Feasibility of Labor Induction Success Prediction based on Uterine Myoelectric Activity Spectral Analysis

C. Benalcazar Parra[1], A.I. Tendero[1], Y.Ye-Lin[1], J. Alberola-Rubio[2], A. Perales Marin[2], J. Garcia-Casado[1] and G. Prats-Boluda[1]
[1]*Centro de Investigación e Innovación en Bioingeniería, Universidad Politécnica de Valencia, Valencia, Spain*
[2]*Obstetric service, Hospital Universitario y Politécnico La Fe de Valencia, Valencia, Spain*

Keywords: Labor Induction, Electrohysterogram, EHG, EHG-Bursts, Spectral Analysis, Deciles, Vaginal Delivery, Cesarean Section, Active Phase of Labor.

Abstract: Labor induction using prostaglandins (PG) is a common practice to promote uterine contractions and to facilitate cervical ripening. However, not all cases of labor inductions result in vaginal deliveries and it has been associated with an increased risk of cesarean delivery. This last situation is associated to a greater healthcare economic impact and to an increment in the maternal and fetal mortality and morbidity. Obstetricians face different scenarios daily during a labor induction and it would be advantageous to be able to infer the result of the labor induction for a better labor management. Uterine electrohysterogram (EHG) has been proven to play an outstanding role in monitoring uterine dynamics and in characterizing the uterine myoelectrical activity. Therefore, the aim of this study was to characterize and to compare the response of uterine myoelectrical activity to labor induction drugs for different labor induction outcomes by obtaining and analyzing the evolution of spectral parameters from EHG records picked up during the first 4 hours after labor induction onset. Specifically, deciles from the EHG-bursts' power spectral density (PSD) were worked out. Our results showed that deciles D8 and D9 are able to discriminate between women who achieved active phase of labor and those who did not. For women who achieved active phase of labor, D5 makes it possible to separate women who delivered vaginally and those who underwent a cesarean section; finally D2-D6 enabled us to distinguish vaginal deliveries within 24 hours after induction onset from the other outcomes. Thus, deciles computed from EHG PSD are potentially useful to discriminate the different outcomes of a labor induction, suggesting the feasibility of induction success prediction based on EHG recording.

1 INTRODUCTION

Labor induction is an ordinary practice in obstetrics whose objective is to induce a vaginal delivery. The induction of labor is used in situations where maternal and fetal risk of continuing pregnancy exceeds those of termination of pregnancy. Approximately 23% of all cases of birth in United states in 2012 were performed with a previous induction (Hamilton *et al.*, 2012). It is a long process which can last many hours, approximately 17-20 hours (Filho, Albuquerque and Cecatti, 2010), and sometimes the waiting can be extended to 36 hours. Pharmacologic methods for cervical ripening and labor induction, such as prostaglandins, have been used for decades (Gilstrop and Sciscione, 2015) with the purpose of ripen the cervix and stimulate uterine contractions. However, this long and uncomfortable process does not ensure a vaginal delivery and almost 20% of women that have been induced end up labor with a cesarean section (Seyb *et al.*, 1999). This last implies the use of more resources and longer hospital stays, both associated to a greater healthcare cost when compared with a spontaneous labor (Garcia-Simon *et al.*, 2016).

Success of a labor induction has been defined as vaginal delivery within 24 or 48 hours from labor induction onset (Pandis *et al.*, 2001; Indraccolo, Scutiero and Greco, 2016) or vaginal delivery at any time after labor induction onset (Ware and Raynor, 2000). From a pharmacological point of view, a labor induction is considered successful if drug action provokes women to achieve active phase of labor (Baños *et al.*, 2015; Benalcazar-Parra *et al.*, 2017). The most common method to predict labor induction success is based on cervix assessment by the Bishop score (Bishop, 1964). However, this measure is not reliable and depends on the examiner subjectivity. In fact, low accuracy of this predictor have been

Parra, C., Tendero, A., Ye-Lin, Y., Alberola-Rubio, J., Marin, A., Garcia-Casado, J. and Prats-Boluda, G.
Feasibility of Labor Induction Success Prediction based on Uterine Myoelectric Activity Spectral Analysis .
DOI: 10.5220/0006649400700077
In *Proceedings of the 11th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2018) - Volume 4: BIOSIGNALS*, pages 70-77
ISBN: 978-989-758-279-0

reported (AUC=0.39) (Bastani *et al.*, 2011). Other studies have considered other obstetrics variables such as cervical length, maternal age, height, weight, parity, and birth weight (Crane *et al.*, 2004; Bastani *et al.*, 2011; Pitarello *et al.*, 2013; Catherine Tolcher *et al.*, 2015; Prado *et al.*, 2016) and showing an AUC maximum of 0.69 for cervical length.

