

Monitoring of contraction activity of uterine muscle by the use of abdominal electrohysterography

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Monitoring of contraction activity of uterine muscle is important diagnostic tool used both during pregnancy and labour. The strain of pregnant uterus exerted on maternal abdomen is measured via external tocography. However, limitation of this approach has caused a development of other technique – electrohysterography, which is based on recording an electrical uterine activity. The comparison between electrohysterography and tocography was made due to the possibility of the simultaneous recording of mechanical and electrical uterine muscle activity. The results obtained show that both methods demonstrate high agreement in relation to the number of contractions recognized as being consistent.

1. Introduction

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

At present the external tocography is most commonly used for uterine activity monitoring, because it is a noninvasive and simple measuring technique. The Toco signal provided is the result of simple transformation of a strain exerted by uterine muscle through the abdominal wall on the strain gauge transducer. In common opinion, the only information from the tocogram which can be considered as reliable is

a number of the contractions detected. Quantitative parameters describing contractions like duration or strength can be estimated with quite poor accuracy. Thus, tocography is mainly treated as a technique useful for the control of labour progress.

This limitation has been confirmed by comparing the external tocography with the intrauterine pressure measurement. The latter technique is able to provide us with the most reliable information on uterine contractions. However, being invasive and very complex the internal tocography has no practical use as a 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). A full information, describing also electrophysiological properties of the uterus, can be obtained by recording its electrical activity.

2. Methodology

2.1. Signal acquisition

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

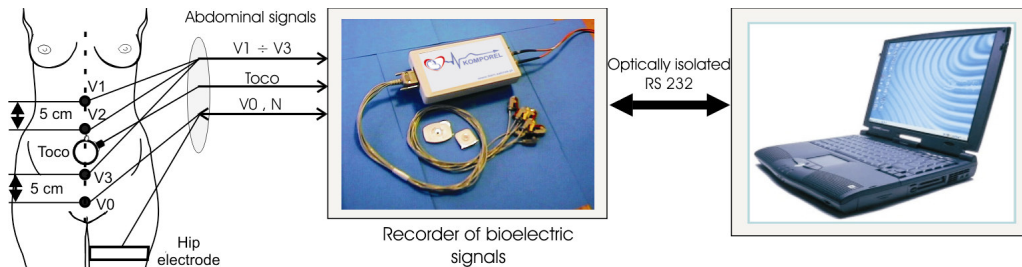


Fig. 1. Computerized system for the analysis of electrical and mechanical uterine contraction activity signals recorded from maternal abdomen

The recorder is based on 8-bit microcontroller and 16-bit A/D converter. Application of the optical serial link and battery supply ensures maximum safety of a mother and her child during the monitoring session. The control of a digital potentiometer for gain adjustment and the cut-off frequency switch takes place exclusively in a digital part. But their power supply and the reference voltage of A/D converter are provided by an additional voltage regulator from the analogue part of the circuit. As in [3], a total separation of an analogue part from a digital one (separate PCBs) has ensured

very low level of own noise measured with reference to input ($0.5 \mu\text{V}$ peak-to-peak) and large CMMR (120 dB).

Three channels were used to record abdominal signals to allow selection of a 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 measuring channel was adopted to cooperate with strain gauge transducer (Oxford, UK) providing the Toco signal in the typical range from 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 figure 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. Analyses of tocography and electrohysterography

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 the number of episodes per 10 minutes) and calculation of parameters used for quantitative evaluation of contractions in the time domain (figure 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 a clinician only to estimate the contraction amplitude as well as 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 closer accuracy compared to 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.

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.

All additional signals (basal tones, contraction curves) determined during the analysis undergo resampling to 20 Hz (sampling frequency established in the system) by the linear interpolation. The tocogram is analyzed in the window of four-minute width and with one-minute step. Such a window comprises prelabour contraction of about

