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# Method for Simultaneous Monitoring of Uterine Contractions and Abdominal Pushing in a Childbirth

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***Abstract*—Effective and safe labour requires good cooperation of all the physiological systems. A proper synchronization of uterine and abdominal muscles is necessary for labour progression. Therefore, a new method for simultaneous monitoring of uterine activities and parturient's pushing efforts is presented. A high sampled, rectified electrohysterographic signal is divided into a low, uterine passband (0.1-3.00Hz) and a high, muscular (40-100Hz) one. The time-dependent mean frequencies arse estimated for each passband separately. At the moments of uterine contraction the time-dependent LOW mean frequency was locally increased. During parturient's pushing effort the HIGH mean frequency was increased in the manner typical for the skeletal muscles. It seems that the proposed method would be less sensitive to a measuring noise than the previously published RMS based estimators. Moreover, the proposed method enables to monitor fatigue of a uterus or abdominal muscles during the prolonged 2$^{nd}$ stage of a labour. It can be helpful to make a decision of Caesarean section.**

***Keywords*—labour; electrohysterography; electromyography; instantaneous frequency**

## I. Introduction

REPRODUCTION is an essential goal of life for many people. However, the biological and psychological mechanism of reproduction, including labour is still little known because of historical and cultural constraints which still prevail in many countries. On the other hand, lack of a model describing a given process makes it impossible to control it effectively. Thus, midwives and obstetricians' lack of knowledge of labor biomechanics makes it difficult for them to manage the labour and delivery process, which r0esults in an excessive number of Caesarean sections and increasing number of neonatal complications observed in developed countries [1].

The most important clinical task in labour management is to control the force which causes delivery of a healthy baby. This force is generated by stageically variable intrauterine pressure which moves the foetus down to the vagina. There are two sources of that pressure: (i) uterine contractions and (ii) abdominal pressure created by parturient's consciously contracting abdominal skeletal muscles and simultaneously relaxing pelvic floor muscles.

On the basis of a biomechanical model Miller et al. indicated that mother's pushing increased the expulsive force twice as compared to the force generated only by uterine contractions [2]. Despite this fact, labour progress monitoring is limited to routine measurement of the uterine component only.

The most accurate method assessing uterine contractions is wmeasurement of intrauterine pressure (IUP) by a balloon sensor placed inside the uterus. This way is treated as a "gold standard". However, it cannot be used `clinically because it is invasive and increases the risk of an intrauterine infection.

The standard method used involves external tocography which indeed measures the increasing stiffness of the uterine wall during its contraction. This way has a number of drawbacks. Comparing the intrauterine pressure course with the tocographic signal shows weak correlation in relation to the moment of a contraction, its duration and amplitude. These discrepancies are greater with the growing BMI of parturient women [3].

Electrohysterography (EHG) – an alternative to external tocography - measures bioelectrical activity of myometrium preceding the mechanical contraction of a uterus. There is a large number of methods used for estimation of mechanical uterine activity based on EHG signals. An excellent review of those methods is provided by Garcia-Cascado et al. [4]. Some of them use linear or nonlinear EHG parameterizations that highly correlate with labour progress . Others construct an IUP estimators based bioelectrical signals.

Multiplicity of these ways stems from the fact that there is no coherent model explaining physiology of a uterine contraction at cell and organ level. It seems likely that a uterus has several pacemakers rather than one (as in case of a heart). They are randomly distributed which works as coupling oscillators [5].

However, there is an agreement among researchers that propagation of bioelectrical signals through the uterus is very slow. Therefore, the interested frequency passband of EHG signals is limited to maximum 3.00 Hz, the highest frequency usually not reaching 1 Hz. Higher frequencies are treated as useless noises.

Yet, the EHG can be seen as a particular case of electromyographic signals (EMG). So, the higher frequencies measured may derive from abdominal muscles.

