Uterine EHG Processing for Obstetrical Monitoring

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Abstract—**The temporal and spectral properties of the human uterine electromyogram are first described, related to two different situations: pregnancy and parturition. Thus, a parameter set is selected, and a discriminant analysis is performed, in order to obtain the best discriminant vector for these two situations. A dynamic control of the efficiency of the contractions during labor is described. The good results of this dynamic control permit us to propose a monitoring device providing information on contraction rate and efficiency.**

Introduction

THE USUAL obstetrical practice includes graphical monitoring of fetal heart rate (FHR) and uterine activity. Uterine contractions tracing is currently obtained in two different ways: external measurement by means of a tocotransducer, positioned on the abdominal wall with an elastic strap [1], or intrauterine pressure measurement (balloon-tipped or open-ended fluid filled catheter) [2], [3], but the mechanical effect of uterine contraction depends on the contractile force of each individual fiber and on the number of simultaneously active fibers [4], [5].

The uterine activity gradually changes from the last months of pregnancy until parturition. Weak and localized (referred to as "nonpropagating") at the beginning, it becomes more and more strong, rhythmical and well propagated ("propagating" contractions) [6], [7]. These changes are on one hand a consequence of an increase of the cell excitability [8]. On the other hand, changes in the temporospatial organization are due to an increase of the contractile wave propagation velocity [7], [9]. The timing of these two phenomena is still controversial and would be subject to species or individual variations [10], [11].

The human uterine electromyogram (electrohysterogram EHG) recorded as early as 1931 [12] was studied *in vivo* by several authors [13]–[15]. The signal, recorded by abdominal electrodes, was described as a "slow" electrical wave (frequency band 0.03–0.1 Hz, amplitude 1–5 mV) on which a "fast" electrical activity (frequency band 0.3–2 Hz, amplitude 50 μV–1 mV) is superimposed.

When recorded by internal electrodes [16], [17] the signal observed during the contractions can be located into a frequency band of 0.3–1 Hz (amplitude of 100 μV–1.8 mV). When EHG was recorded simultaneously by internal and abdominal electrodes, a good temporal relationship was found between the two signals [18], [9]. But part of the electrical activity, picked up by the abdominal electrode set, was a consequence of artifact appearance (skin stretching, abdominal muscles, respiratory movements, etc.). More recent studies on EHG, recorded with multiple internal electrodes, described the signal from the very beginning of labor to the expulsion [4]. During the prelabor phase, the recorded signal shows frequent bursts of potential that are not always related to an increase of the intrauterine pressure. These bursts can appear anywhere in the uterus but remain restricted to a small area. As labor progresses, the duration and amplitude of the bursts increase. Each burst is associated with an increase of intrauterine pressure. There is no constant site of pacemaker activity and the whole uterus is activated within a short time. No electrical activity is recorded between contractions. All these observations strongly suggest that the electrohysterogram offers information about both excitation and propagation of uterine activity. Some authors tried to quantify the electrical uterine activity and its evolution, related to the progress of labor.

Val [19] worked on abdominal EHG and intrauterine recordings and computed the power spectrum density of the signal in the 0–0.8 Hz bandwidth. A classification of "resting" and contraction phases permitted selection of the frequency band (0.2–0.6 Hz) which was representative of uterine activity. These frequency limits confirm the previous results describing the "fast" electrical activity.

Planes [20] analyzed this "fast" uterine activity through parametric autoregressive modeling. He concluded that easy implementation of AR modeling permitted study of the signal by means of six parameters. Moreover, he tried to measure the propagation velocity of the electrical waves using two simultaneously recorded EHG. The scatter of the results was too large to conclude in favor of a possible evolution of this velocity during labor.

The EHG, when recorded in a noninvasive way from abdominal electrodes, could be of great interest for obstetrical monitoring. As the electromyogram usually offers information about both excitation and propagation of electrical activity, it should be possible to compute from EHG useful parameters which are representative of contraction efficiency. This set of parameters should be able to classify contractions into "efficient" (labor) or "inefficient" (pregnancy) groups, related to their mechanical effect. This classification can give supplementary infor-

Manuscript received August 28, 1986.