On the other hand, monitoring uterine contraction is fundamental to assess maternal and fetal wellbeing during the process, as well as, to estimate the labor induction success. Intrauterine pressure is the most accurate technique for monitoring uterine contractions. However, it is an invasive technique and its application requires membrane rupture (Vinken *et al.*, 2009). The most widely used method for non-invasively monitoring uterine activity is to place a tocodinamometer (TOCO) on women abdomen to record changes of pressure in the abdominal contour during uterine contractions. But they are uncomfortable, often inaccurate and depend on a subjective interpretation by the examiner (Vinken *et al.*, 2009).

Alternatively, electrohysterography (EHG) has been proved to be a potentially useful technique for non-invasively monitoring of uterine dynamics obtaining better performance than TOCO (Alberola-Rubio *et al.*, 2013; Euliano *et al.*, 2013; Benalcazar-Parra *et al.*, 2017). It consists of recording the electrical activity of the uterus on the abdominal surface using electrodes. At present, great efforts have been made to differentiate between effective contractions and non-effective contractions and between term and preterm EHG records (Fele-Zorz *et al.*, 2008; Fergus *et al.*, 2013). A shift of the energy content toward higher frequencies as labor approaches has been identified by literature (Marque *et al.*, 1986). Several spectral parameters have been extracted from the power spectral density of the EHG such as the deciles (D1-D9), which correspond to frequencies below which it is contained 10-90% of the total energy respectively (Alamedine *et al.*, 2014), and it has been reported its ability to distinguish between pregnancy and labor contractions.

However, few efforts have been made to characterize the uterine myoelectrical response to labor induction drugs and to predict labor induction outcome based on EHG recording (Tibor Toth, 2005; Aviram *et al.*, 2014; Benalcazar-Parra *et al.*, 2017). Therefore, the aim of this work was to determine the feasibility of predicting different labor induction outcomes, during the first 4 hours after labor induction onset, by analyzing changes in the EHG spectral characteristics as response of induction drugs. Specifically, it was analyzed the time evolution of deciles of the EHG-burst's PSD.

2 MATERIAL AND METHODS

2.1 Signal Acquisition

The study adheres to the Declaration of Helsinki and was approved by the ethics committee of the Hospital Universitario y Politécnico La Fe (Valencia, Spain). All subjects were informed of the nature of the study and signed an informed consent form. Recording sessions were carried out in healthy women with singleton pregnancies and without risk who were determined to undergo labor induction by medical prescription. Specifically, 72 pregnant women with a gestational age between 40 and 41 weeks were enrolled in the study. The induction was carried out by administration of two different types of drugs: vaginal insertion of 25 µg misoprostol (Misofar, Bial, Coronado, Portugal) with repeated doses every 4 hours up to a maximum of 3 doses (N=35) and 10 mg of dinoprostone (Propess, Ferring, Germany) by vaginal insertion (N=37). The following obstetrical data was collected: maternal age, body mass index (BMI), Bishop score and the labor induction outcome. Patients were divided in 4 groups according to the outcome of the delivery: G1: vaginal delivery within 24 hours after induction onset (N=26), G2: vaginal delivery> 24 hours (N=26) after induction onset, G3: cesarean section after achieving active phase of labor (N=11), G4: cesarean section without achieving active phase of labor (N=9).

Three different labor outcome scenarios were studied:

- Scenario 1 (S1): Women achieving active phase of labor (Successful group S1GS= G1+G2+G3; N=63) vs women non achieving active phase of labor, (Failed group, S1GF=G4; N=9)
- Scenario 2 (S2): From women who achieved active phase of labor, those achieving vaginal delivery (Successful group, S2GS=G1+G2; N=52) vs cesarean section (Failed group S2GF=G3; N=11)
- Scenario 3 (S3): Women achieving vaginal delivery within 24 hours (Successful group S3GS=G1; N=26) vs other outcomes, (Failed group (S3GF=G2+G3+G4; N=46)

TOCO and EHG were simultaneously acquired in each recording session. The electrode arrangement for the acquisition of EHG is shown in Figure 1: 2 electrodes were placed supraumbilically at each side of the abdominal medial line with 8 cm of inter-electrode distance corresponding to EHG monopolar records (M1, M2), 1 reference electrode in the right hip and 1 ground electrode in the left hip. The recording time comprises 30 minutes corresponding to recording of basal activity and 4 hour recording from drug administration (induction onset). Details of the recording protocol can be found in an previous study (Benalcazar-Parra *et al.*, 2017).