Such a concept is presented by Qian et al. who showed that uterine EMG bursts preceded abdominal bursts and were accompanied by feelings of "urge to push" by the subjects. This conclusion was derived from the analysis of RMS values and

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power spectrum values computed for a higher passband of EHG signals. It is a promising direction but the parameters used are highly sensitive to any impulse disturbances or noise.

It is well known that there is a strong relation between instantaneous frequency of EMG signals and skeletal muscle activities. Potvin showed clearly that the instantaneous frequency of EMG signal varies during static and dynamic muscle contractions [6]. Moreover, the signal frequency usually is more resistant to amplitude disturbances.

The second important obstetrical problem is dystocia. Labor dystocia is a broad term defined statistically as cervical dilation occurring at a rate slower than the 95th percentile of normal labors. Treatment of labor dystocia is limited to oxytocin augmentation followed by cesarean birth if inadequate cervical dilation persists. However, approximately 12% of women do not respond adequately to oxytocin. Augmentation suggesting variation in the underlying pathophysiology of labor dystocia that is not well understood.

Measures of contractioncoordination including contraction shape, uterine electrical activity, and patterns of contractions over time may be effective for identifying uterine fatigue and differentiating it from other causes of labor dystocia such as understimulation of contractions or fetal malposition. The purpose of this integrated literature review was to synthesize existing evidence from studies of uterine activity during labor dystocia with an emphasis on evaluating measures that may identify uterine muscle fatigue.

Therefore, the author proposed to use the instantaneous frequency and its mean value computed for the lower and higher passband of the EHG signals for simultaneous monitoring of uterine contractions and parturient's pushing.

## II. METHODS

### A. EHG signals acquisition

There is a great variety of the EHG signals researched in different studies. In most 1of them EHG acquisitions were performed by their authors. Then, the signals were recorded with a low sampling frequency according to the EHG passband. Some authors used the database of the EHG signals available in a public database of physiological signals called Physionet [7]. The use of these signals enables a more sophisticated comparison of the results published, independent of acquisition methods and the studied groups of pregnant women.

Physionet consists of two EHG sets. The first one includes 300 registered EHG signals in pregnant women who had preterm or term labours. However, the passband of these signals is limited up to 4Hz. It makes it impossible to analyse the activity of abdominal muscles.

The second set of EHG records contains signals registered du0ring labour or in 3rd trimester of pregnancy. These signals are not filtered. Their sampling frequency 200 Hz enables signal analysis within the passband characteristic for EMG signals. This database is called Icelandic 16-Electrodes Electrohysterogram Database. The signals were registered by 16 monopolar electrodes placed in the form of the 4 x 4 matrix on abdominal skin within half the distance between uterine fundus and pubic symphysis. Detailed description of the signals is given in [8[.

Fig.1 present placement of EHG electrodes on the abdominal skin of a pregnant woman, These EHG signals were used for the presented analysis because of a wide frequency range.

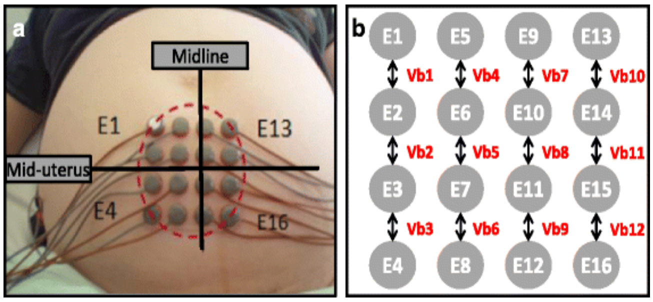


Fig 1. The system of EHG electrodes placed on the abdominal skin of a pregnant woman

### B. EHG signals processing

The Icelandic EHG database contains raw data so any signal processing can be applied. In this study the EHG was treated as a particular case of electromyography so the methods used for EMG were applied to the these signals.