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IEEE Log Number 8611204.

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mation for obstetrical monitoring; tocography only provides information on the pressure variation, which does not automatically involve cervical dilatation, and cervical measurements give information on the mechanical effect. In case of too slow progress of labor, the clinician cannot decide if this fact is due to cervical tonicity or to inefficient electrical command, represented by the EHG signal.

Material and Methods

Parturition recordings were made on 14 women, admitted to the Obstetrics and Gynaecology Department of the Compiegne St. Joseph Hospital, for spontaneous or induced labor. The patient age range was 19–32 years and their estimated gestational age 37–41 weeks. The recording session duration ranged from 1 to 8 h.

During pregnancy, the experiments were carried out in the Biomedical Department, Compiegne University, on three women whose age ranged from 27 to 36 years. Tests were performed every one or two weeks. The corresponding gestational ages spread out from 32 to 40 weeks.

EHG Recording

Two Ag–AgCl Beckman electrodes (8 mm in diameter, 25 mm spaced centers) were placed on the abdominal wall after careful preparation of the skin. They were set near the umbilicus, on the median vertical axis of the uterus, being thus parallel to the most superficial uterine muscle fibers [21]. The ground electrode was laterally placed on the hip.

The EHG signal was differentially amplified, bandpass filtered (0.05–30 Hz, second-order) and recorded on a magnetic tape (frequency range 0–250 Hz).

The mechanical effect of uterine contractions was measured by external strain gauge tocometry (Cardiotocograph Model 8030A, Hewlett-Packard). The corresponding signal was collected from the cardiotocograph output interface and simultaneously recorded with the EHG on the magnetic tape, providing a time reference for the appearance of contractile activity.

EHG Analysis

Spectral Analysis: In order to specify the frequency range which was concerned with the previously defined "fast" electrical activity, a spectral analysis was performed on the EHG. Only electrical activity phases corresponding to contractions that were detected on the tocographic signal, were selected. The EHG signal was high-pass filtered (0.2 Hz, fourth-order) and put into a 3582A Hewlett-Packard Spectrum Analyzer. There, the signal was digitized at a sampling rate of 20 Hz. The power spectral density was computed in the frequency range 0–5 Hz with a Hanning bandpass filter. The acquisition time window (1024 points, about 51 s) was approximately equal to the mean duration of the burst of electrical activity corresponding to only one contraction.

Pregnancy Versus Parturition Study: For discrimination purpose, a set of temporal and spectral parameters was computed from the EHG. The signal was simultaneously filtered in different frequency bands with fourth-order filters. These filtered EHG and the tocographic signal were then fed into a multichannel acquisition device.

The simultaneous acquisition of these different channels was performed at a sampling rate of 10 Hz. Only the bursts of electrical activity corresponding to contractions were treated. A digital processing was performed that computed the relative energy in the different chosen bands and the total duration for each electrical burst. For each analyzed patient, a vector was defined, which was formed by these different computed parameters. For parturition recordings, the vector components were defined as the mean values of the parameters which were computed from all the processed contractions. For pregnancy recordings, the parameter means were computed from all the detected contractions on the signal which was recorded during two successive weeks. The obtained vectors consisted of 11 "labor," 6 "pregnancy," and 4 "supplementary" vectors. In order to prove that these parameters contain discriminant information between "labor" and "pregnancy" classes (i.e., between efficient and inefficient contractions), an optimal transformation for discriminant analysis was performed [22].

Results

Spectral Analysis

When recorded in the 0.05–30 Hz bandwidth, the abdominal EHG shows "slow" electrical waves on which "fast" electrical bursts are superimposed, which are related to the mechanical uterine activity (Fig. 1). When filtered in the 0.2–5 Hz frequency band, the slow electrical activity disappears, giving a baseline stability during the "resting" phases (intervals between mechanical contractions).

