Assessment of linear parameters of Electrohysterograph (EHG) in diagnosis of true labor

Farah Fatehalla Shero1*, Ghassan Thabet Saeed Al-Ani2, Ekhlas Jabbar Khadim3, Hind Zuhair Khaleel4

1, 2University of Baghdad/Alkindy College of Medicine/Department of Physiology.
3University of Baghdad/Baghdad College of Medicine/Department of Obstetrics and Gynecology.
4University of Technology/ Control and Systems Engineering Department/Baghdad-Iraq.

Corresponding author: Farah Fatehalla Shero (farah_shero@yahoo.com)

Abstract
The diagnosis of true labor has been described as one of the most difficult and important judgments made by providers of maternity care as accurate diagnosis of true labor is essential to predict preterm birth as early as possible to prevent subsequent complications associated with prematurity. Currently used techniques for prediction of true labor are either highly invasive (IUCP) or highly subjective with low predictive values (TOCO). There is a great need for a more reliable and non-invasive method to detect electrical changes in uterine muscles that occur during the transition from pregnancy towards labor. Analyzing EHG records and some linear parameters extracted from these records among Iraqi women during pregnancy and delivery.

Pregnant ladies who attended the obstetrical wards and labor rooms of Baghdad Teaching Hospital and Private Nursing Home at Baghdad Medical City from April- July 2019 and met the inclusion criteria were enrolled and divided into laboring and non-laboring groups based on presence of labor signs. EHG was recorded for 30 minutes using 4 disposable Ag/AgCl electrodes attached to the abdominal surface and a reference electrode. EHG records were digitized, stored and then analyzed to extract and compare some linear parameters between the two groups. Thirty-two pregnant ladies with a mean age of (27.72±5.64 years) were included in the study then were subdivided into 18 laboring and 14 non-laboring matched groups. Results showed a significantly higher root mean square, mean and peak frequency of the power spectral density values in labor compared to non-labor groups. In conclusion, Uterine EHG monitoring in pregnant women can be a very promising tool to diagnose the onset of true labor. Linear features extracted from EHG record, i.e. root mean square, peak and mean frequency of the power spectral density increase significantly in labor than pregnancy groups.

Keywords: Electrohysterograph, labor, EHG,


Introduction
Labor is the physiological process by which the fetus and other products of conception are expelled to the outside world and is defined as painful regular uterine contractions accompanied by cervical effacement and dilatation1. Preterm labor, defined as labor before 37 weeks of gestation, is the most common obstetric complication that occurs in about 20% of pregnant women2,3 and the most common cause of perinatal morbidity and mortality accounting for 75% and 50% of perinatal mortality and long-term morbidity, respectively4,5. In high- income countries with valid data, despite efforts of health care providers for several decades, preterm birth rates appear to have increased from 1990 to 20106. Similarly, the rate of preterm labor in Iraq increased from 6.5% in 2010 to 10% in 2016, and complications of preterm birth are considered the leading cause (33%) of neonatal mortality and the most common cause (20%) of death in children under 5 years of age7,8. The diagnosis of labor onset has been described as one of the most difficult and important judgments made by providers of maternity care9. More than 50% of patients who deliver preterm have no apparent risk factors10 and up to 50% of women admitted with the diagnosis of preterm labor are subsequently found not to be in true labor. On the other hand, 20% of symptomatic patients that are diagnosed as not being in preterm labor will deliver prematurely11, therefore; accurate diagnosis of true labor is essential to predict preterm birth as early as possible because most common interventions recommended preventing preterm birth, such as bed rest, tocolytics, antibiotics, and cervical cerclage have been proven to have little or no benefit once preterm

©Annals of Tropical Medicine & Public Health

Labor is established \[12\]. The diagnosis of labor today still often relies on the presence of contractions assessed by tocodynamometry (TOCO) and cervical change assessed by digital cervical examination. However, contractions occur commonly in normal pregnancy, and their detection through maternal perception and/or TOCO has a low sensitivity and positive predictive value for preterm delivery \[13, 14\]. Moreover, digital cervical examination suffers from large variations among examiners, and its prognostic values have also been shown to be low \[15, 16\].