The signal obtained from 16 electrodes was averaged to reduce a measurement noise. Averaging integrates bioelectrical activity of the uterine space located under the electrode matrix. Next, the trend was removed from the signal. According to EMG guidelines such a signal was rectified. The processed EHG signal is denoted by $x(t)$ . The 4$^{th}$ order Butterworth filter was used to extract the uterine component (0.1-3Hz) and the abdominal muscles component (40-100Hz). The applied notch filter attenuated the 60Hz component derived from an 2electrical grid.

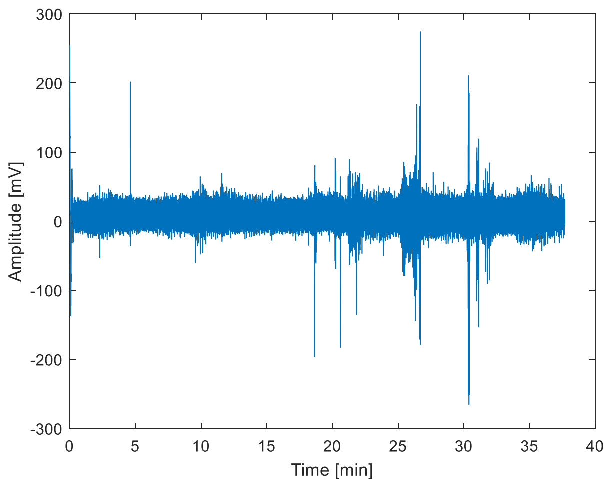


Fig 2. Raw EHG signal registered during an active phase of a labour

### C. Estimation of instantaneous frequency

A conception of instantaneous frequency derives from the theory of signal modulation. Electromyographic signals are also modulated because the number of activated myocytes depends on a muscle load. Instantaneous frequency is defined as follows[9]:

$$f(t)=\frac{1}{2\pi}\frac{d\varphi(t)}{dt} \quad (1)$$

where $\varphi(t)$ is the instantaneous phase expressed by

$$\varphi(t)=\arctan\frac{\mathrm{H}\left(x(t)\right)}{x(t)}\,. \quad (2)$$

The operator $\mathrm{H}\left(x(t)\right)$ is a Hilbert transform of the EHG signal. It is given by the following formula:

$$X(s)=\mathrm{H}\left(x(t)\right)=\frac{1}{\pi}\int_{-\infty}^{\infty}\frac{x(t)}{s-t}dt \quad (3)$$

Computing of the instantaneous frequency is impractical by definition because it produces negative frequencies. Therefore, the instantaneous frequency was estimated using the first moment of the time-frequency power spectrum, i.e.

$$f(t)=\frac{\int_0^{\frac{F_S}{2}} f\,P\left(f,t\right)df}{\int_0^{\frac{F_S}{2}} P\left(f,t\right)df} \quad (4)$$

There are many methods for estimating the time-frequency power spectrum $P(f,t)$. The most accurate is the Wigner-Ville distribution. However, this method is RAM- and time-consuming so its use in clinical monitoring is limited. Also, it gives biased instantaneous frequency in case of noisy signals.

Moreover, we do not need high time-frequency resolution because we want only to observe changes of instantaneous0 frequencies caused by uterus or abdominal muscles. Therefore, the power spectrum was estimated by Short Time Fourier Transform:

$$P(f,t)=\left|\int_{-\infty}^{\infty}x(\tau)h(\tau-t)e^{-j2\pi f\tau}d\tau\right|^2 \quad (5)$$

The Hann sliding window $h(t)$ was applied.

