



Comparing uterine electromyography activity of antepartum patients versus term labor patients

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KEY WORDS

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Objective: The purpose of this study was to compare uterine electromyography of patients delivering >24 hours from measurement with laboring patients ≤24 hours from measurement.

Study design: Fifty patients (group 1: labor, n = 24; group 2: antepartum, n = 26) were monitored using transabdominal electrodes. Group 2 was recorded at several gestations. Uterine electrical “bursts” were analyzed by power-spectrum from 0.34 to 1.00 Hz. Average power density spectrum (PDS) peak frequency for each patient was plotted against gestational age, and compared between group 1 and group 2. Frequency was partitioned into 6 bins, and associated burst histograms compared.

Results: Group 1 was significantly higher than group 2 for gestational age (39.87 ± 1.08 vs 32.96 ± 4.26 weeks) and average PDS peak frequency (0.51 ± 0.10 vs $0.40 \pm .03$ Hz). Histograms were significantly different. A correlation coefficient of .41, with significance, was found with PDS vs gestation.

Conclusion: Uterine electromyography in antepartum patients is significantly lower than in laboring patients delivering ≤24 hours from measurement.

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It is widely accepted that uterine contractions are generated by the electrical activity originating from the depolarization-repolarization of billions of smooth-muscle myometrial cells.¹ Such action-potential events,

when involving many myometrial cells and occurring in immediate succession, form “bursts” of activity. Bursts are formed from a series of successive spikes in the voltage, and are higher in magnitude than the background noise. In the human, such bursts can last more than a minute in duration, and can produce voltages over a millivolt in amplitude, with electrical frequencies mostly concentrated in the <1 Hz realm. This electrical activity is low and uncoordinated early in gestation,² but becomes intense and synchronized later in pregnancy and peaks at term.³ Poor electrical coupling between the myometrial cells is partly responsible for the relatively inactive uterus early on,⁴ and the development of vast

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numbers of gap junctions undoubtedly plays a role in the electrical evolution of the myometrium.⁵ Other factors may also play a role, but it is generally thought that the uterus undergoes some critical transition into electrical preparedness for labor.

There have been 2 commonly used methods to acquire the uterine electromyography (EMG) signals abdominally: directly from the uterus via needle electrodes through the abdomen; and noninvasively through the use of abdominal-surface electrodes. The earliest uterine EMG studies established that the electrical activity of the myometrium is responsible for myometrial contractions.^{1,2} Extensive studies were done over the last 60 years to monitor uterine contractility using the electrical activity measured from needle electrodes placed on the uterus.⁶⁻⁸ This method, of course, has the advantage of providing electrical data directly from the uterus, but has the disadvantage of being invasive and, hence, less desirable. However, more recent studies indicate that uterine EMG activity can be monitored accurately from the abdominal surface.⁹⁻¹¹ It has also been established that the uterine electrical signals can be quantified sufficiently with power spectral analysis to evaluate the state of the uterus in order to predict delivery.¹²

Some groups have previously categorized “fast-F” and “slow-S” uterine electrical signal frequencies, with the S lying somewhere within 0.03 to 0.30 Hz, and the F being from 0.30 Hz up to approximately 1.50 to 3.00 Hz.¹³⁻¹⁵ However, our most recent previous work focused on changes occurring in the “uterine-dominant” range, ie, within the 0.34 to 1.00 Hz realm,¹² so as to eliminate respiration artifact, typically below 0.34 Hz, and to nullify cardiac components, generally found at above 1.0 Hz for the patients in our studies. Gut muscle signals, which are similar to the EMG signals in frequency content,¹⁶ make minimal contributions to the abdominal surface EMG recordings in pregnant patients. This is because gut muscle signals are much smaller in amplitude than uterine electrical signals by the time the signal is transmitted to the electrode since gut EMG signal sources are relatively far removed from the electrodes compared with the underlying uterus, and are generally shielded from the abdominal surface electrodes by the partially or fully developed uterus and fetus (which at the very least will alter conduction pathways¹⁷ for nonmyometrial signals to the abdominal surface, and which probably also act as electrical obstructions for the gut signals originating beyond them, especially in the gestations from about 24 to 36 weeks, caused in part by the presence of the non-conductive vernix caseosa¹⁸).

