal abdomen and the mechanical contractions via strain gauge transducer. As a research material we collected 108 traces during 24-hour period before labour from the group of patients between 37 and 40 week of gestation. We detected contractions in both signals and compared their descriptive parameters. Obtained results shows that the methods demonstrate high agreement only in relation to the number of contractions recognized as being consistent. But, the agreement of detailed contractions parameters is unacceptable to consider these methods as fully alternative.

1. INTRODUCTION

Electrohysterography is a monitoring technique developed for the medical diagnostics, which like other but much more known techniques: electrocardiography and electroencephalography, relies upon recording of bioelectrical signals. The aim of this technique is to provide information on uterine contraction activity during the course of pregnancy and labour. This is accomplished by measurement of action potential changes associated with the uterine contraction with the help of electrodes placed on the maternal abdomen [1].

At present the most commonly used technique for uterine activity monitoring is the external tocography. Its widespread application is a result of noninvasive and simple measurement technique. In common opinion, the only information from the tocogram which can be considered as reliable is a number of detected contractions. Quantitative parameters describing contractions like duration or strength can be estimated with quite low accuracy. Thus, tocography is treated mainly as a technique useful to control the labour progress. This limitation has been confirmed by comparing the external tocography with the intrauterine pressure measurement. This direct technique is able to provide to most reliable information on uterine contractions. However, being the invasive and very complex the internal tocography has in practice been excluded as the routine diagnostic tool. The information provided by both internal and external tocography is limited to the mechanical attributes of the uterine contraction activity (pressure or strain respectively). Complete information, describing also electrophysiological properties of the uterus, can be obtained by recording of its electrical activity.

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2. MATERIALS AND METHODS

2.1. SIGNAL ACQUISITION

System for monitoring the uterine contraction activity was based on personal computer. The data acquisition and analysis software was created with a help of LabView (National Instruments) and based on the algorithms that were developed during our previous research work [2]. The bioelectrical signals recorder developed by us was used (Fig. 1).

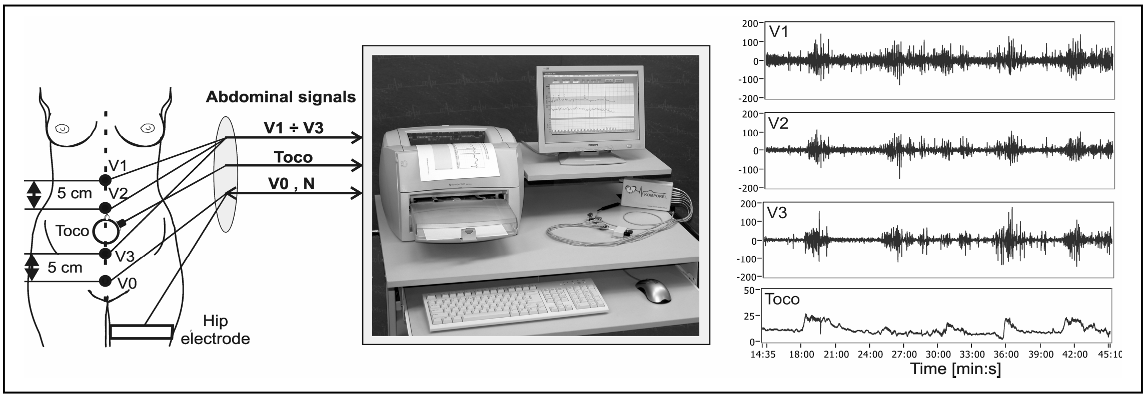

Fig.1 Computerized system for analysis electrical and mechanical uterine contraction activity signals recoded from maternal abdomen

Three channels were used to record abdominal signals to allow selection of the better electrohysterogram. The low cut-off frequency of 0.05 Hz and the gain of 2500 V/V were set. The high cut-off frequency was 150 Hz. Hence the sampling frequency is 500 Hz the recorder circuit is fully protected against the aliasing. One measurement channel was adopted to cooperate with strain gauge transducer (Oxford, UK) providing the Toco signal in the typical range of 0 to 100 relative units. During monitoring session, the Ag/AgCl electrodes were attached to the skin in the vertical median axis of the abdomen as it was shown in Fig. 1. The first EHG differential signal was calculated as (V1 – V0) – (V2 – V0) = V1 – V2, while the second signal was obtained as V3 – V0. The distance between the electrodes constituting the differential channels was set at 5 cm. The electrode attached to patient’s hip was used in the active ground circuit to reduce the common mode interferences mostly coming from the power line. Since the frequency range was limited to 5 Hz by low-pass filtration, the acquired abdominal signals could be downsampled to 20 Hz. This significantly reduced the amount of data affecting the computational efficiency of the main analysis.