The estimator (4) can be treated as a time dependent mean frequency because the following equation holds:

$$\overline{f}\overset{!}{=}\frac{1}{T}\int_0^T f(t)dt=\frac{\int_o^{\frac{F_S}{2}} f\,P(f)df}{\int_o^{\frac{F_S}{2}} P(f)df}\,, \quad (6)$$

where $P(f)$ is a power spectrum. The right side of the equatio0n (6) is the mean frequency of the EHG signal. This parameter is often used in electromyographic analyses. Generally, the maximal energy of EMG signals for skeletal muscles is located within the range: 40-80 Hz [10]. Sbrolini *et al.* showed that the time-dependent median frequency for an abdominal rectus varied from 40-150 Hz [11]. Therefore, in our study, the passband for abdominal muscles ranged from 40 to100 Hz while the frequency interval for uterine EHG equalled 0.02-3.00Hz. By setting the integral limits to values corresponding to the uterine or muscle passband we can assess the activity of a contractile organ.

The total power spectrum for uterine and abdominal muscles was also computed as follows:

$$P=\int_0^T\int_{f_d}^{f_u}P(f,t)\,df\,dt\,, \quad (7)$$

where $f_d, f_u$ are the passband limits for the uterus or the abdominal muscles. $T$ is the analysed signal duration.

Additionally, the RMS values were computed for the uterine and muscle components of the EHG signals.

## III. Results

### A. *EHG signals registered in women in labour*

The analysis was performed of the EHG signals registered in 10 parturients. For clarity of the obtained results, firstly the case of a woman going through the 2nd stage of labour is presented. Unfortunately she had still too rare uterine contractions so the oxytocin was administered. It is important that the woman was trained in a childbirth school. Thus, in the Fig. 3 we see the complete synchronization between the uterine and he abdominal muscle contractions. The birthing woman feels contractions of her uterus and pushes at these moments.

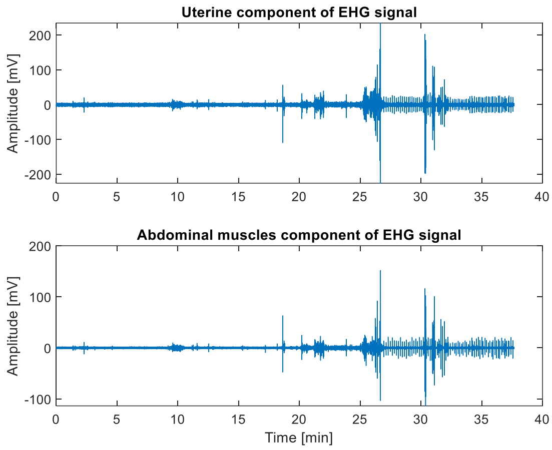


Fig 3. Uterine and abdominal muscles components of the EHG signal registered during the 2nd stage (active) of a labour in the woman trained in a childbirth school

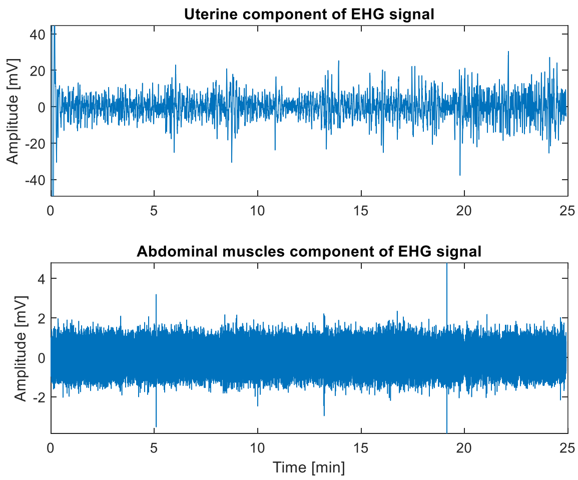


Fig 4. Uterine and abdominal muscles components of the EHG signal registered during the 1st stage of a labour

In opposition, Fig. 4 presents the uterine and abdominal muscles bioelectrical activities during the 1st stage of a labour. Then, there is no contractions of abdominal muscles. Only the uterus adopts for an impending birth.