The power spectral density (PSD) which is computed from the filtered "fast" electrical burst, related to only one contraction, and the corresponding time samples are shown in Fig. 2 for one "pregnancy" and one "labor" typical contraction. Notice the presence of "high" frequencies on the PSD as well as on the temporal shape, for labor contraction. The pregnancy contraction is mainly represented by "low" frequency signal. For the two kinds of activity, the signal energy is localized into the 0.2–3 Hz bandwidth.

Pregnancy Versus Parturition Comparison

Each PSD curve was first divided into 20 frequency bands and a first discriminant analysis was performed in order to define the most significant parameters (i.e., the most discriminant frequency bands). The strongly correlated bands were concatenated, and the least discriminant bands were removed. Therefore, three frequency bands were finally selected from the spectral analysis results: the "total band" (T), frequency range 0.2–3 Hz, the "low band" (L), frequency range 0.2–0.45 Hz, and the "high band" (H), frequency range 0.8–3 Hz. Thus, the computed parameters were defined as the relative energy in the low band (L/T), the relative energy in the high band

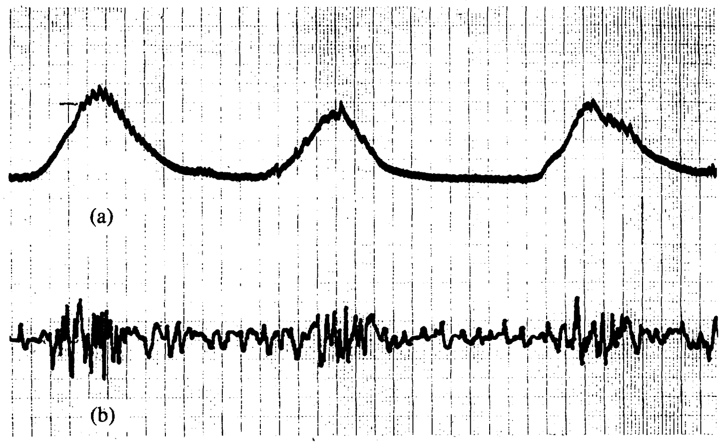
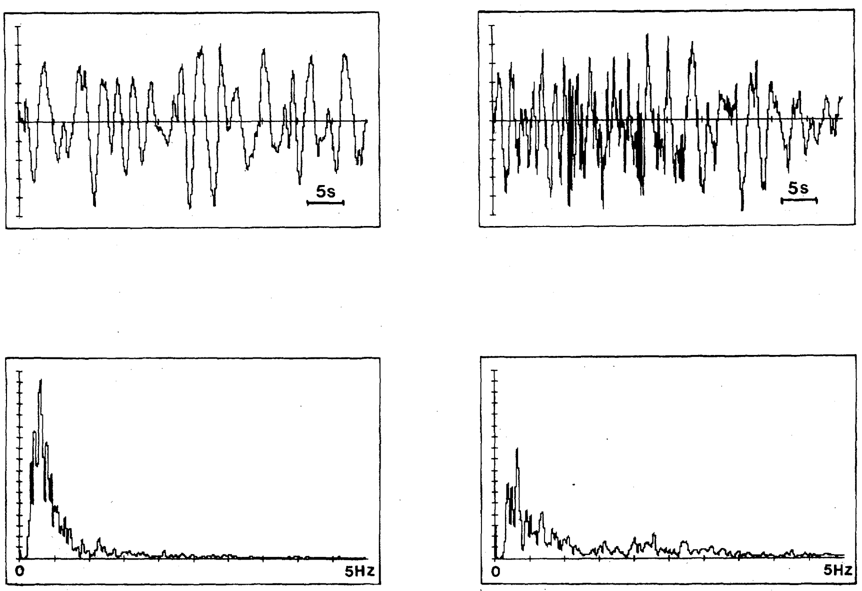


Fig. 1. (a) Uterine contraction tracing obtained by external tocographic measurement. (b) Abdominal EHG tracing simultaneously recorded when filtered in the 0.05–30 Hz bandwidth. Vertical axes present arbitrary scales.



