Non-invasive transabdominal uterine electromyography correlates with the strength of intrauterine pressure and is predictive of labor and delivery

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Objective: The study was conducted to investigate whether the strength of uterine contractions monitored invasively by intrauterine pressure catheter could be determined from transabdominal electromyography (EMG) and to estimate whether EMG is a better predictor of true labor compared to tocodynamometry (TOCO).

Study design: Uterine EMG was recorded from the abdominal surface in laboring patients simultaneously monitored with an intrauterine pressure catheter ($n = 13$) or TOCO ($n = 24$). Three to five contractions per patient and corresponding electrical bursts were randomly selected and analyzed (integral of intrauterine pressure; integral, frequency, amplitude of contraction curve on TOCO; burst energy for EMG). The Mann–Whitney test, Spearman correlation and receiver operator characteristics (ROC) analysis were used as appropriate (significance was assumed at a value of $p < 0.05$).

Results: EMG correlated strongly with intrauterine pressure ($r = 0.764$; $p = 0.002$). EMG burst energy levels were significantly higher in patients who delivered within 48 h compared to those who delivered later (median [25%/75%]: 96 640 [26 520–322 240] vs. 2960 [1560–10 240]; $p < 0.001$), whereas none of the TOCO parameters were different. In addition, burst energy levels were highly predictive of delivery within 48 h (AUC = 0.9531; $p < 0.0001$).

Conclusion: EMG measurements correlated strongly with the strength of contractions and therefore may be a valuable alternative to invasive measurement of intrauterine pressure. Unlike TOCO, transabdominal uterine EMG can be used reliably to predict labor and delivery.

Key words: UTERINE ELECTROMYOGRAPHY; PRETERM LABOR; UTERINE CONTRACTILITY; TOCODYNAMOMETRY; INTRAUTERINE PRESSURE

INTRODUCTION

During the major part of pregnancy the uterus maintains a quiescent state while the cervix remains firm and closed. In preparation for labor, the cervix softens and the myometrium undergoes changes to allow efficient generation and propagation of electrical activity. The key to identifying labor, and ultimately preterm labor, probably lies in the identification and interpretation of this preparatory phase. Current methods of evaluating uterine contractility include the use of external tocodynamometers (TOCO) or an intrauterine pressure catheter (IUPC).

External TOCO devices utilize a strain gauge pressure-sensing device to determine changes in the maternal

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abdominal contour as an indirect indicator of uterine contractions. In clinical settings, TOCO has been used as a tool to diagnose preterm labor. However, this tool only provides information relating to the frequency of the uterine contractions. Although it has previously been reported that contraction frequency might have some potential to differentiate between threatened and true labor, the data are controversial[1]. Therefore, at present we do not have a single instrument that would reliably predict true labor and would prevent dangerous under- or overtreatment[2].

A more reliable tool for labor monitoring is the recording of intrauterine pressure by an IUPC. The major drawback of this technique is that it is invasive and can be used only after rupture of membranes. Moreover, quantitative analysis of intrauterine pressure curves using Montevideo units (product of peak pressure and frequency or contractions) or Alexandria units (product of peak pressure, frequency of contractions and duration of contractions) has been shown to be unreliable and of limited value in prediction of labor[3]. While the integral over the baseline of the intrauterine pressure contraction curves may be a better measure of contractile activity, it does not overcome the problem of invasiveness and lack of accuracy[4].

Previous studies have established that electrical activity of the myometrium is responsible for myometrial contractions[5,6]. The propagation of this electrical activity is facilitated by gap junctions, which increase in number prior to the onset of labor[7]. Gap junctions are composed of connexin proteins that provide channels of low electrical resistance between the myometrial cells, thus creating a pathway for efficient conduction of action potentials. The contractile activity of the myometrium is a direct result of voltage- and time-dependent changes in membrane ionic permeability. The electrical discharges of the myometrium consist of intermittent bursts or spike action potentials[8]. A single spike can initiate a contraction while multiple spikes are required to increase the strength and duration of contractions. Therefore, the frequency, amplitude and duration of uterine contractions can be determined by the frequency of the action potentials within a burst, the duration of a burst and the total number of cells that are activated simultaneously.

Characterization of these uterine electrical events is possible non-invasively through recording of uterine electromyographic signals (EMG) from the abdominal surface[9–13]. In addition to providing the usual information concerning the frequency of uterine contractions, the analysis of the characteristics of electrical events measured by transabdominal EMG can assess the progression of uterine preparedness for labor[7,8]. The objectives of this study were to investigate whether the strength of uterine contractions monitored invasively by IUPC could be determined from transabdominal EMG recordings; and to assess whether EMG is a better predictor of true labor compared with TOCO.