Figure 1: Surface electrodes arrangement for monopolar EHG recordings (M1, M2).

2.2 EHG Signal Analysis

Since the EHG signal mainly distributes its energy in the range of 0.1 - 4 Hz, a digital band pass filter was performed to eliminate unwanted components. Then EHG signal was down-sampled to a sample frequency of 20 Hz to decrease the computational cost. After signal pre-processing, the bipolar register was obtained digitally as follows:

$$Bip = M2 - M1 \quad (1)$$

Subsequently, from bipolar signal, EHG-bursts associated to uterine contractions were manually segmented using the same criteria as in a previous study (Benalcazar-Parra *et al.*, 2017). Next, in order to characterize the EHG bursts, the deciles of the power spectral density were obtained in the range of (0.2-1Hz) since it has been reported that the main uterine activity is distributed in this frequency range (Marque *et al.*, 1986; Garfield and Maner, 2007). First, the Welch periodogram method was used to calculate the power spectral density of each EHG-burst with a window size of 60 seconds and 50% overlap. Subsequently deciles were computed as follows:

$$\sum_{fi=D_{j-1}}^{D_j} P(fi) = 0.1 \sum_{fi=0.2Hz}^{1\,Hz} P(fi) \quad (2)$$

Where P is the power vector from the PSD and [D_{j-1}, Dj] is the frequency range associated to the decile D_j with j=1…9.

To analyse the evolution of the EHG-bursts' spectral parameters in response to labor induction drugs, firstly the median values of the deciles associated to the EHG-bursts present in consecutive intervals of 30 minutes were worked out for each patient. Then, for each decile and 30-minuteinterval, the mean and standard deviation were calculated for all patients of a group. Finally, a statistical analysis was performed by the Mann–Whitney test (α=0.05) to determine if there were statistical differences between the groups of each obstetrical scenario.

3 RESULTS

Table 1 summarizes the obstetrical variables and the labor induction outcome of the population under study. For a total of 72 patients, 87.5% achieved active phase of labor. However, only 72.2% reached vaginal delivery and 27.8% ended up with a cesarean section. This last include all cesarean sections: women who succeed to achieve active phase of labor, but due to other medical issues (loss of maternal-fetal wellbeing or pelvic-fetal disproportion) underwent cesarean section and those who did not reach active phase of labor.

Table 1: Patients' obstetrical and clinical variables. Mean (std).

Obstetric variables	Mean ± std
Maternal age (years)	31.7 ± 4.6
BMI (kg/m^2)	28.9 ± 4.1
Bishop	1.4 ± 0.7
Active phase of labor	63/72 (87.5%)
Vaginal delivery	52/72 (72.2%)
>24h	26/52 (50%)
<=24h	26/52 (50%)
Cesareans	20/72 (27.8%)

Figure 2 shows a representative EHG recording from an induced woman who reached active phase of labor and vaginal delivery within 24 hours after induction onset. Comparing the characteristics of the EHG-bursts recorded before drug administration (basal period) and those presented at the last recording hour, EHG-bursts after 4 hours from induction onset were of higher amplitude, shorter duration than those at basal period. Moreover the PSD analysis revealed a shift of the energy content toward higher frequencies as labor induction progresses.

Figure 3 shows the temporal evolution of the deciles' mean values for the groups G1, G2, G3 and G4. Increasing tendencies can be noticed in all deciles for G1 and G3 groups except for D9. This reveals that there is a clear shift toward higher frequencies for the group of women that are closer to vaginal delivery and for women delivering by a cesarean section but achieving active phase of labor (G1 and G3 respectively). While for the group that is further away from vaginal delivery (G2) and the group of women that failed in reaching active phase of labor (G4), there is not a clear tendency in any decile, remaining almost constant throughout the recording session.