(a) (b)

Fig. 2. (a) Pregnancy contraction: upper tracing represents the temporal shape of one typical pregnancy contraction and lower tracing, the corresponding PSD. (b) Labor contraction: upper tracing is the temporal shape of one typical labor contraction and lower tracing the corresponding PSD. Each temporal shape represents only one burst of electrical activity when filtered in the 0.2–5 Hz bandwidth. The PSD's are normalized in order to equalize their surfaces (both temporal and spectral vertical axes present arbitrary scales).

(H/T), and the duration of the burst (D) for each electrical burst, the duration being obtained from the signal detection (dynamic threshold on both raw EHG and rms value). Fig. 3 shows the results of the discriminant analysis which was performed on the 11 "labor," 6 "pregnancy," and 4 "supplementary" vectors for which the components were L/T, H/T, and D. The projection on the discriminant plane shows how these parameters provide useful information on the discrimination between the two predefined classes: "labor" and "pregnancy." The discriminant ratio (DR) is found to be 63 percent on the first axis. This relatively small value is mainly due to the scattered values of the "pregnancy" cluster. This scatter can be explained by the contractile activity evolution which occurs during the last trimester of pregnancy: in this cluster, the symbols which are linked by arrows represent the same patient at different recording dates, with respect to an increasing gestational age. Notice the progression from the "pregnancy" to the "labor" class with respect to the gestational age.

The supplementary vectors correspond to different observed situations: an induced labor which failed because of lack of contractions (α), an induced labor which failed because of inefficiency of the contractions (δ), and a

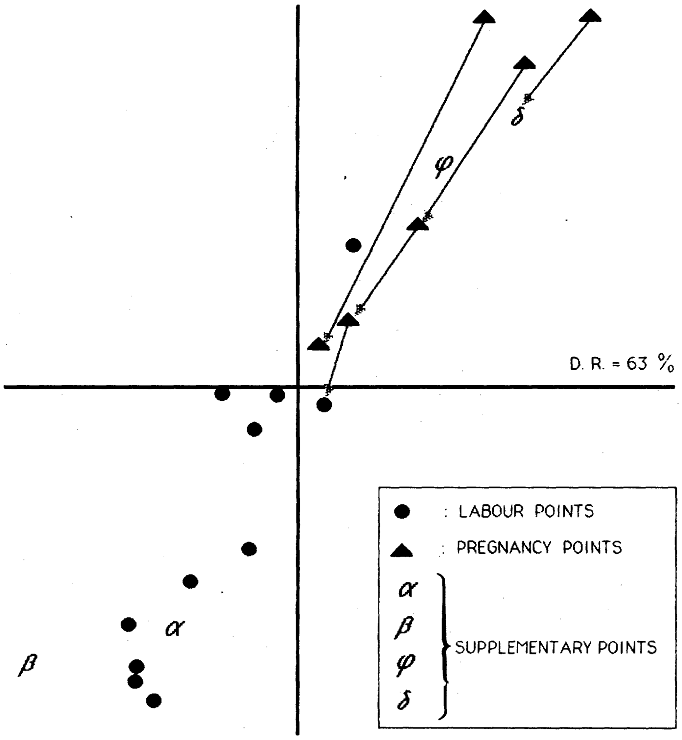


Fig. 3. Projection of the "labor" and "pregnancy" classes onto the discriminant plane computed from three variables: L/T, H/T, and D. In the pregnancy cluster, linked symbols represent same patient at different increasing gestational ages. Supplementary points correspond to two induced labors (lack of contractions α, inefficient contractions δ), one premature labor risk (β) and one labor with incoordinate contractions (φ).