MATERIALS AND METHODS

Patients

Thirteen gravidas in labor at term who had ruptured membranes and were being monitored with an IUPC were included in the study comparing intrauterine pressure and EMG.

Twenty-four pregnant women in whom EMG and TOCO were simultaneously recorded were included in the study comparing both methods. These patients were evaluated in the labor and delivery unit and differentiation between false and true labor could not be made clinically. Inclusion criteria in this part of the study were singleton gestation; > 24 weeks' gestation; intact membranes; cervical dilatation of < 2 cm and effacement of $< 80\%$, no signs of infection; and spontaneous vaginal delivery, since the timing of delivery may have been affected by factors unrelated to true versus false labor. These women were then followed, their date and time of delivery was recorded, and the measurement-to-delivery interval was calculated.

All procedures were approved by the institutional review board (protocol no. 94-188). All patients signed a written informed consent form before enrolment into the study.

Uterine activity monitoring

The sites of electrode attachment (approximately 3 cm^2) were prepared by gentle rubbing with fine abrasive paper. Two pairs of $AgCl_2$ electrodes were applied to the abdominal wall, approximately 5 cm apart, at points where external palpation indicated the uterus to be in close contact with the abdominal wall. A ground electrode was placed laterally on the right hip. EMG signals were acquired at 100 Hz, band-pass filtered from 0.2 to 4 Hz and stored.

At the same time (Figure 1) the patients were monitored with either an IUPC ($n = 13$) or TOCO ($n = 24$) according to the usual protocol. Intrauterine pressure was recorded only when indicated for obstetric reasons. Simultaneous recordings were performed for at least 45 min.

Evaluation of uterine activity

Five (intrauterine pressure vs. EMG) or three (TOCO vs. EMG) contractions per patient were randomly selected and analyzed. Analysis was performed using Chart 4.0.3 software (AD Instruments, Castle Hill, Australia). The following parameters were determined for each method of monitoring:

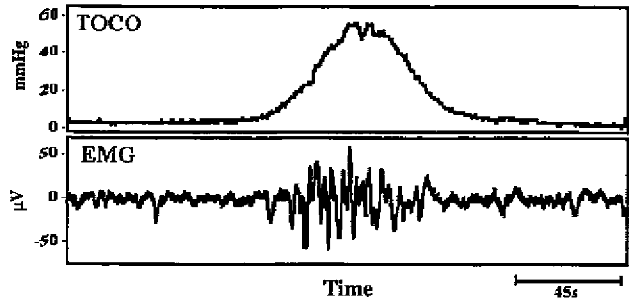

Figure 1 Typical contraction recorded by external tocodynamometry (TOCO; upper half). The y-axis unit is given as mmHg. Since in the case of TOCO no pressure is recorded, this unit was put in hyphens. The corresponding burst recorded non-invasively by transabdominal electromyography (EMG) is shown in the lower panel. Note that the change in EMG activity corresponds to the change in pressure recorded by TOCO

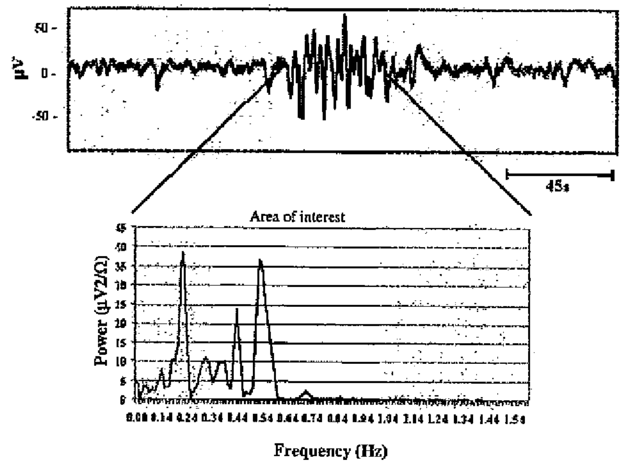

Figure 2 For electromyography burst analysis, the power spectrum of single bursts was acquired. Within the power spectrum, only the area of interest from 0.34 to 1 Hz, where 98% of uterine electrical activity is found, was selected. Additionally, this technique ensures that effects of maternal breathing movements (represented by the peak in the left shaded area of the power spectrum) are excluded. Burst energy was calculated as the product of the burst duration in seconds and the sum of the power components in the area of interest

(1) TOCO: The frequency as well as the peak amplitude and the integral (from beginning to end of contraction) over the baseline were determined.
(2) Intrauterine pressure: Only the integral (over baseline from beginning to end of contraction) was calculated, as this was previously suggested to be the best intrauterine pressure parameter[3]. For intrauterine pressure, this parameter represents an estimate of the energy level of the contraction. EMG: The energy of electrical bursts was determined by multiplying the sum of the Y-values of the power density spectrum between 0.34 and 1.0 Hz by the duration of the electrical burst in seconds (Figure 2).