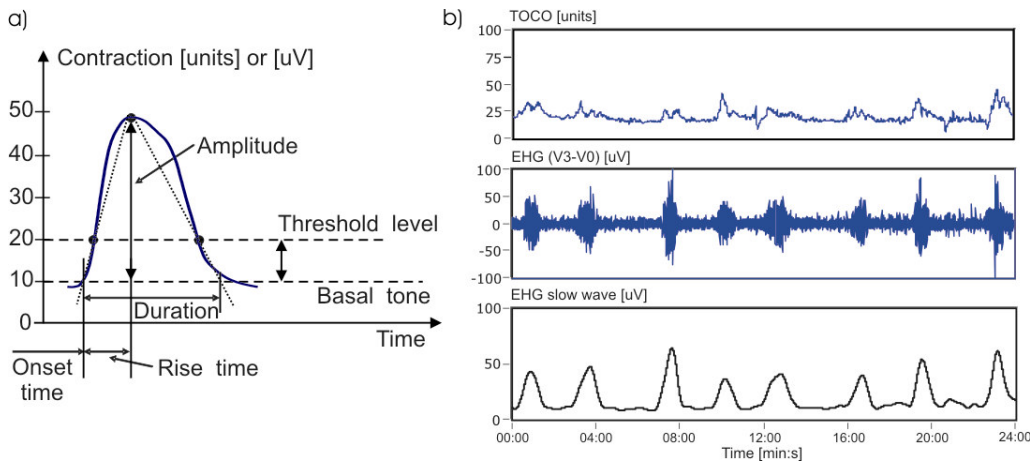


Fig. 2. Parameters describing features important for the contraction detection (a). The contractions curve obtained from EHG signal (V3–V0) together with simultaneously recorded Toco signal after preliminary low-pass filtration (b)

1.5 min duration together with the non-activity segment. The one-minute step is enough, taking into account a very narrow variation of the basal tone. Within each window the histogram of Toco samples is created with values ranging from 0 to 100 in the classes of one-unit width. The modal value of histogram is taken as a basal tone value. New value is calculated every one minute and the linear interpolation between this value and the previous one is carried out. If the Toco signal exceeds the 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 the time-dependent relationships between the contraction pattern and the variability of fetal heart rate, which allows classification of the deceleration patterns. The contraction area represents the area below the curve and it is expressed in seconds \times units [s \cdot units].

The time domain analysis of the electrohysterogram starts from the extraction of a slow wave and then contractions detection can be accomplished in the way similar

to that of 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 for the amplitude variation in electrohysterograms. The slow wave is extracted by the RMS-based approach. The consecutive RMS values are calculated in 60 s Hanning window of the electrohysterograph 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, the 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 window analyzed. The contraction is recognized when its duration is longer than 30 s and its amplitude is higher than the double distance between the basal tone and the threshold.

2.3. Comparison procedure

The analysis of both tocogram and electrohysterogram can provide timing parameters of particular contractions recognized as being consistent. The criteria of contractions consistency were determined based on the analysis of phenomena being the background for electrical and mechanical uterine activity as well as on the 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:

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

where: N_T – the number of contractions detected in Toco signal, N_E – the number of contractions detected in EHG signal, N_C – the number of consistent contractions.

This index takes the boundary value of 0 when $N_C = 0$ and this means full inconsistency. The value of CCI is 1 when $N_T = N_E = N_C$ and this 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 made using the 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 the areas) of the consistent contractions cannot 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 whether the amplitudes (areas) of the consistent contractions are linearly dependent.

3. Results

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

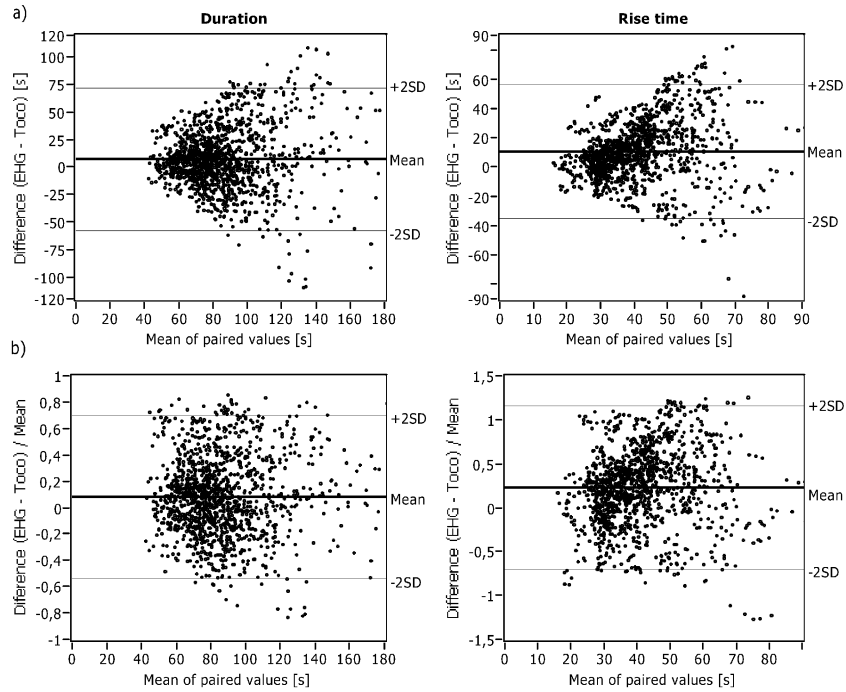


Fig. 3. Plot of differences (a) and relative differences (b) against means of paired values with regard to the duration and rise time of consistent contractions