The present work aims to employ noninvasive trans-abdominal uterine EMG monitoring to further understand how uterine change manifests itself electrically, and to identify the variables to which this evolution is

related as the patient passes from the antepartum state into the labor stage. Knowledge of the electrical activity of the uterus before and after initiation of labor may yield clues as to the underlying behavior of uterine muscle, may allow for more accurate patient classification, and could aid in patient management, reducing needless admissions, and enabling a greater chance for predicting true labor and subsequent delivery.

Material and methods

Patients

The Institutional Review Board gave approval for this study, and all patients were required to sign written consent forms. General inclusion criteria into this study were singleton gestation, ultimate spontaneous vaginal delivery at term, >24 weeks gestation, and no signs of infection. Patients with unusual distress were excluded. Furthermore, in order to insure optimal electrical traces from the abdominal surface, those patients weighing more than 230 pounds were excluded.

Fifty pregnant patients (group 1: term-labor, stage 1, n = 24, spontaneous vaginal delivery within 24 hours of measurement; group 2: antepartum, n = 26, ultimate spontaneous vaginal term delivery more than 24 hours from measurement) exhibiting contractions were included. Antepartum patients were recorded on multiple occasions by appointment, with 95 total measurements for an average of 3.65 recordings per antepartum patient, and each was recorded on at least 2 occasions at different gestational ages. Successive antepartum recordings were performed at least 1 week apart. Antepartum patients' gestations ranged from 24 to 40 weeks. Term-laboring patients were included upon clinical diagnosis of labor (contractions and dilation), and their gestations ranged from 38 to 41+ weeks. However, no data were used for the analysis from patients who ultimately underwent cesarean section. Sixty-three total patients were recruited over a 22-month period, with 13 dropped because of cesarean section. All maternal ages were within the 17- to 36-year-old range. All patients included were admitted to the labor and delivery area of the University of Texas Medical Branch at Galveston, Tex.

Electrical recordings

Electrode attachment sites were prepared by first cleaning away excess oil with alcohol prep pads, and then using a mild abrasive and impedance-reducing gel to gently rub off the outer layers of the skin, improving electrical conduction to the electrode. The electrodes were self-adhesive Ag₂Cl models, each approximately 1.65 cm² in area (Quinton, Bothell, Wash). Two sets of these bipolar electrodes were attached to the abdomen

near the navel. Each electrode was separated from its respective partner by about 3 cm. Grounding was accomplished by placing another lead laterally on the patient's hip. The patients were asked to lie supine and very still in order to reduce any movement artifact (labor patients were in the first stage of labor, ie, not pushing). Sampling was done at 100 Hz. The differential signal was analog band-pass filtered from 0.05 Hz to 4.00 Hz to remove unwanted signal components and to prevent aliasing. The information was then amplified and stored in a personal computer. Analysis was performed using Chart 4.0 software (AD Instruments, Castle Hill, Australia). Patients were monitored with this system continuously for 30 minutes for any given visit. Respiration rate and heart rate were checked periodically during the recording and noted.

Signal analysis

Fourier analysis is predicated on the notion that virtually any signal can be constructed from a sum of sinusoidal components.¹⁰ The Fourier transform deconstructs a signal into its frequency components, the magnitudes of which are in units of power, or power density. Because the recording electrodes are located on the abdomen in the immediate vicinity of the myometrium, and because the myometrium becomes such a relatively large muscle, the contributions to the electrical signal from the uterus should predominate the recordings over other biological events in the supine, relaxed patient. Therefore, aside from artifacts such as possible patient movement, respiration, or skin potentials,¹⁹ the frequency at which the highest power occurs should correspond primarily to the contributions from the myometrium. The power density spectrum (PDS) peak frequency was therefore chosen as the parameter of interest, as in this group's previous studies.^{11,12,15} In every recording, each burst of uterine activity was analyzed by obtaining the 8192-size Fast Fourier Transform to generate the PDS, and then the largest power component in the uniquely uterine range was found. No information was quantified for those periods of the record during which activity was quiescent.