2.2. ANALYSIS OF TOCOGRAM AND ELECTROHYSTEROGRAM

The aim of the classical analysis of the signal describing uterine contraction activity is to recognize the contraction patterns. This enables determination of their frequency (expressed in number of episodes per 10 minutes) and calculation of parameters used for quantitative evaluation of contractions in the time domain (Fig. 2). Contraction curve is printed by bedside fetal monitor as a continuous waveform characterized by a very low variability. During visual interpretation, the paper grid allows the clinician only to estimate contraction amplitude, duration and frequency of contractions. Additionally, the samples of tocogram are available on the digital output which enables the connection of the monitor to the computerized fetal monitoring system. Such systems are commonly used in present-day perinatology and they perform automated on-line recognition of contractions and calculation of timing parameters with much higher accuracy than using the paper tocogram. For the automated determination of contractions the so called basal tone has to be determined at first. The basal tone represents some basal strain exerted by the uterine muscle on the Toco transducer when contractions do not occur. The basal tone varies, usually from 0 to 20 units.

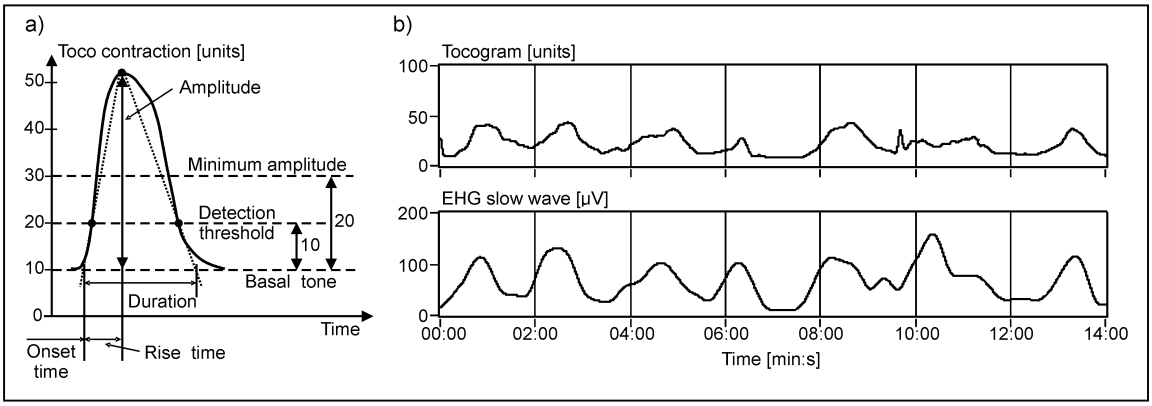

Fig.2 Time domain parameters important for the contraction detection (a). The contractions curve obtained from EHG signal (from figure 1) together with simultaneously recorded Toco signal after preliminary low-pass filtration (b)

The algorithm for automated detection of contractions implemented in our system is based on the analysis of frequency distribution of Toco values. The preliminary low-pass filtration at 0.04 Hz is used to suppress the maternal breathing movements. The tocogram is analyzed in the window of four-minute width and with one-minute step. Such window comprises prelabour contraction of about 1.5 min duration together with the non-activity segment. The step of one minute is enough taking into account the very low variation of the basal tone. Within each window the histogram of Toco samples is created with values ranging from 0 to 100 in classes of 1 unit width. The modal value of histogram is taken as a basal tone value. New value is calculated every 1 minute and the linear interpolation between this value and the previous one is carried out. If the Toco signal exceeds threshold level (10 units above the basal tone) the procedure for contraction detection starts. The contraction is valid when the tocogram remains above the detection threshold for the time longer than 30 s and the amplitude of contraction exceeds 20 units. Apart from the amplitude and duration, other timing parameters of contractions are calculated. The onset time is related to the start of monitoring whereas the rise time is defined as a difference between the onset time and the time when the contraction reaches the maximum amplitude. These parameters are usually used to determine time dependencies between contraction pattern and fetal heart rate variability, which allows classification of the deceleration patterns. The contraction area represents the area below the curve and it is expressed in seconds × units – [s. units].