For each patient, the mean value for each parameter was calculated and used in the final analysis in order to exclude autocorrelation.

Statistical analysis

Data were checked for normality. The Mann–Whitney rank sum test and Spearman's rank sum correlation test were used as appropriate (SigmaStat 2.03; Jandel Scientific Software Corporation, San Rafael, CA, USA). Receiver-operator characteristic (ROC) analysis was also performed to predict delivery within 48 h (True Epistat; Epistat Services, Richardson, TX, USA). A p-value of < 0.05 was considered statistically significant.

RESULTS

In the 13 patients who were monitored by IUPC, the energy levels determined from transabdominal uterine EMG correlated strongly with the energy of corresponding uterine contractions determined by intrauterine pressure ($r = 0.764$; $p = 0.002$, Figure 3).

Of the 24 patients who were monitored using TOCO and who ultimately delivered spontaneously, eight women delivered within 48 h and 16 delivered more than 48 h after evaluation. No statistically significant differences between subgroups were seen regarding the proportion of singleton gestations and gestational age. When these two groups were compared, no significant differences were seen regarding the contraction frequency, amplitude, or integral (Figure 4a–c). In contrast, the EMG data showed significant differences. The burst energy was significantly higher in patients who delivered within 48 h (median [25th/75th centile] 96 640 [26 520–322 240] μV^2s/Ohm vs. 2960 [1560–10 240] μV^2s/Ohm; $p < 0.001$; Figure 4d).

The ROC analysis demonstrated that the burst energy level was significantly predictive for delivery within 48 h (area under the ROC curve [AUC]: 0.95; $p < 0.0001$). When using a cut-off value of 661 μV^2s/Ohm, the positive and negative predictive values were 94 and 88%, respectively (Figure 5).

COMMENTS

Our data have shown that EMG measurements correlated strongly with the strength of uterine contractions measured by IUPC, leading us to conclude that uterine EMG accurately reflects uterine contractile activity. We have previously demonstrated similar findings in animals, even in those with intact membranes[14]. Monitoring uterine EMG activity can be useful clinically when objective evaluation of uterine contractions is needed prior to rupture of membranes.

Our results also confirmed that external TOCO had limited value in assessing uterine activity and prediction of true labor. None of the three parameters examined differentiated between those women who delivered within 48 h and those who delivered after 48 h.

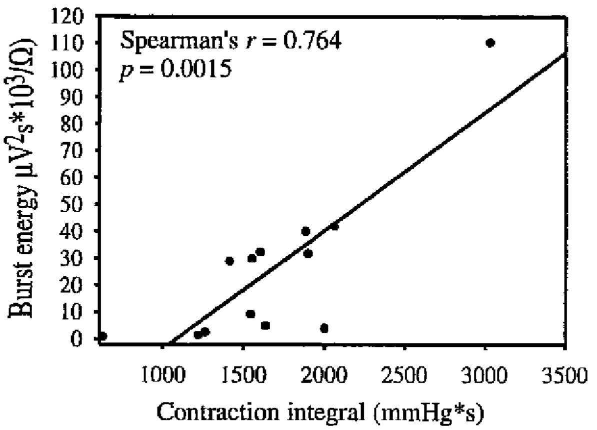

Figure 3 Correlation between the energy of the electromyographic burst and the integral of the intrauterine pressure curve acquired during the corresponding contraction

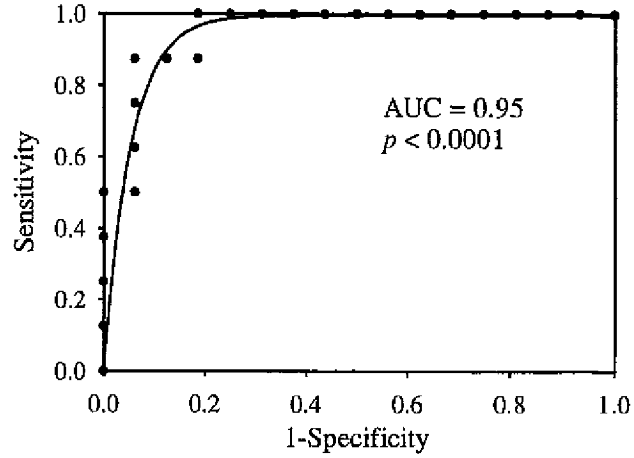

Figure 5 The receiver operator characteristic curve using the electromyographic burst energy level to predict spontaneous delivery within 48 h