In order to again exclude most components of motion, respiration, and cardiac signals from the analysis, the corresponding PDS peak frequency only in the 0.34 to 1.00 Hz range was noted for each burst, as was done previously.¹² This spectral region was also isolated because shifts in uterine electrical frequency have been observed to occur in this domain as patients enter labor and begin actual delivery.¹⁹ Although large uterine components have been seen in the lower frequency range (<0.34 Hz), it is unclear whether these exhibit detectable changes useful for patient classification or prediction, and they are thus not the subject of this study.⁶

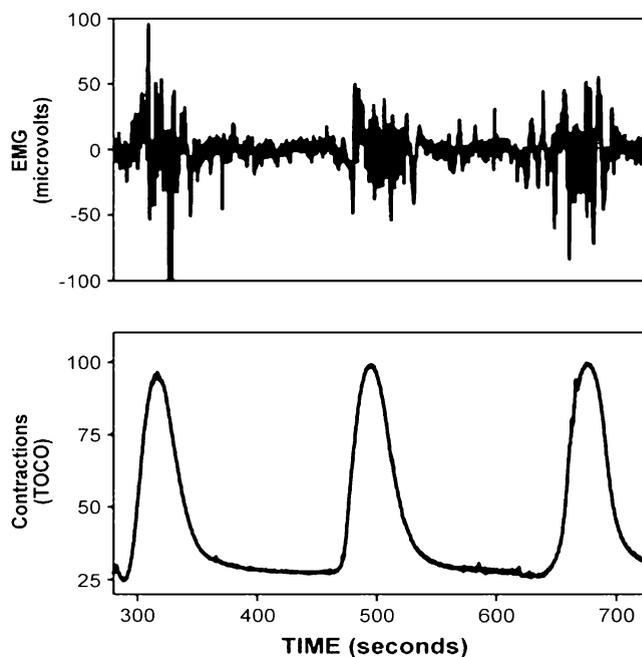


Figure 1 Correspondence of uterine contractions with uterine electrical “bursts.” Because the electrical activity is responsible for the contraction events, monitoring the uterine EMG is a viable alternative to bulky, unreliable tocodynamometers and invasive intrauterine pressure catheters.

Statistics

The mean PDS peak frequency was obtained for each patient at each time point measured by averaging the values from multiple bursts, and this was then plotted against the gestational age, as well as compared between group 1 and group 2. The frequency domain was then partitioned into 6 bins (≤ 0.36 Hz, 0.37-0.38 Hz, 0.39-0.40 Hz, 0.41-0.42 Hz, 0.43-0.44 Hz, and >0.44 Hz), and normalized histograms of the PDS peak frequency distribution (incorporating values of the bursts from all patients) were generated and compared between groups. Correlation analysis was performed using gestational age and PDS peak frequency as variables, and using all recordings from all patients. Rank-sum, chi-square, and Pearson product-moment tests were used for comparison, and correlation, as appropriate, with $P < .05$ indicating significance. Further refinements of the groups were later made (see below) to control for gestation.

Results

Bursts of uterine electrical activity corresponded to uterine contraction events (Figure 1). Average PDS peak frequency was generally greater for higher gestational age, when near or at term (Figure 2A and B). In fact, only 3 antepartum patients ever had average PDS