The time domain analysis of the electrohysterogram starts from extraction of the slow wave and then contractions detection can be accomplished in the similar way like for the tocogram [4]. However, the lack of any established variation range of EHG amplitude has to be taken into account. Therefore, we have proposed the algorithm for the contractions detection, which compensates the amplitude variation between electrohysterograms. The slow wave is extracted by the RMS-based approach. The consecutive RMS values are calculated in 60 s Hanning window of the electrohysterography signal (1200 samples) shifted with 3 s step.In the second stage the basal tone is determined at first, and then the threshold values considering both duration and amplitude of contraction are applied. In every window of 4-minute width, samples of slow wave are ordered from the lowest to the highest value, and the mean value from the 10 % of samples from the lower side is calculated. So, this process can be called as the join median – moving average filtration.The threshold level for contractions detection is obtained by adding to the basal tone the value equal to 25 % of the signal range in the analyzed window. The contraction is recognized when its duration is greater than 30 s and its amplitude is higher then the double distance between the basal tone and the threshold.

2.3. COMPARISON PROCEDURE

Analysis of both tocogram and electrohysterogram can provide timing parameters of particular contractions recognized as being consistent. The criteria of contractions consistency were determined basing upon analysis of phenomena being the background for electrical and mechanical uterine activity as well as on relation between both signals. Electrical excitation of myometrium cells is a source, while a mechanical contraction is a result. Mechanical contraction of cell starts after the cell reaches the depolarization phase. Hence, it should be expected that electrical action precedes the mechanical contraction and the maximum action potential should occur in a rising phase of the contraction. On the other hand, excitation propagation in uterus is undetermined and the time needed for the excitation to reach the measurement area of electrodes may be variable. Finally, the criteria of contractions consistency have been defined as follows: the beginning of the contraction detected on a basis of the slow wave of the EHG signal should be prior to the maximum of the mechanical contraction. Furthermore the maximum of the EHG contraction should occur within the duration of the corresponding contraction in tocogram. For the quantitative evaluation of contractions consistency we defined CCI index:

$$CCI = \frac{N_C}{\frac{1}{2}(N_T + N_E)} \tag{1}$$

where: NT – the number of contractions detected in Toco signal, NE – the number of contractions detected in EHG signal, NC – the number of consistent contractions.

This index takes the boundary value of 0 when NC = 0 and it means full inconsistency. The value of CCI is 1 when NT = NE = NC and it means full consistency, when in both signals the same number of contractions are detected and all of them are found to be consistent. Quantitative comparison of consistent contractions with regard to duration and rise time was carried out using Bland and Altman method. This is based on a plotting the differences between pairs of values against their means. If there is no obvious relation between the difference and the mean, the level of agreement can be evaluated by calculating the mean difference (estimating the bias) and the standard deviation of the differences. The amplitudes (as well as areas) of the consistent contractions can not be evaluated directly using the differences between their values, because of different units in which both signals are expressed. Therefore we have decided to use Pearson’s correlation coefficient to check if amplitudes (areas) of the consistent contractions are linearly associated.

3. EXPERIMENTS AND RESULTS

We have acquired 108 traces during 24-hour period before labour from the group of patients between 37 and 40 week of gestation. The average time of recording was 40 minutes. Total number of contractions recognized in electrical signals (1392) was higher by several percent than the number obtained from the mechanical activity signals (1325). It can be the result of the expected higher sensitivity of the electrical approach. Moreover, the significant impact of basal tone estimation method as well as the established thresholds should be taken into account.