Another method, using an invasive intrauterine pressure catheter provides the best information concerning uterine contractions, allowing the exact quantification of the mechanical effect of contractions, and is often considered the gold standard in assessing uterine activity. However, it requires ruptured membranes in order to insert the catheter into the uterus which is unpleasant to the woman and increases the risk of infection, accidental induction of labor, placental abruption, and uterine rupture \[17, 18\]. The labor process, both at term and preterm, involves activation of the uterine myometrium. Several events in the myometrium precede labor. Excitability of cells increases due to changes in transduction mechanisms and synthesis of various proteins, including ion channels and receptors for uterotonia \[19-21\]. At the same time, systems that inhibit myometrial activity, such as the nitric oxide system, are down-regulated, leading to the withdrawal of uterine relaxation \[22\].

Electrical coupling between myometrial cells also increases by an increasing number of gap junctions, and an electrical syncytium allowing the propagation of action potentials from cell to cell is formed \[23, 24\]. These changes are required for effective contractions that result in the delivery (expulsion) of the fetus. Researches have demonstrated that the electrical activity of the uterine myometrium is responsible for its contractions \[25, 26\]. It is well known that a single spike can initiate uterine contraction but multiple, coordinated, higher frequency spikes are essential for sustained and forceful contractions \[27\]. Uterine electrical activity is the result of the depolarization and repolarization of thousands of myometrial smooth muscle cells. The immediate succession of depolarization and repolarization results in intermittent bursts of spike-like action potentials. It has been shown that each contraction is associated with a burst of action potentials \[28\]. The uterine electromyogram arises from the generation and transmission of these bursts of action potentials in the uterine muscle. By spreading through gap junctions, from one myometrial cell to another, this activation results in an increased and organized electrical activity, particularly in the last trimester of pregnancy and during labor \[29\]. Studies have been done to monitor uterine contractility using the electrical activity measured from electrodes placed directly on the uterus \[30, 31\]. More recent researches indicate that uterine electrical activity and the transition from the non-labor to the labor state of the myometrium can be monitored non-invasively from the abdominal surface using uterine EMG (electromyography) \[32-34\]. Uterine EMG (electromyography) or EHG (electrohysterography) is a noninvasive technique that detects electrical signals from the uterus. The method uses electrodes that are applied on the abdominal surface over the pregnant woman’s uterus and identifies electrical activity and thereby contractions in the myometrium \[35\]. This current study is aimed at analyzing EHG records and some linear parameters extracted from these records among Iraqi women during pregnancy and delivery.

**Patients and Methods**

This observational case-control prospective study was conducted at the obstetrical wards and labor rooms of Baghdad Teaching Hospital and Private Nursing Home at Baghdad Medical City during the period from April to July 2019. The study was approved by the institutional medical ethical committee. In this study, the electrical signals of the uterus were measured both in labor and non-labor patients who were at term (gestational age ≥37 weeks), between 18-45 years of age, had singleton pregnancy with cephalic presentation and no current life-threatening medical condition.

While women with any of the following were excluded from the study: those who didn’t have an ultrasound report when admitted to hospital, those with body mass index ≥ 35 and/or polyhydramnios because both fat and fluid may compromise the quality of myometrial signal to be detected by the Electrophysterogram on the abdomen, multiple gestations, malpresentation/malpositions, those who were admitted for induction of labor, premature rupture of membranes (PROM), antepartum hemorrhage (e.g. placenta previa, placenta abruption), uncontrolled gestational diabetes, pre-eclampsia or severe anemia, any signs of fetal or maternal distress, known uterine malformations, fetal congenital anomalies by US and abdominal skin irritation.

The recording procedure was thoroughly explained to all pregnant women recruited in the study, verbal and written consent were obtained from all participating women. A detailed obstetrical, socioeconomic, and past medical and surgical history was obtained from the patients. The degree of cervical dilatation and final delivery mode (spontaneous, instrumental, and cesarean) for the labor group patients were also recorded. Gestational age was calculated from the date of the first day of the last menstrual period (LMP) and was confirmed by ultrasound (US) scan. The US also confirmed singleton pregnancy, fetal presentation, and wellbeing, placental position and amount of amniotic fluid. Vaginal examination of the patients for cervical dilatation and...
effacement and state of membranes was conducted by the attending physician. Labor was managed following the local obstetrical protocol.