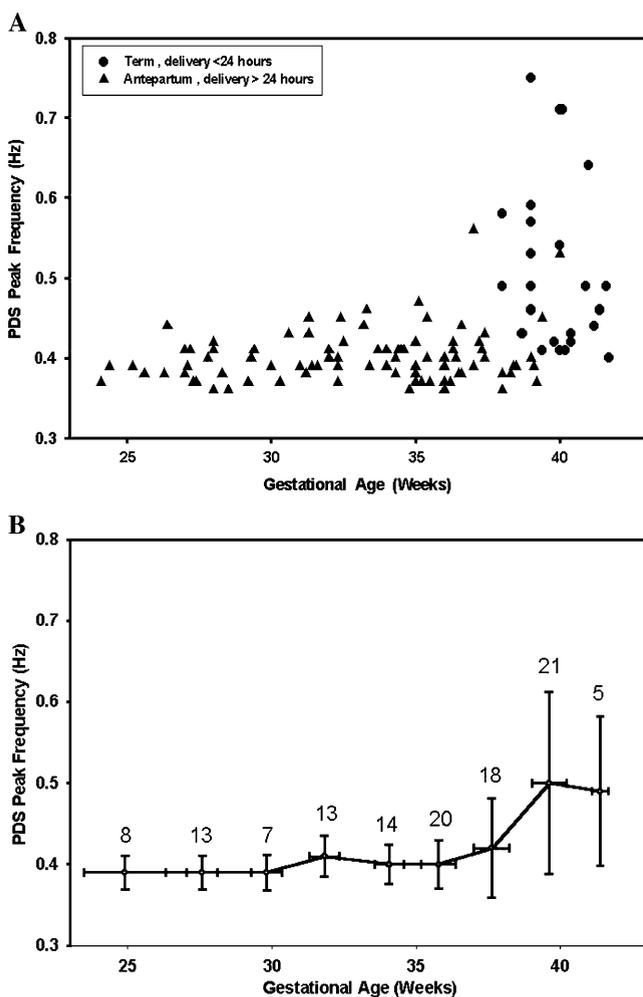


Figure 2 (A) Average power density spectrum (PDS) peak frequency vs gestational age for labor and antepartum patients, as demonstrated by scatter-plot of all EMG recordings made for all patients. (B) Average power density spectrum (PDS) peak frequency vs gestational age for labor and antepartum patients, as demonstrated by 9 gestational bins (mean \pm SD shown): <27 wk, 27-28.9 wk, 29-30.9 wk, 31-32.9 wk, 33-34.9 wk, 35-36.9 wk, 37-38.9 wk, 39-40.9 wk, and 41+ wk. The number of EMG recordings comprising each bin is also shown.

peak frequency values measured that were considerably high (measured value above 0.46 Hz, or >2 standard deviations above the antepartum mean) during any one of their multiple recorded time-points. However, most patients had at least some degree of both high- and low-frequency activity observed in their uterine electrical signals for any given recording. Group 1 had significantly higher ($P < .05$, rank-sum) values than group 2 for gestational age (39.87 ± 1.08 weeks vs 32.96 ± 4.26 weeks; Figure 3) and average PDS peak frequency (0.51 ± 0.10 Hz vs $0.40 \pm .03$ Hz; Figure 4). Normalized histograms (Figure 5A and B) of the PDS peak frequencies of bursts showed a significant difference between group 1 and group 2 ($P < .05$, $\chi^2 = 55.60$),

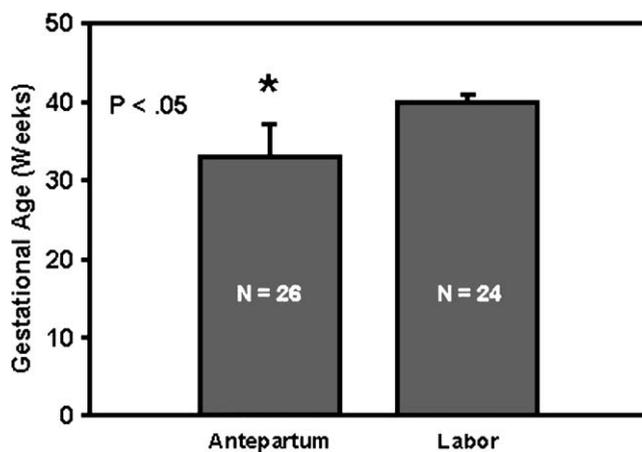


Figure 3 Gestational age in the antepartum vs labor patients (mean \pm SD shown).

with group 1 having a much greater number of high-frequency PDS peak observations. Correlation analysis using all recordings from all patients, and using gestational age and PDS peak frequency as variables, gave a correlation coefficient of .41 with significance (Pearson product moment, $P < .05$).

For the 3 antepartum patients exhibiting unusually high average PDS peak frequency values at some time-point during their evaluations, it was thought that the increased burst electrical frequency content was possibly related to circadian rhythm.^{20,21} However, all 3 patients were measured between 9:00 am and 3:30 pm during their respective “elevated” periods, so the effect of nocturnal activity was discounted for explaining why the high-frequency electrical activity was observed. It was interesting that the average gestational age at these patients’ elevated-measurement time-points was 37.4 weeks, which is just at the onset of term. This higher gestational age may explain the tendency for these few antepartum patients to exhibit some elevated uterine electrical activity over the lower-gestation antepartum patients, even though they were still considered far removed from delivery (by an average of 16 days, in fact).