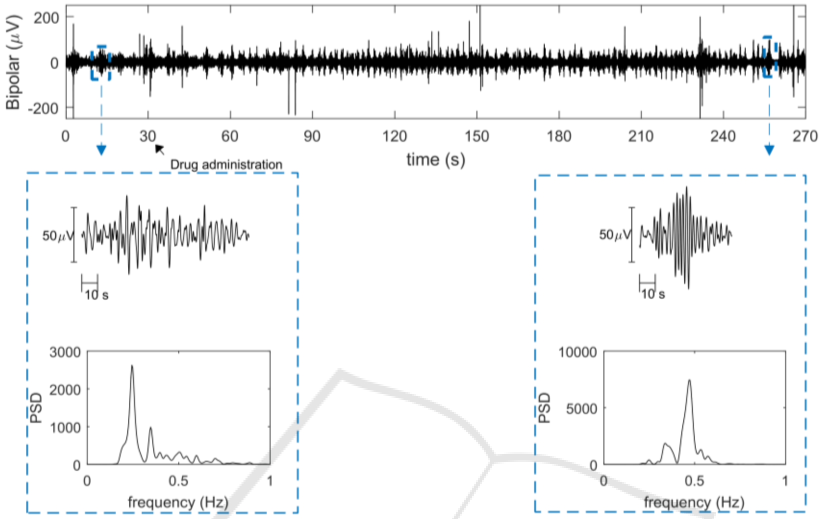

Figure 2: EHG recordings from a woman that reached active labor period and vaginal delivery within 24 hours from labor induction onset.

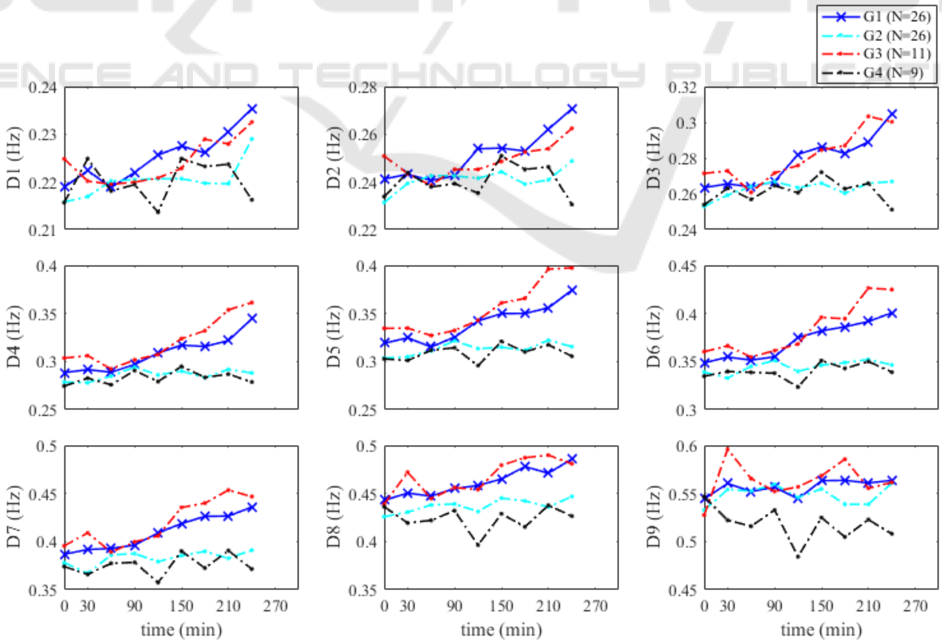

Figure 3: Deciles' temporal evolution for the groups: G1: vaginal delivery within 24 hours after induction onset, G2 vaginal delivery> 24 hours after induction onset, G3: cesarean section after achieving active phase of labor, G4: cesarean section without achieving active phase of labor.

In order to study the different situations derived from labor induction, and to analyze the capacity of the deciles derived from EHG bursts' PSD to discriminate between success and failure groups in each scenario, statistical Mann-Whitney test was performed for each scenario (Tables 2-4).

Table 2 shows the statistical significance for each 30-minute analysis interval when comparing the EHG parameters of women that succeed in achieving active phase of labor (S1GS) to those that failed (S1GF). It can be noticed that all deciles show statistically significant difference at least in one 30-minute interval (generally the last) except for D6. Outstanding results to discriminate between S1GS and S1GF are found for D8 and D9, both showing sustained statistical difference after 120 minutes from drug administration to the last analysis interval (except for 210')

Table 2: Statistical differences in scenario 1 (S1GS vs S1GF). Shaded cells represent p-values <0.05.