Patients’ weight (kilogram) and height (meter) were measured by appropriate scales and Body Mass Index (BMI) was calculated using the equation: \( \text{BMI} = \frac{\text{Weight (Kg)}}{\text{Height (m)}} \) [35]. Patients were subdivided into laboring and non-laboring groups depending on the following criteria [36]: Presence of efficient regular uterine contractions \( \geq 3 \) times per 10 minutes, and Cervical dilatation \( \geq 4 \) cm with progressive cervical effacement.

**EHG Signal Acquisition System:**

The system used to measure uterine electrical uterine activity comprised of a multichannel surface EMG, an Arduino which is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on the computer, used to write and upload computer code to the physical board. And a personal computer providing data analysis and a graphical user interface.

**Data Acquisition:**

One record per pregnancy was recorded noninvasively. The records are of 30-min duration and consist of four channels and a reference electrode. The records were collected from the abdominal surface using Myoware Muscle Sensors (Figure 1) with attached disposable bipolar Ag/AgCl electrodes signals has been demonstrated to effectively reduce a large portion of the noise affecting the EHG, e.g. the maternal electrocardiogram, part of the motion artifacts and the electromagnetic noise [37]. The time frame of 30 minutes was chosen to compute features because it is both long enough to capture rhythmic patterns of contractions and short enough not to include noise which could be present in longer measurements simply due to maternal movement.

![Figure (1): Myoware Muscle Sensor](image)

During the recording procedure, the participating women were in the supine position and the sites of electrode attachment were prepared by shaving extra hair and gentle rubbing with the alcoholic solution to reduce electrode contact impedance. These women were informed that they could ask the recording to be stopped at any time and encouraged to notify the researcher if they felt any kind of discomfort during the recording.

The four disposable Ag/AgCl electrodes were applied to the abdominal wall in a diamond shape around the umbilicus. The first electrode was placed above the umbilicus at the point where external palpation indicated the uterus to be in close contact with the abdominal wall. Two electrodes were placed 4 cm to the right and left of the umbilicus respectively close to midline where the skin is thinnest, while the last electrode was placed in the centerline of the abdomen 10cm above the symphysis pubis. A ground electrode was placed laterally on the right hip. Women were encouraged to remain still without disturbing the electrodes of the recordings. EMG signals were sampled (acquired) at a sampling frequency of 20 Hz using Matlab R2018b, to reduce the computational cost of the data analysis. This sampling frequency is enough to compute the spectral parameters later described. The raw EMG signal was digitized then stored.

**Pre-processing:**

Signals were filtered using a low band-pass filter at range from 0.1 to 4 Hz to isolate the main frequency of interest for EHG data and to eliminate low and high-frequency noise caused by motion, respiration and cardiac signals while preserving the main contraction power and to optimize the signal-to-noise ratio.
Feature Extraction:
Various time and frequency linear parameters are calculated in this study:

Root mean square (RMS):
RMS is calculated as the root of the mean of the squares of all samples in that signal, as in the following equation:

\[
\text{RMS} = \sqrt{\frac{1}{N} \sum_{i=0}^{N-1} x(i)^2}
\]

Where \(N\) is the length of the signal.

Frequency-related parameters:
The EHG signal was transformed into the frequency domain using the fast Fourier Transform (FFT) in order to extract and analyze the frequency related features. All frequency parameters were then calculated from the power spectrum density (PSD).

1) Mean Frequency of the Signal Power Spectrum:
Mean power frequency (MPF) is the frequency at which the average power of the PSD is reached. It is calculated by the following equation:

\[
\text{MPF} = \frac{\sum_{i=1}^{N} t_i f_i}{\sum_{i=1}^{N} t_i}
\]

Where \((n)\) denotes the number of frequency components in the PS, \((f_i)\) is the value of the frequency and \((t_i)\) is the intensity of the power spectrum corresponding to the frequency \((f_i)\).