"premature labor risk" (at 32 weeks gestational age) (β). In fact, the failed induced labors are projected in a position which corresponds to the failure cause. The first one (due to lack of contractions α) is classified with "labor" patients. This fact permits us to suppose that the contractions were efficient but not frequent enough to ensure labor progress. The second one (due to "inefficient" contractions δ) is classified in the "pregnancy" group. This fact confirms the clinical observation (no cervical dilatation was obtained after 4 h of oxytocin infusion). The premature labor risk (β) is projected onto the "labor" class. This is confirmed by the clinical observation (small cervical dilatation was observed). The patient had to take uterine activity inhibitors to prevent preterm labor.

The fourth supplementary point (φ) corresponds to one labor recording. But the patient presented frequent "atypical" or "incoordinate" contractions patterns [23], [24] during the whole parturition.

Real Time Monitoring

A real time monitoring involves the dynamic analysis of the electrical activity in order to provide useful information on the efficiency of the corresponding contraction.

Real time processing needs to acquire the EHG signal, to compute the H/T, L/T, and D parameters and to project the obtained point onto the previously computed discriminant vector. A way to obtain this projection consists of acquiring first the entire electrical burst and then computing the parameters and the corresponding projection onto the discriminant vector. Another method can be used to obtain the same final result: after detection of the onset of electrical activity, a reduced time window is first acquired (50 points, that is, the first 5 s of electrical burst); the L/T, H/T, and D parameters are estimated using these initial points and the corresponding projection onto the discriminant vector is computed. Then, each new acquired point will modify the previously estimated projection until the end of the electrical burst.

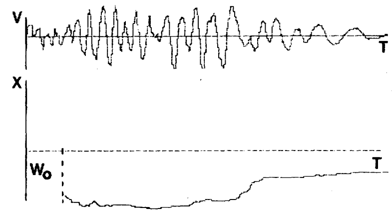


Fig. 4. Dynamic efficiency of only one contraction. Upper tracing represents the time shape of one burst of electrical activity. Lower tracing represents the evolution of the parameters projection onto the first discriminant axis with respect to each new acquired point (W_o corresponds to the delay which is necessary to acquire the 50 first points of the burst). The dashed line indicates the projection of the "labor" class centroïd; over this line are the uncertain and inefficient areas; below this line is the efficient area.

The two methods obviously yield the same final point, but the second method also provides information on the electrical activity efficiency during the contraction itself. In this case, EHG real time processing corresponds to three successive steps: burst detection, first parameters estimation, and real time updating, using the new acquired points (Fig. 4).

Fig. 5 shows contraction's evolutions in both efficient [Fig. 5(a)] and inefficient [Fig. 5(b)] situations, the dashed line indicating the position of the "efficient" cluster centroïd. It is clearly shown that the two situations are well separated using this dynamic method. This good result has been confirmed on all the analyzed signals.

Conclusion

The selected parameters which were extracted from both temporal and spectral analysis are significative of the two studied physiological states: pregnancy EHG is mainly characterized by low frequencies and a long duration (the duration mean was computed as 74.6 s for the pregnancy points), whereas labor EHG is related to the presence of "high" frequencies and shorter duration (the duration mean was computed as 59.3 s). These observations permit us to suppose that the low frequencies of the EHG are representative of a local uterine activity. On the other hand, the presence of "high" frequencies in the EHG is related to "propagating" or "coordinated" labor uterine activity. The spectral changes which were observed from pregnancy to parturition (increase of H/T and decrease of L/T) could be related to the improvement of electrical coupling in uterine muscle due to appearance of gap junctions just before and during labor [25], [26].