	0'	30'	60'	90'	120'	150'	180'	210'	240'
D1	0.55	0.29	0.97	0.88	0.05	0.61	0.99	0.94	0.01
D2	0.58	0.51	0.70	0.97	0.11	0.65	0.94	0.77	0.01
D3	0.44	0.77	0.54	0.86	0.24	0.77	0.52	0.66	0.01
D4	0.23	0.78	0.34	0.74	0.14	0.52	0.28	0.31	0.04
D5	0.24	0.25	0.96	0.45	0.04	0.43	0.16	0.30	0.03
D6	0.40	0.80	0.77	0.21	0.06	0.34	0.16	0.32	0.14
D7	0.69	0.41	0.67	0.31	0.07	0.28	0.04	0.51	0.07
D8	0.84	0.20	0.29	0.38	0.01	0.04	0.01	0.25	0.05
D9	0.91	0.12	0.07	0.23	0.01	0.04	0.03	0.20	0.03

Table 3 displays the statistical significance for each 30-minute analysis interval when comparing the EHG parameters, from women who achieved active phase of labor, those of women achieving vaginal delivery vs those of women that underwent cesarean section. For this scenario, deciles D3 and D9 are the only ones that do not show statistical difference in any analysis interval. The best decile to discriminate between S2GS and S2GF was D5, showing statistical differences in intervals 150'-210'.

Table 4 shows the statistical difference of the EHG parameters of women that achieve vaginal delivery within 24 hours after labor onset compared to the rest of labor outcomes. All deciles show statistical difference at least one analysis interval except for D9. Deciles D2-D6 and D8 seem to be potential predictors of the vaginal delivery within 24 hours, since they show statistical differences in at least 3 analysis intervals, being the best result obtained for D6.

Table 3: Statistical differences in scenario 2 (S2GS vs S2GF). Shaded cells represent p-values <0.05.

	0'	30'	60'	90'	120'	150'	180'	210'	240'
D1	0.02	0.75	0.85	0.99	0.80	0.99	0.18	0.30	0.95
D2	0.01	0.87	0.72	0.49	0.99	0.86	0.30	0.40	0.95
D3	0.06	0.39	0.62	0.36	0.57	0.41	0.06	0.07	0.97
D4	0.05	0.15	0.73	0.47	0.39	0.18	0.03	0.02	0.59
D5	0.07	0.23	0.54	0.47	0.22	0.03	0.05	0.01	0.55
D6	0.22	0.22	0.75	0.57	0.27	0.05	0.11	0.02	0.39
D7	0.39	0.05	0.95	0.54	0.32	0.02	0.13	0.02	0.55
D8	0.76	0.01	0.88	0.35	0.33	0.05	0.14	0.06	0.87
D9	0.49	0.09	0.93	0.95	0.50	0.53	0.11	0.88	0.82

Table 4: Statistical differences in scenario 3 (S3GS vs S3GF). Shaded cells represent p-values <0.05.

	0'	30'	60'	90'	120'	150'	180'	210'	240'
D1	0.86	0.40	0.55	0.80	0.06	0.03	0.16	0.04	0.07
D2	0.43	1.00	0.83	0.64	0.09	0.25	0.05	0.04	0.01
D3	0.23	0.90	0.76	0.77	0.10	0.03	0.03	0.15	0.01
D4	0.41	0.33	0.43	0.81	0.07	0.04	0.04	0.26	0.00
D5	0.15	0.10	0.98	0.71	0.07	0.04	0.02	0.32	0.01
D6	0.49	0.15	0.77	0.65	0.03	0.05	0.03	0.12	0.02
D7	0.77	0.15	0.80	0.55	0.06	0.13	0.03	0.08	0.03
D8	0.26	0.33	0.48	0.41	0.03	0.26	0.02	0.08	0.02
D9	0.39	0.98	0.75	0.67	0.59	0.34	0.20	0.14	0.14

4 DISCUSSION

In clinical practice, a large percentage of all deliveries are performed through induction of labor, being one of the most frequent procedures in obstetrics. In fact, the number of labor inductions has increased significantly in recent years (Hamilton et al., 2012). However, not all inductions end in vaginal delivery, associated with an increase in the rate of cesarean sections. The latter may simply be due to the fact that the uterus is not well prepared for delivery by presenting an immature cervix or a myometrium unable to achieve effective synchronous contractions or any other condition that make vaginal delivery be inviable (Cunningham et al., 2010). It would be a key aspect to know, as soon as possible, the outcome of a labor induction so that clinicians may be able to better plan deliveries, preventing maternal and fetal stress which can appear in this long process.