### B. *Time-dependent mean frequencies of EHG signals*

Figure 5 shows the time-frequency power spectrum. Its maximal value was obtained for a uterine activity up to 20th minutes. It equalled $P_{first}^{uterus} = 1.10E7$ .At the en0d of the recording, this value decreased to $P_{end}^{uterus} = 5.06E6$ , which can suggest fatigue of the uterine myometrium. On the other hand, the total power spectrum for the abdominal muscles increased 0significantly from $P_{first}^{muscles} = 6.10E3$ up to $P_{end}^{muscles} = 1.38E5$ . However, this power value did not exceed the start0ing power value of uterine contractions.

The time dependent mean frequency called the instantaneous frequency for the uterine and abdominal muscles components is presented in Fig. 6. We can observe three frequencies increased locally. The time duration of these peaks does not exceed 1 minute, which is consistent with the interval of a uterine contraction. They also correspond to the time-location of uterine contractions provided for in the clinical data for that parturient.

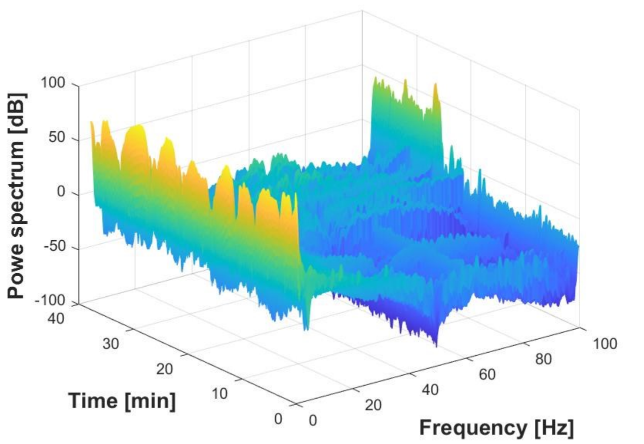


Fig 5. Time-frequency distribution of the EHG power spectrum for women being in the active phase of labour. The uterine (low frequency) and the abdominal muscles (high frequency) components are observed

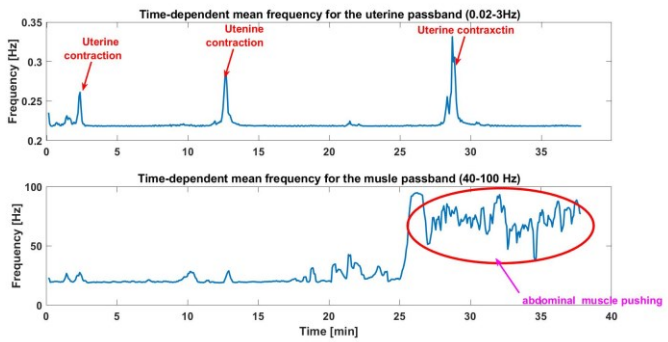


Fig 6. Times-dependent mean frequency estimated for the uterine and abdominal muscle activity during the active labour phase for a woman untrained in a school of childbirth

On the other hand, the abdominal muscles frequency increases significantly around the third, strongest contraction of the uterus. Three sequential maxima can be observed, which can correspond with the parturient's pushing efforts. However, the first and second uterine activities are not related with the labour pressure. This woman was untrained in a school of childbirth.

By increasing the time resolution of the instantaneous frequency of the abdominal muscles we note fast changes of this frequency (Fig. 7).

Moreover, we can see an almost linear trend since the muscles become activated. The results are compatible with the study carried out by Yousif et al [12].

Interestingly, this variability differs from the strictly stageical character of the mean frequency obtained for the uterine ranges (0.02-3.00 Hz). Such a diversity has been observed for the first time. Perhaps, it stemmed from a different histological structure of a skeletal muscle (striated muscles) and the myometrium belonging to smooth muscles. It seems that the stageic frequency dynamic allows for energy recovery for the nex0t uterine contraction. Moreover, it saves the foetus because each uterine contraction produces short foetal hypoxia.