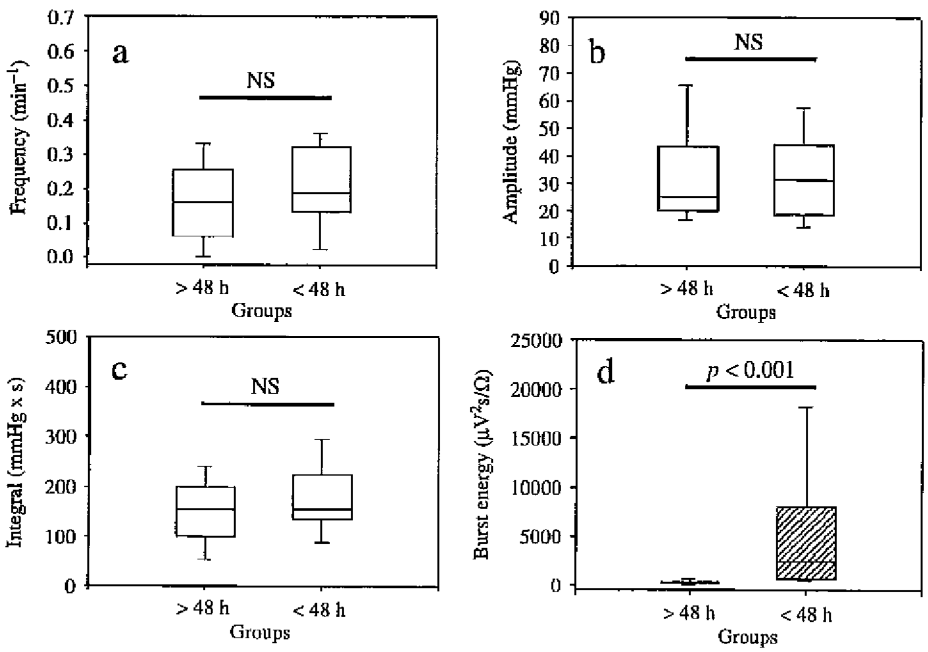

Figure 4 Boxplots of the data obtained from the tocodynamometry trace (a, b and c) in patients who delivered spontaneously within 48 h of evaluation versus those who delivered more than 48 h later. No significant differences were noted regarding the contractions' frequency (a), amplitude (b), or integral (c). In contrast, the electromyographic burst energy (d) was significantly higher in patients who delivered within 48 h

In contrast, analysis of EMG bursts showed that burst energy increased significantly within 48 h before delivery. When performing a ROC analysis, sensitivity and specificity as well as positive and negative predictive values were around 90%, indicating that EMG can be a useful instrument not only for objective and reliable evaluation of the changes in the electrical pattern of the myometrium when delivery approaches, but also for differentiation between true and false labor. Being an extremely precise diagnostic tool, EMG elegantly points to the dramatic increase in uterine contractility during the last 48 h of active labor, resulting in the great variation of this parameter seen in the < 48-h group. However, we used 48 h as the cut-off level because it is generally accepted that women who do not deliver within 48 h of their presentation with contractions must have been in false labor. Indeed, this accounts for the data not being normally distributed in the < 48-h group. The results, however, would have been similar even if a 24-h cut-off level had been used.

It is also interesting to note that, despite contractions detected on external TOCO, the EMG burst energy in women who did not deliver within 48 h of evaluation was almost nil (Figure 4). Poor propagation of electrical activity or lack of recruitment of enough myometrial cells may explain why these women were in false labor despite frequent contractions. While intrauterine pressure recording was not possible in these women, as they were not in active labor, the correlation between EMG and intrauterine pressure energies demonstrated in the first part of our study led us to speculate that the changes in uterine configuration detected by the external TOCO and labeled as contractions did not result in a significant increase in intrauterine pressure. The results of the two parts of this study indicate that EMG monitoring may provide more objective and clinically useful information than TOCO. This may be especially important in clinical scenarios such as differentiation between true and false labor, and management of labor augmentation, labor induction or tocolysis.

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