2) Median Frequency of the Signal Power Spectrum
The median frequency (MDF) is defined as the frequency that divides the power of the PSD above and below it into two equal parts. It is calculated as:

\[
\text{MDF} = F_{\frac{i_m}{N}} \sum_{i=0}^{i_m} P(i) = \sum_{i=i_m}^{i=N-1} P(i).
\]

Where \(f_s\) and \(N\) are the sampling frequency and the number of samples, respectively.

3) Peak Frequency of the Signal Power Spectrum:
The peak frequency of the signal power spectrum corresponds to the largest amplitude peak as determined by the power spectrum of the uterineEMG signals. It is calculated as follows:

\[
F_{\text{Peak}} = \arg \left( \frac{f_s}{N} \max_{i=0}^{N-1} P(i) \right)
\]

Statistical Analysis:
All statistical analyses were performed using (SPSS version 23). Independent sample t-test (two-tailed) and chi-square were used. Descriptive statistics were expressed as mean (\(X\)) and standard deviations (SD). P-value < 0.05 was considered statistically significant.

Results
32 term pregnant women (GA ≥ 37 completed weeks) who met the inclusion criteria with a mean age of (27.72±5.64) years ranging between 18-43 years were recruited in this study and divided into two main groups depending on presence of signs of active labor; 18 women were inactive first stage of labor with a mean age of (27.39 ±5.18) years and 14 were not in labor (28.14 ±6.35) years. The demographical characteristics of women in all groups are shown in table (1).
Table (1): Sociodemographic features of the study groups.

<table>
<thead>
<tr>
<th>Patient characteristic</th>
<th>Term labor (N=18)</th>
<th>Term non-labor (N=14)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maternal age (y)</td>
<td>27.39 (±5.18)</td>
<td>28.14 (±6.35)</td>
<td>0.72</td>
</tr>
<tr>
<td>GA (weeks)</td>
<td>39.45 (±1)</td>
<td>38.19 (±1.8)</td>
<td>0.12</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>28.89 (±3.23)</td>
<td>31.11 (±3.02)</td>
<td>0.55</td>
</tr>
<tr>
<td>Nullipara</td>
<td>7 (38.9%)</td>
<td>4 (28.6%)</td>
<td>0.34</td>
</tr>
<tr>
<td>Previous Abortion(s)</td>
<td>3 (16.7%)</td>
<td>5 (35.7%)</td>
<td>0.19</td>
</tr>
<tr>
<td>Oxytocin Augmentation</td>
<td>7 (38.9%)</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Spontaneous ROM</td>
<td>8 (44.4%)</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

*Results are described as (mean±SD) or (No. &%)

No significant difference between labor and non-labor groups regarding maternal age, BMI, GA, socioeconomic status, gravida, parity or previous abortions.

Samples of EHG signals of term labor and non-labor patients are shown in figure 2, 3 respectively.

**Figure (2):** EHG signal recorded from a 38-week pregnant lady in active labor.
All examined parameters are higher in labor than non-labor groups; as shown in Table (2), significantly higher RMS, mean and peak values (P<0.05) in labor compared to non-labor groups (1.225±0.435 vs. 0.705±0.236), (0.060 ±0.0290 vs. 0.039 ±0.012) and (0.081 ±0.1222 vs. 0.026 ±0.007), respectively. The median frequency of the PSD was slightly higher in the labor group but the result was not statistically significant.

### Discussion

Currently used techniques for prediction of true labor are either highly invasive (IUCP) that can only be applied after rupturing of membranes or highly subjective with low predictive values (TOCO) which doesn’t assess the onset of increased myometrial electrical activity during labor. There is a great need for a method that can accurately identify true labor that has been greatly hindered by the inability to exclude patients in false labor from the analysis. Analyzing the entire recorded EHG signal in a certain time period (30 minutes was chosen in our study) makes it possible to get insights into the readiness of the uterus for labor, even in the state when contractions are not perceived by the patient.