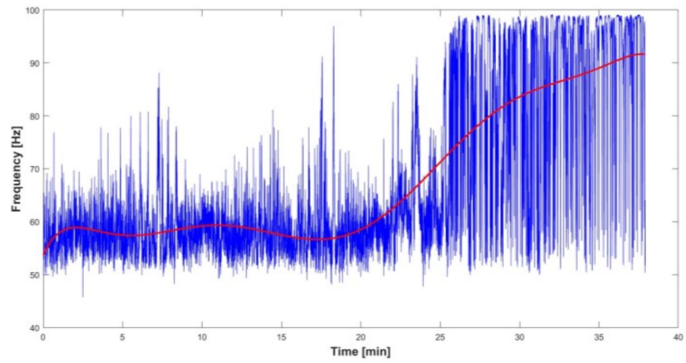


Fig 7. Variability of the time dependent mean frequency for the abdominal muscles passband. The red line shows the trend

Whereas, Fig. 8 illustrates coordination between labour activity of the uterus and the abdominal muscles for the woman earlier trained in a school of childbirth. In this case increasing of the mean EHG frequency in the uterine passband is related to of the mean EHG frequency in the abdominal passband. So, the woman pushes simultaneously with the uterine contractions to increase labour effectiveness.

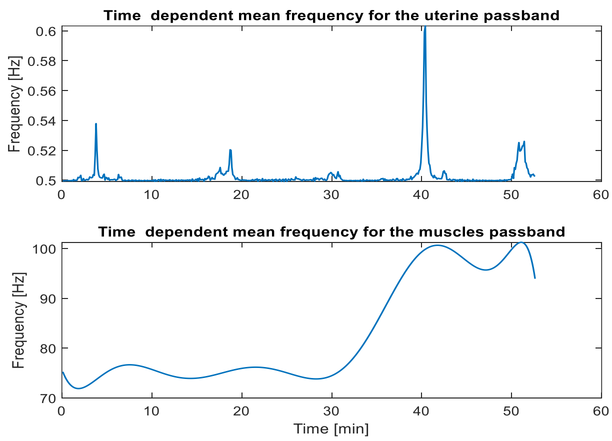


Fig 8. Times-dependent mean frequency (instantaneous frequency) estimated for the uterine and abdominal muscle activity during the active labour phase for the woman trained in a school of chilbirth

The Fig.4 shows the clear relation between bioelectriocal actvities of the uterus and tension of the abdominal muscles expressed by increasing of the signal instaneous frequency. This woman was taught tu push together with constractions of the usterus.

To confirm the above results we also computed the RMS values of the rectified EHG signal obtained after filtering to the abdominal muscles passband. By computing RMS values for up to and over 25th minute we also note that the laobur pressure increases the amplide of the muscle component of the wideband EHG signals (2.09 vs. 11.25) (Fig.9)

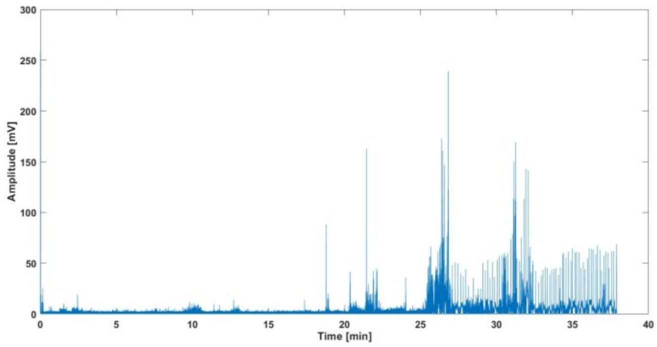


Fig 9. Abdominal muscles component of the EHG signal for a pushing parturient in the active phase of a labour

### C. *Uterus and muscles fatigue identification*

The time-dependent mean frequency of two components of EHG signals can be used for fatigue identification of a uterus or abdominal muscles. This situation is presented in Fig. 10.