Spectral parameters from EHG have been extracted and used wideley in intention to predict preterm labor (Buhimschi et al, 1997; Leman et al, 1999; Alamedine et al, 2013; Fergus *et al.*, 2013; Alamedine *et al.*, 2014). Nonetheless, the applicability of EHG during induction of labor or its ability to predict the outcome to be obtained from induction has not been thoroughly explored.

In this study, it was analyzed the response of uterine muscle electrical activity to labor induction drugs. The results of this work indicate that patients from G1 and G3 experimented an evident shift of their energy content toward higher frequencies throughout the recording session (increasing tendencies are seen in all deciles). This is consistent with the literature which points out that agents for the stimulation of uterine activity, act favoring the increase of cell junctions (gap junction) and the ratio of cells' excitability (Garfield and Maner, 2007) which is related with the presence of more intense contractions and with higher frequency components. Moreover, this increment is consistent with another study in which was found that decil D8 experienced an increment in its values from pregnancy to labor (Alamedine *et al.*, 2014).

In contrast, the group that did not reach active phase of labor (G4) did not exhibit clear trends in any decile, that is, no spectral displacement was observed during the first four hours after labor induction onset. Nevertheless, the same phenomenon was observed for women that delivered in more than 24 hours after induction onset. This result may suggest that more recording time will be needed to observe the shift of the EHG-Bursts spectral content towards higher frequencies for women with a relatively slow response to labor induction drugs.

Our work confirms the utility of decile parameters to characterize the electrophysiological response of the uterus to labor induction drugs, and points to the possibility of predicting the different outcome of the labor induction by analyzing the EHG-Bursts during the first 4 hours after induction onset. D8 and D9 show statistical difference between women achieving active phase of labor to those that failed after 120 minutes from labor induction onset to end of the recording session except for the time interval 210'. Then for women who achieved active phase of labor, D5 could be useful, to discriminate between vaginal deliveries and cesarean section in the time intervals 150'-210'. Finally, D2-D6 showed statistical difference between vaginal deliveries within 24 hours and the rest of women under study, being D6 the one with best results and showing statistically significant difference in the time intervals 120'-240' (except for 210'). Moreover, the time required to observe statistical significant differences in EHG spectral parameters between women achieving active phase of labor to those that failed (S1) is consistent with pharmacokinetics studies: literature reported that the time to reach sustained uterine dynamics was 106 and 127 minutes after misoprostol and dinoprostone vaginal administration respectively (Yount and Lassiter, 2013).

Although it has been shown that EHG spectral parameters contain relevant information for predicting labor induction outcomes, this study is not exempt of limitations. First, a larger database is needed to corroborate these results. Second, the prediction of labor induction success remains a challenge from the scientific-technical point of view. Vaginal delivery> 24 h presents a similar trend to the non-PAP group during the first 4 hours of recording, which makes it necessary to extend the recording time in order to be able to predict more accurately whether a woman is going to reach active phase of labor or not. On the other hand, the EHG record only contains information of the myoelectric uterine activity, and there are multiple causes, such as loss of maternal-fetal wellbeing or pelvic-fetal disproportion, that could lead to cesarean delivery that are not necessary reflected in the EHG recording. In this sense, the use of EHG recording together with other obstetric parameters (bishop score, cervical length, maternal age, birth weight, etc) could improve prediction accuracy of induction success. In addition, the application of advanced pattern identification techniques such as neural networks and/or support vector machines could be another key point for developing new tools for predicting labor induction success that could help obstetric clinicians in labor management. .

5 CONCLUSION

To conclude, EHG can provide relevant information about the uterine myoelectrical state through labor induction. A clear shift of the EHG-Bursts energy content toward higher frequencies was identified in the temporal evolution of G1 (vaginal delivery within 24 hours after induction onset) and G3 (cesarean section after achieving active phase of labor) groups for all deciles. In contrast, non-remarkable changes in the spectral characteristics of the EHG were seen for G2 (vaginal delivery> 24 hours after induction onset) and G4 (cesarean section without achieving active phase of labor) during the first four hours after labor onset. Moreover, deciles of the EHG-Bursts' PSD are potentially useful to discriminate between the different outcomes of the labor induction, suggesting the feasibility of EHG recording for predicting labor induction success.