Comparing labor and non-labor EHG signals reveal increased frequency and amplitude of bursts which reflects the series of myometrial events required for entering true labor. Various temporal and spectral linear parameters were extracted, analyzed and compared between labor and non-labor groups in this study. RMS was chosen for temporal analysis because of having a great advantage of being easy to calculate simple and suitable to apply. RMS analysis was significantly higher in labor than in the pregnancy group.

This is consistent with a study of Verdinic et al 2001[32] who found that the most important risk factor for preterm delivery is high RMS value because as delivery becomes imminent the electrical activity of the myometrium becomes more vigorous suggesting that high RMS value could be a predictive sign of pregnant women prone to preterm delivery independently from GA or other risk factors as they found that RMS value changes only a few days before true labor begins. Significantly larger RMS values of EHG bursts than non-contractions within the term group were also reported by (Liu et al 2017)[40].

Other studies41,42 reported no significant difference of RMS values in separating term and preterm delivery groups using three filter bandwidth (0.08-4Hz, 0.3-3Hz, 0.3-Hz) on the entire record or on EHG-burst respectively. This nonagreement of findings between studies could be due to the long interval of time between the recording date and that of labor in these studies which further supports the hypotheses that RMS values change only shortly before labor.

Frequency related parameters derived from PSD analysis have been widely used to evaluate EHG records and prediction of preterm labor and found to be suitable by many authors because they are less sensitive to sensor position and distance from pacemaker cells[43], therefore, they are a good representative of the efficacy of contractions and very reliable in predicting delivery.

The results of this study showed an increase in the frequency spectrum of the PSD occurs along with the transition from pregnancy to labor which is expected as myometrial electrical activity changes as pregnancy progress towards labor. The peak frequency of the PSD has demonstrated to be the most discriminating frequency related parameter between pregnancy and labor classes, significantly higher peak frequency supports...
what previous studies[44-46] found, which considered Fpeak as the most important predictive of true labor in human as well as animal studies[47].

This shift may be explained by the underlying physiology. AP potentials within a burst is a direct measure of the rate of depolarization/repolarization process in uterine muscle cells, this process is governed to a great extent by Ca+2 influx across ion channels of myometrial plasma membranes. Modification of these ion channels that occurs during initiation of the labor process increases the excitability of the uterus and further strengthens uterine contractions and therefore higher frequencies of the contractions are expected[48].

Other researchers[49-51] reported a slight increase in peak frequency throughout pregnancy but not to the extent to be considered a significant parameter of diagnosing true labor. The median frequency of PSD which divides the power spectrum into two equal parts was found to be slightly higher in labor than a pregnancy group but the results were not significant. MDF is expected to increase as there are significant spectral changes during the transition from pregnancy to labor. Multiple studies[44, 45, 52] reported an increase in the MDF immediately as parturition becomes imminent but not earlier in the pregnancy.

Alamedine and Khalil[53] found a similar shift of EHG content towards higher frequencies when passing from pregnancy towards labor. An opposite finding by Fele-Zorz and his team[41], who found that the MDF shifts towards lower frequency when going from non-contraction to contraction. One study[51] stated that median frequency presented the most discriminating parameter between pregnancy and labor probably because they analyzed the bursts of uterine electrical activity during contractions rather than the entire record. The mean frequency of the PSD, similar to other frequency-related parameters studied, increased with the transition from pregnancy to parturition. Alamedine and Khalil[53] demonstrated that MPF can be discriminating between pregnancy and labor when applied to the whole EHG strip and agrees with other works done by different teams[49-51].

In conclusion, Uterine EHG monitoring in pregnant women can be a very promising tool to diagnose the onset of true labor. Linear features extracted from EHG record, i.e. root mean square, peak and mean frequency of the power spectral density increase significantly in labor than pregnancy groups.

References

7. https://www.healthynewbornnetwork.org/country/iraq/
37. Gao, Pei & Hao, Dongmei& An, Yang & Wang, Ying &Qiu, Qian & Yang, Lin & Yang, Yimin& Zhang, Song & Li, Xianpei& Zheng, Dingchang. (2017). Comparison of electrohysterogram signal measured by surface electrodes with different designs: A computational study with dipole band and abdominal models. Scientific Reports. 7. 10.1038/s41598-017-17109-3.