Contraction rate was not taken in account in the electrical activity analysis. In fact, this parameter, which can be easily computed from the EHG (bursts rate) has not to

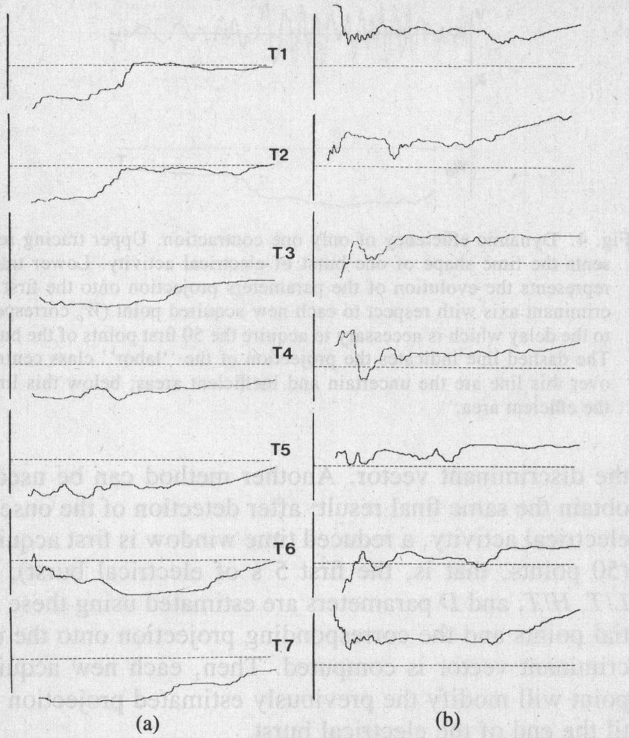


Fig. 5. Evolution of the contraction dynamic with respect to time from $T1$ to $T7$ (one contraction every 15 min). (a) Represents a successful labor evolution. Every contraction dynamic point is projected onto the efficient area (below the dashed line). (b) Represents a failed induced labor evolution (δ point on Fig. 3). Every contraction dynamic point remains into the inefficient area (over the dashed line).

be considered for contraction efficiency analysis; but it is obvious that its value is of greatest interest for labor evolution monitoring.

The previously defined parameter set is representative of the contraction's efficiency. Its computation can be easily implemented in a reduced instrumentation which offers real time monitoring of the uterine activity efficiency, as a complement of tocography.

References

[1] Hewlett Packard, "Cardiotocograph," Appl. Note 700 F, 1979.

[2] D. O. Thorne, I. Assadi, J. Flores, and J. Seitchik, "The relationship of the maximum amplitude and the maximum and minimum slope of the intrauterine pressure waveform in late pregnancy and labor," *IEEE Trans. Biomed. Eng.*, vol. BME-19, p. 388, 1972.

[3] P. J. Steer, M. C. Carter, and R. W. Beard, "Normal levels of active contraction area in spontaneous labour," *Brit. J. Obstet. Gynaecol.*, vol. 91, p. 211, 1984.

[4] G. M. J. A. Wolfs and M. Van Leeuwen, "Electromyographic observations on the human uterus during labour," *Acta Obstet. Gynec. Scand.*, suppl. 90, 1979.

[5] A. Csapo, "Model experiments and clinical trials in the control of pregnancy and parturition," *Amer. J. Obstet. Gynecol.*, vol. 85, p. 359, 1963.

[6] C. Wood, "Myometrial and tubal physiology," in *Human Reproductive Physiology*, Blackwell, Ed. Oxford, England: 1972, ch. 7, p. 324.

[7] R. Caldeyro-Barcia and J. J. Poseiro, "Physiology of the uterine contraction," *Clin. Obstet. Gynecol.*, vol. 3, p. 386, 1960.

[8] A. R. Fuchs, "The role of oxytocin in parturition," *Current Topics Exp. Endocrinol.*, vol. 4, p. 231, 1983.

[9] G. Wolfs and H. Rottinghuis, "Electrical and mechanical activity of the human uterus during labour," *Arch. Gynäk*, vol. 208, p. 373, 1970.

[10] G. Germain, D. Cabrol, A. Visser, and C. Sureau, "Electrical activity of the pregnant uterus in the cynomolgus monkey," *Amer. J. Obstet. Gynecol.*, vol. 142, no. 5, p. 513, 1982.