ACKNOWLEDGEMENTS

This work was supported in part by the the Ministry of Economy and Competitiveness and the European Regional Development Fund (DPI2015-68397-R).

REFERENCES

Alamedine, D. *et al.* (2014) 'Selection algorithm for parameters to characterize uterine EHG signals for the detection of preterm labor', *Signal, Image and Video Processing*, 8(6), pp. 1169–1178. doi: 10.1007/s11760-014-0655-2.

Alamedine, D., Khalil, M. and Marque, C. (2013) 'Comparison of Different EHG Feature Selection Methods for the Detection of Preterm Labor', *Computational and Mathematical Methods in Medicine*, 2013, pp. 1–9. doi: 10.1155/2013/485684.

Alberola-Rubio, J. *et al.* (2013) 'Comparison of non-invasive electrohysterographic recording techniques for monitoring uterine dynamics', *Medical Engineering and Physics*, 35, pp. 1736–1743. doi: 10.1016/j.medengphy.2013.07.008.

Aviram, A. *et al.* (2014) 'Effect of Prostaglandin E2 on Myometrial Electrical Activity in Women Undergoing Induction of Labor', *J Perinatol*, 31, pp. 413–418. doi: 10.1055/s-0033-1352486.

Baños, N. *et al.* (2015) 'Definition of Failed Induction of Labor and Its Predictive Factors: Two Unsolved Issues of an Everyday Clinical Situation', *Fetal Diagn Ther*, 38, pp. 161–169. doi: 10.1159/000433429.

Bastani, P. *et al.* (2011) 'Transvaginal ultrasonography compared with Bishop score for predicting cesarean section after induction of labor', *International Journal of Women's Health*, 3, pp. 277–280. doi: 10.2147/IJWH.S20387.

Benalcazar-Parra, C. *et al.* (2017) 'Characterization of Uterine Response to Misoprostol based on Electrohysterogram', in *Proceedings of the 10th International Joint Conference on Biomedical Engineering Systems and Technologies*. SCITEPRESS - Science and Technology Publications, pp. 64–69. doi: 10.5220/0006146700640069.

Bishop, E. H. (1964) 'Pelvic Scoring For Elective Induction', *Obstetrics and gynecology*, 24, pp. 266–8. Available at: http://www.ncbi.nlm.nih.gov/pubmed/14199536 (Accessed: 6 June 2017).

Buhimschi, C., Boyle, M. B. and Garfield, R. E. (1997) 'Electrical activity of the human uterus during pregnancy as recorded from the abdominal surface', *Obstetrics & Gynecology*, 90(1), pp. 102–111. doi: 10.1016/S0029-7844(97)83837-9.

Catherine Tolcher, M. *et al.* (2015) 'Predicting Cesarean Delivery After Induction of Labor Among Nulliparous Women at Term', *Obstet Gynecol*, 126(5), pp. 1059–1068. doi: 10.1097/AOG.0000000000001083.

Crane, J. M. G. *et al.* (2004) 'Predictors of successful labor induction with oral or vaginal misoprostol', *The Journal of Maternal-Fetal & Neonatal MedicineOnline) Journal*, 15(5), pp. 319–323. doi: 10.1080/14767050410001702195.

Cunningham, F. G. *et al.* (2010) *Williams Obstetrics*. 23rd edn. McGraw-Hill Professional.

Euliano, T. Y. *et al.* (2013) 'Monitoring uterine activity during labor: A comparison of 3 methods', *American Journal of Obstetrics and Gynecology*, 208(1), p. 66.e1-66.e6. doi: 10.1016/j.ajog.2012.10.873.

Fele-Zorz, G. *et al.* (2008) 'A comparison of various linear and non-linear signal processing techniques to separate uterine EMG records of term and pre-term delivery groups', *Med Biol Eng Comput*, 46, pp. 911–922. doi: 10.1007/s11517-008-0350-y.

Fergus, P. *et al.* (2013) 'Prediction of Preterm Deliveries from EHG Signals Using Machine Learning', *PLoS ONE*, 8(10). doi: 10.1371/journal.pone.0077154.

Filho, O. B. M., Albuquerque, R. M. and Cecatti, J. G. (2010) 'A randomized controlled trial comparing vaginal misoprostol versus Foley catheter plus oxytocin for labor induction', *Acta Obstetricia et Gynecologica Scandinavica*. Blackwell Publishing Ltd, 89(8), pp. 1045–1052. doi: 10.3109/00016349.2010.499447.