The mean duration of EHG contractions was slightly longer than the mean duration of Toco contractions. In the whole material, 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. Its negative value shows that the contraction recognized in electrical signal usually precedes the corresponding contraction in the mechanical signal.

The Bland–Altman plots showed that both in the case of the duration and the onset time of contractions the differences between the pairs of values were considerably dependent on their mean values (figure 3a). Therefore, each of the differences was related to the means of two values being compared (figure 3b). This allowed us to evaluate the compatibility of both methods using the mean value of related differences and the standard deviation. We obtained the mean value of 0.08 (2SD = 0.62) and 0.22 (2SD = 0.94) when comparing respectively the duration and onset time of contractions. This testifies to a very poor compatibility between the methods. Very low correlation ($r = 0.16$) between the amplitudes of consistent contractions has been noted, the lack of linear relationship is illustrated in figure 4. A higher correlation ($r =$

0.46) has been obtained for contraction areas: however, it is still very weak and, as a result, the compatibility between the methods is low.

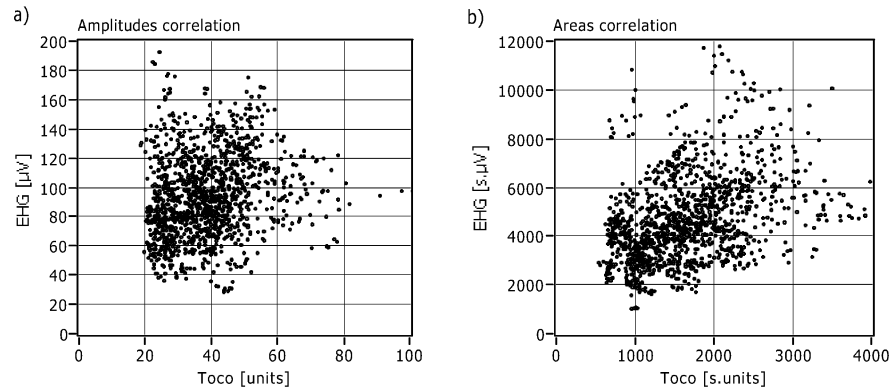


Fig. 4. Consistent contractions – correlation of amplitudes and areas

4. Conclusions

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 for determining the timing parameters of the contractions recognized. In the case of external tocography, the reason is an inaccurate mechanical technique based on indirect measurement of strain exerted by the uterine muscle on the abdominal wall. As for the electrohysterography, a 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 depend mainly on the so-called gap junctions, which allow a rapid communication between adjacent cells. Concluding we can say that the electrohysterography and external tocography, presenting two different approaches to the monitoring of uterine contraction activity, demonstrate high compatibility in relation to the number of contractions recognized as consistent. However, their compatibility in relation to quantitative description of recognized patterns is unacceptable to consider these methods as fully alternative.

References

- [1] HARRISON A., CROWE J.A., HAYES-GILL B.R., VAN WIJNGAARDEN W., *Use of the electrohysterogram for uterine contraction monitoring during labour*, Proc. 3rd Eur. Conf. on Eng. and Med., 1995, 90.
- [2] HOROBA K., JEZEWSKI J., WRÓBEL J., GRACZYK S., *Algorithm for detection of uterine contractions from electrohysterogram*, 23rd Int. Conf. of the IEEE Engineering in Medicine and Biology Society, Istanbul X, 2001, pp. 461–464.
- [3] JEZEWSKI J., HOROBA K., MATONIA A., GACEK A., BERNYS M., *A new approach to cardiotocographic fetal monitoring based on analysis of bioelectrical signals*, Proc. 25th Int. Conf. IEEE EMBS, 2003, pp. 3145–3149.
- [4] RADHAKRISHNAN N., WILSON J.D., LOWERY C., ESWARAN H., MURPHY P., *A fast algorithm for detecting contractions in uterine electromyography*, IEEE Eng. Med. Biol., 2000, 19, pp. 89–94.