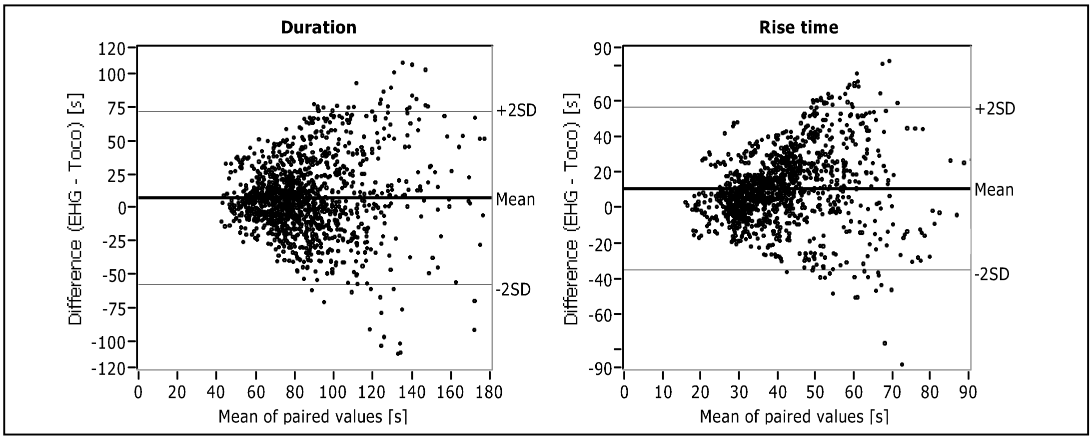

Fig.3 Plot of differences against means of paired values with regard to duration and rise time of consistent contractions

The mean duration of EHG contractions was slightly higher than the mean duration of Toco contractions. In the whole material the 1238 contractions were recognized as consistent, which corresponded to 89 % of EHG and 93% of Toco contractions. The consistency coefficient CCI reached a very high value of 0.91. The mean value of the time shift between EHG and Toco contractions (referring to the bias shift) calculated for all consistent pairs was –14 s. Negative value shows that the contraction recognized in electrical signal usually precedes the corresponding contraction in the mechanical signal.

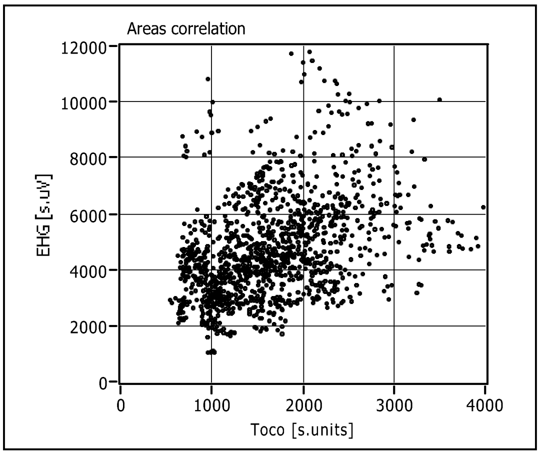

Fig.4 Correlation of areas determined for consistent contractions

The Bland-Altman plots showed us that both for the duration and the onset time of contractions the differences between the pair of values were considerably dependent on their mean values (Fig. 3). Rather low correlation (r = 0.46) between areas of consistent contractions has been noted, the lack of linear relationship is illustrated in Fig 4.

4. CONCLUSION

The electrohysterogram, unlike the tocogram, is very difficult for visual interpretation because of its more complex structure. Although the bursts of action potential spikes can be recognized visually, their quantitative parameters concerning both time and frequency domain can be determined only by the use of computer-aided system.

None of the methods discussed can be assumed as reference method with regard to the determination of timing parameters of recognized contractions. In case of external tocography, the reason is the inaccurate mechanical technique based on indirect measurement of strain exerted by the uterine muscle on the abdominal wall. As for the electrohysterography, the slow wave undergoes the analysis. This wave represents the change of action potentials amplitude which is related to the mechanical contraction. However, the amplitude recorded from maternal abdomen is also influenced by other conditions which are not associated with mechanical activity: propagation of electrical excitation and the surface area from which the action potentials are recorded. In the uterine muscle a direction and range of excitation depends mainly on so called gap junctions, which allow for the rapid communication between adjacent cells. Concluding we can say that the electrohysterography and external tocography, presenting two different approaches to monitoring of uterine contraction activity, demonstrate high agreement in relation to the number of contractions recognized as consistent. However, their agreement in relation to quantitative description of recognized patterns is unacceptable to consider these methods as fully alternative.

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