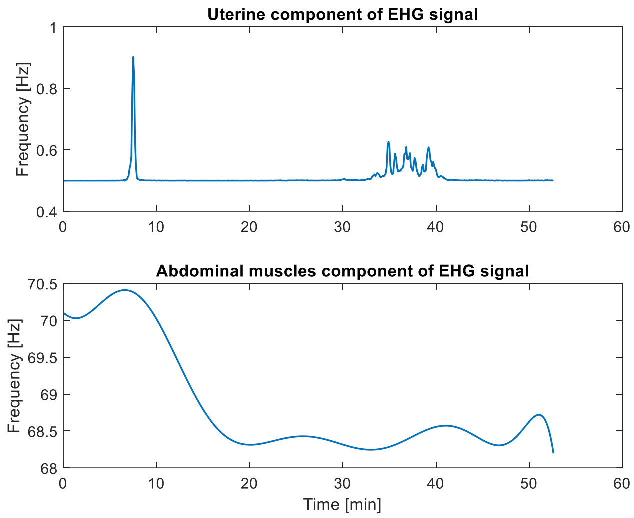


Fig 10. Time dependent frequencies of the uterine and abdominal muscles components of the EHG signal registered during the prolonged 2nd stage of a labour

Uterine and abdominal muscle components of the EHG signal registered in during the prolonged 2nd labour stage

In this case we observe time-decreased frequencies of the uterine and abdominal muscles components of the EHG signal. It is compatible with the well-known theory of EMG signals stating that muscle fatigue is associated with decreasing of frequencies and amplitudes of electromyographic signals.

## IV. Conclusions

From a biomechanical point of view, labour is a complex process which requires synergetic activities of the uterus, skeletal muscles, diaphragm, pelvis and pelvic floor. Clinically, only uterine contractions are monitored using tocography.

Numerous studies show that the electrohysteriography 0gives superior advantages, particularly in pregnant women suffering from0 obesity [3].

According to my best knowledge this is the first analysis to present the application of the instantaneous frequency for simultaneous monitoring of uterine contractions and parturient's pushing effort. The results discus00sed suggest that the frequency passband of EHG signals should be expanded up to 500 Hz because it is recommended for the classical electromyography.

Considering a pregnan0t woman featuring the optimal anatomical structure of her reproductive duct, Miller *et al* found out that the intrauterine pressure applied, the expulsive force on the foetal head equalled to 54N. It increased to 120N when the parturient pushed. There is a monotonic relation between a force generated by a muscle and the EMG frequency [13]. On the other hand, results of epidemiological studies indicate that too strong and too long pushing effort can produce hypoxia and increase intracranial pressure in the foetus which leads to neurodevelopmental complications [14]. Thus, considering this fact along with the ultrasound- based estimation of the foetal weight, perhaps a regression model may be built to predict a chance or time of vaginal delivery. Such a model can use the "on line" computing mean frequencies of uterine and muscles components.

The obtained results also suggest that monitoring of the mean frequencies of the proposed two components of EHG signals may help to identify fatigues of a uterus or abdominal muscles. It can be a clinical indicator for emergency surgical delivery of a foetus preventing her or his sever hypoxia.

Moreover, this paper offers the first ever presentation of a different character of the mean frequency variability between the uterine and abdominal passband. It may suggest that the components measured come from organs which have different histologic structures.

It is also possible that contractions of abdominal muscles give the high frequency "noise" of the tocographic signal. Maybe mechanomyography similar to EHG would be a more effective technique for the purpose discussed.

The results presented may be useful for the recognition of labour biomechanical mechanism and better management of parturition. In the future they might be applied for the purposes of electrostimulation of the abdominal muscular and/or uterine contractions, already known in physiotherapy, as well as for the purpose of biofeedback to help a parturient woman synchronize pushes with uterine contractions.

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