Garcia-Simon, R. *et al.* (2016) 'Economic implications of labor induction', *International Journal of Gynecology & Obstetrics*, 133(1), pp. 112–115. doi: 10.1016/j.ijgo.2015.08.022.

Garfield, R. E. and Maner, W. L. (2007) 'Physiology and electrical activity of uterine contractions', *Seminars in Cell & Developmental Biology*, 18, pp. 289–295. doi: 10.1016/j.semcdb.2007.05.004.

Gilstrop, M. and Sciscione, A. (2015) 'Induction of labor—Pharmacology methods', *Seminars in Perinatology*, 39, pp. 463–465. doi: 10.1053/j.semperi.2015.07.009.

Hamilton, B. *et al.* (2012) *Births: Final data for 2012*. Hyattsville. Available at: www.cdc.gov/nchs/data/nvsr/nvsr62/nvsr62 09.pdf.

Indraccolo, U., Scutiero, G. and Greco, P. (2016) 'Sonographic Cervical Shortening after Labor Induction is a Predictor of Vaginal Delivery', *Revista Brasileira de Ginecologia e Obstetrícia*. Federação Brasileira das Sociedades de Ginecologia e Obstetrícia, 38(12), pp. 585–588. doi: 10.1055/s-0036-1597629.

Leman, H., Marque, C. and Gondry, J. (1999) 'Use of the electrohysterogram signal for characterization of contractions during pregnancy', *IEEE Transactions on*

Biomedical Engineering, 46(10), pp. 1222–1229. doi: 10.1109/10.790499.

Marque, C. *et al.* (1986) 'Uterine EHG Processing for Obstetrical Monitorng', *IEEE Transactions on Biomedical Engineering*, BME-33(12), pp. 1182–1187. doi: 10.1109/TBME.1986.325698.

Pandis, G. K. *et al.* (2001) 'Preinduction sonographic measurement of cervical length in the prediction of successful induction of labor', *Ultrasound in Obstetrics and Gynecology*. Blackwell Science Ltd., 18(6), pp. 623–628. doi: 10.1046/j.0960-7692.2001.00580.x.

Pitarello, P. da R. P. *et al.* (2013) 'Prediction of successful labor induction using transvaginal sonographic cervical measurements', *Journal of Clinical Ultrasound*. Wiley Subscription Services, Inc., A Wiley Company, 41(2), pp. 76–83. doi: 10.1002/jcu.21929.

Prado, C. A. de C. *et al.* (2016) 'Predicting success of labor induction in singleton term pregnancies by combining maternal and ultrasound variables.', *The journal of maternal-fetal & neonatal medicine : the official journal of the European Association of Perinatal Medicine, the Federation of Asia and Oceania Perinatal Societies, the International Society of Perinatal Obstetricians*, pp. 1–35. doi: 10.3109/14767058.2015.1135124.

Seyb, S. T. *et al.* (1999) 'Risk of cesarean delivery with elective induction of labor at term in nulliparous women.', *Obstetrics and gynecology*, 94(4), pp. 600–7. Available at: http://www.ncbi.nlm.nih.gov/pubmed/10511367 (Accessed: 15 September 2016).

Tibor Toth (2005) 'Transcutaneous Electromyography of Uterus in Prediction of Labor Outcome Induced by Oxytocine and Prostaglandine Shapes', *Gynaecologia et perinatologia: journal for gynaecology, perinatology, reproductive medicine and ultrasonic diagnostics*, 14(2), pp. 75–76.

Vinken, M. P. G. C. *et al.* (2009) 'Accuracy of frequency-related parameters of the electrohysterogram for predicting preterm delivery: a review of the literature.', *Obstetrical & gynecological survey*, 64(8), pp. 529–41. doi: 10.1097/OGX.0b013e3181a8c6b1.

Ware, V. and Raynor, B. D. (2000) 'Transvaginal ultrasonographic cervical measurement as a predictor of successful labor induction', *American Journal of Obstetrics and Gynecology*, 182(5), pp. 1030–1032. doi: 10.1067/mob.2000.105399.

Yount, S. M. and Lassiter, N. (2013) 'The Pharmacology of Prostaglandins for Induction of Labor', *Journal of Midwifery and Women's Health*, 58(2), pp. 133–144. doi: 10.1111/jmwh.12022.