This finding raised the question as to whether the difference in electrical activity for the groups was solely related to gestational age, regardless of time to delivery. Because all of the laboring patients included in group 1 were measured at ≥ 38 weeks’ gestation, and all of the antepartum patients from group 2 were measured at ≤ 40 weeks’ gestation, 2 new groups were formed and compared; group 3 ($n = 19$): laboring, and measured at ≥ 38 and ≤ 40 weeks’ gestation, and group 4 ($n = 7$): antepartum, and measured at ≥ 38 and ≤ 40 weeks’ gestation. There was no significant difference in gestational age between the 2 groups (group 3, $39.14 \pm .66$ weeks vs group 4, $38.79 \pm .66$ weeks), yet group 3 had a significantly higher average PDS peak frequency than

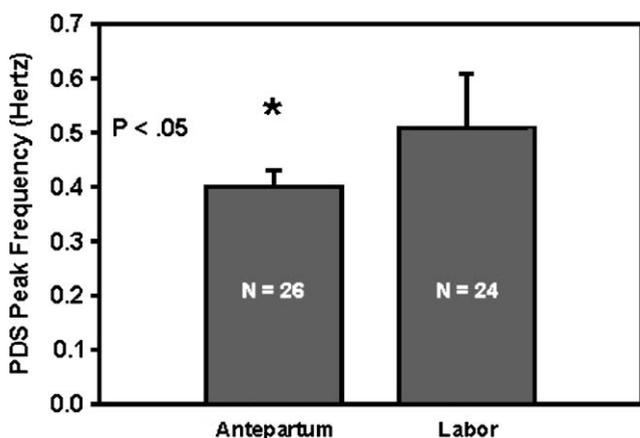


Figure 4 Average burst PDS peak frequency (in the 0.34 to 1.00 Hz range) of antepartum vs labor patients (mean \pm SD shown). Higher frequencies are seen in the labor group.

group 4 (.53 \pm .11 Hz vs .40 \pm .05 Hz; $P < .05$). We also performed additional χ^2 statistics on group 3 versus group 4, again using normalized histograms for the power spectrum peak frequencies (as was done for Figure 5A, group 1, and B, group 2). We arrived at $\chi^2 = 54.37$, and $P < .001$. Because all of the patients in group 3 were measured within 24 hours of delivery, and all of those in group 4 were measured at more than 24 hours from delivery, this supports the notion that the increased electrical activity is not purely related to gestational age, or necessarily caused by a preterm versus term effect, but also depends intimately upon how close to delivery the patients are. This is also supported by our previous studies, where we found preterm-delivering labor patients had similarly high average uterine electrical frequency components, as did term-delivering labor patients.¹²

Comment

It has been proposed that a critical transition occurs in the uterus, ultimately preparing it for active expulsion of the fetus during labor and subsequent delivery.⁹ The present work verifies that such a change occurs a day or so before delivery in term patients delivering spontaneously. This study further verifies that the change from antepartum to labor causes significant increases in average electrical burst PDS peak frequency components, and causes shifts in the distribution of burst frequencies such that a statistically greater number of observed high-frequency electrical burst events occur in laboring patients than in nonlaboring patients. For antepartum patients, a preponderance of low-frequency electrical activity is observed. However, most laboring and antepartum patients do exhibit at least some amount of both low- and high-frequency uterine elec-