[11] A. Verhoeff, R. E. Garfield, J. Ramondt, and H. C. S. Wallenburg, "Electrical and mechanical uterine activity and gap junctions in peripartal sheep," *Amer. J. Obstet. Gynecol.*, vol. 153, no. 4, p. 447, 1985.

[12] O. Bode, "Das elektrohysterogram," *Arch. Gynaekol.*, vol. 146, p. 123, 1931.

[13] L. Dill and R. M. Maiden, "The electrical potentials of the human uterus in labor," *Amer. J. Obstet. Gynecol.*, vol. 52, p. 735, 1946.

[14] C. M. Steer and G. J. Hertsh, "Electrical activity of the human uterus in labor," *Amer. J. Obstet. Gynecol.*, vol. 59, p. 25, 1950.

[15] C. M. Steer, "The electrical activity of the human uterus in normal and abnormal labor: Part I and Part II," *Amer. J. Obstet. Gynecol.*, vol. 68, p. 867, 1954.

[16] C. Sureau, "Etude de l'activité électrique de l'utérus au cours du travail," *Gynecol. Obstét.*, vol. 55, p. 153, 1956.

[17] P. Lopes, G. Germain, G. Breart, S. Reinato, R. Le Houezec, and C. Sureau, "Electromyographical study of uterine activity in the human during labor induced by Prostaglandin F2 Alpha," *Gynecol. Obstet. Invest.*, vol. 17, p. 96, 1984.

[18] E. H. G. Hon and C. D. Davis, "Cutaneous and uterine electrical potentials in labor," *Obstet. Gynecol.*, vol. 12, no. 1, p. 47, 1958.

[19] N. Val, B. Dubuisson, and F. Goubel, "Aide au diagnostic de l'accouchement par l'électromyogramme abdominal. Sélection de caractères," *Reconnaissance de Forme et Intelligence Artificielle*, vol. 3, p. 42, 1979.

[20] J. G. Planes, J. P. Morucci, H. Grandjean, and R. Favretto, "External recording and processing of fast electrical activity of the uterus in human parturition," *Med. Biol. Eng. Comput.*, vol. 22, p. 585, 1984.

[21] B. Bengtsson, "Factors of importance for regulation of uterine contractile activity," *Acta Obstet. Gynec. Scand.*, suppl. 108, p. 13, 1982.

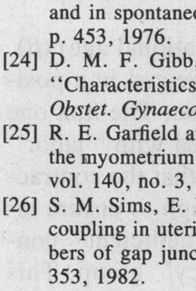
[22] D. H. Foley and J. W. Sammon, "An optimal set of discriminant vectors," *IEEE Trans. Comput.*, vol. C-24, p. 281, 1975.

[23] G. Lindmark and B. A. Nilsson, "A comparative study of uterine activity in labour induced with Prostaglandin F2 Alpha or oxytocin and in spontaneous labour," *Acta. Obstet. Gynec. Scand.*, vol. 55, p. 453, 1976.

[24] D. M. F. Gibb, S. Arulkumaran, K. C. Lun, and S. S. Ratnam, "Characteristics of uterine activity in nulliparous labour," *Brit. J. Obstet. Gynaecol.*, vol. 91, p. 220, 1984.

[25] R. E. Garfield and R. H. Hayashi, "Appearance of gap junctions in the myometrium of women during labor," *Amer. J. Obstet. Gynecol.*, vol. 140, no. 3, p. 254, 1981.

[26] S. M. Sims, E. E. Daniel, and R. E. Garfield, "Improved electrical coupling in uterine smooth muscle is associated with increased numbers of gap junctions at parturition," *J. Gen. Physiol.*, vol. 80, p. 353, 1982.



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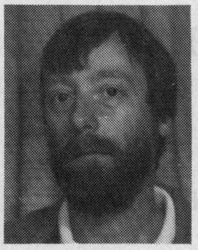

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