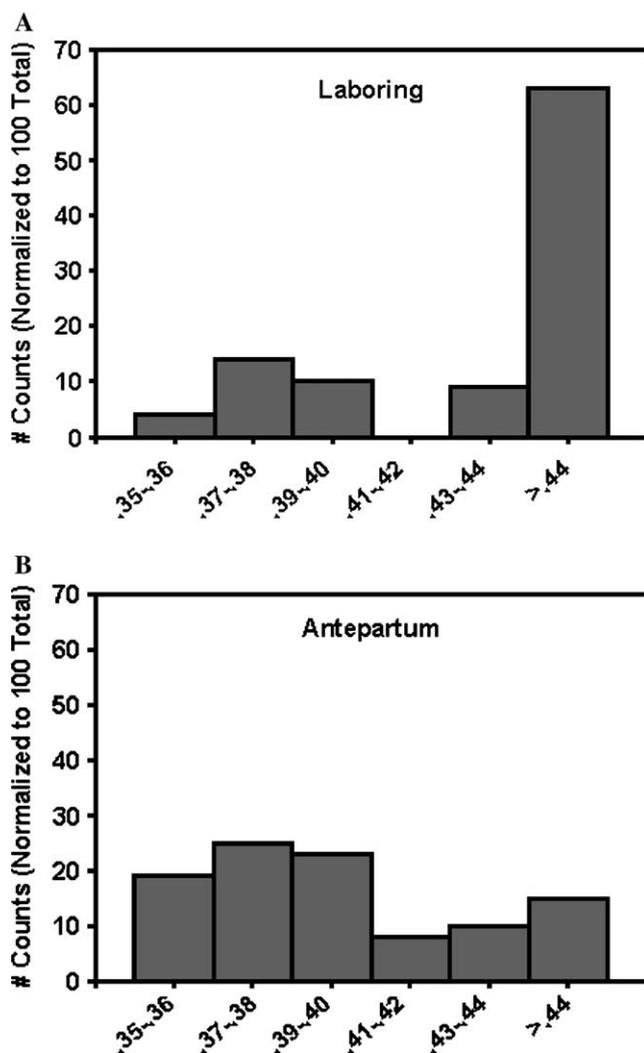


Figure 5 (A, B) Comparison of normalized histograms for labor vs antepartum patients using the PDS peak frequency variable through 6 “bins.” There is a significant ($P < .05$, chi-square) shift in the frequency distribution of power within bursts toward higher frequencies for the labor group compared with the antepartum group.

trical activity. This provides an indication as to how the uterine muscle behaves before and after the uterus becomes prepared for labor.

It is possible that the uterus may exhibit natural fluctuations in electrical frequency, varying slightly up and down in the frequency of contraction electrical spectral components, possibly throughout pregnancy. Related fluctuations have been observed previously in the resting potentials of uterine cells.^{6,22} When considering the PDS peak frequency parameter at least, this effect does not seem related to circadian rhythm, but a more rigorous determination of this conclusion should be conducted. The effects on power spectrum caused by fatigue in the uterus are essentially unknown, but this could certainly be a contributing factor here, especially in laboring patients, where the uterine action is most

vigorous.^{23,24} Nevertheless, depending on whether or not the uterus has made a critical transition to labor, one may find the uterus in an electrical state of high frequency or low frequency with different likelihood. According to this and our previous studies, the uterus shows high-frequency activity only about 10% to 20% of the time when far removed from delivery, and it shows high-frequency activity about 80% to 90% of the time when within 24 hours of delivery for term patients. This could explain why both positive and negative predictive values were around 80% to 90% in our previous study.¹² Hypothetically, even when a woman is measured far from actual delivery, she could be in a temporary "high-electrical-frequency state," and this would give a false positive for that patient for that 30-minute recording. On the other hand, the uterus of a woman close to labor is in this high-electrical frequency mode a greater percentage of the time, which is why it is likely that bursts will be measured for her that have more high-frequency components, at least over a relatively short recording period such as was used for this study. Continuous monitoring of patients as they enter into and proceed through labor may prove to be most informative about the temporal evolution of any uterine electrical frequency fluctuations.

It must be stated that the fluctuations in frequency content may also be related to nonlinear components in the measured uterine signals,²⁵ and false-positive and -negative patient classifications could be influenced by an inherent limitation on power spectrum analysis to completely quantify any existing dynamic uterine signal components. Much more work still needs to be done to resolve this somewhat controversial issue. Our opinion is that the power spectrum method applied to the narrow frequency band produced by the uterus, where power peaks can nearly always, in fact, be discerned, is not only appropriate but also greatly effective. However, the effectiveness of nonlinear analysis techniques applied to uterine EMG data should indeed continue to be investigated, and the results compared with those rendered by the power spectrum technique.

The underlying conclusion from our present work is that patients far removed from delivery do not seem to produce low-frequency uterine electrical bursts at all times, only most of the time; and patients close to delivery apparently do not generate high-frequency uterine electrical bursts at all times, only most of the time. The implication is that the important measure of uterine electrical activity is the shift to greater probability of observing high-frequency bursts after the transition to preparedness for labor is made. This is, in fact, reflected in the histogram shift that the present data display. This shift does not appear to be solely related to gestational age, but also to the measurement-to-delivery interval, and evidently occurs a day or so from delivery in patients ultimately delivering sponta-

neously at term. In this sense, the critical transition to electrical preparedness for labor is measurable as a statistical shift with regard to spectral content, and is quantifiable with power spectrum methods sufficiently to give good results in the classification of patients into those who are in labor and those who are not.

Uterine activity is routinely measured successfully by using the noninvasive transabdominal electromyograph rather than by tocodynamometer or intrauterine pressure catheter. As previously described, and as further evidenced by this study, uterine electromyography information may be used to improve management of pregnant patients, as well as to predict labor effectively. In the clinic, uterine EMG can potentially yield much more comprehensive and useful information than other presently used methods of uterine monitoring.

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