OBSTETRICS

Uterine electromyography for identification of first-stage labor arrest in term nulliparous women with spontaneous onset of labor

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OBJECTIVE: We sought to study whether uterine electromyography (EMG) can identify inefficient contractions leading to first-stage labor arrest followed by cesarean delivery in term nulliparous women with spontaneous onset of labor.

STUDY DESIGN: EMG was recorded during spontaneous labor in 119 nulliparous women with singleton term pregnancies in cephalic position. Electrical activity of the myometrium during contractions was characterized by its power density spectrum (PDS).

RESULTS: Mean PDS peak frequency in women undergoing cesarean delivery for first-stage labor arrest was significantly higher (0.55 Hz), than in women delivering vaginally without (0.49 Hz) or with (0.51 Hz) augmentation of labor ($P = .001$ and $P = .01$, respectively). Augmentation of labor increased the mean PDS frequency when comparing contractions before and after start of augmentation. This increase was only significant in women eventually delivering vaginally.

CONCLUSION: Contraction characteristics measured by uterine EMG correlate with progression of labor and are influenced by labor augmentation.

Key words: cesarean delivery, electromyography, labor arrest, parturition, uterine electromyography/EMG

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Worldwide cesarean delivery (CD) rates increase rapidly.[1] The majority of intrapartum CD (about 47%) are performed for failure to progress in term nulliparous women with a fetus in cephalic position.[2] Effective treatment strategies to address the problem of labor arrest are needed to reduce or at least stabilize the CD rate. Paradoxically, the widespread use of uterotonic drugs does not seem to be the answer to the problem. Comparison between a historic cohort and modern practice has shown that the length of labor has increased during the last 50 years, while the proportion of women receiving uterotonic drugs has increased several fold, even when controlling for factors such as maternal age and body mass index.[3] These data stress the importance of studies on the normal process and progress of labor and on prognostic factors regarding the efficacy of uterotonic medication. The challenge is to identify which labors will respond to oxytocin and which would benefit from other, not-yet-defined interventions.

Current monitoring techniques of uterine contractility, either by external tocography or by intrauterine pressure catheters, have not been shown to improve outcomes.[4] However, in the last 15 years several groups have revived interest in uterine electromyography (EMG), a noninvasive technique enabling measurement of electrical activity through the maternal abdominal surface, developed 70 years ago.[5-9] In case of threatened preterm labor, EMG identifies patients delivering at short term more accurately than other current methods.[10-13] We hypothesized that the findings in preterm labor could be translated into the possibility to differentiate between normal and protracted labor at term.

The objective of this study was to investigate whether uterine EMG can differentiate between inefficient contractions resulting in a CD for first-stage labor arrest, and efficient contractions (with or without labor augmentation) leading to a vaginal delivery in term nulliparous women with a spontaneous onset of labor.

Materials and Methods

A prospective multicenter observational study was conducted in 3 centers in The Netherlands from August 2009 through May 2011. The inclusion criteria were singleton pregnancies in cephalic position

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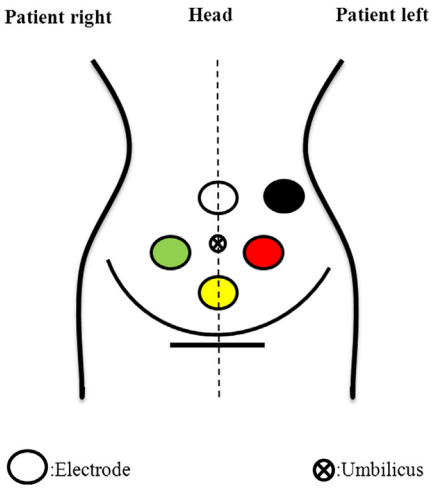
FIGURE 1
Positioning of electrodes on maternal abdomen



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(gestational age ≥37 weeks and ≤42 weeks) admitted to the labor ward for spontaneous labor. Exclusion criteria were suspected congenital or chromosomal abnormalities. The study was approved by the institutional medical ethical committees of the participating hospitals. Patients who were eligible for participation were approached consecutively. After informed consent was obtained, measurements of uterine activity were performed using EMG as recorded noninvasively from the maternal abdominal surface. EMG recordings started from the onset of labor or during first stage of labor upon arrival at the labor ward until delivery. There was no predefined time frame for registration duration and EMG recordings were conducted for as long as possible after inclusion. Registrations were analyzed post hoc.

All participating centers belong to a network of teaching hospitals taking part in the same residency program in obstetrics and gynecology. They follow a similar clinical policy inspired by the active management of labor approach.[14] According to this common policy, onset of active labor was defined as: painful regular contractions ≥2/10 minutes and ruptured membranes or cervical effacement ≥75% and/or cervical dilation ≥2 cm. Progress of labor was monitored with the use of cervical examinations performed at least every 2 hours, or more frequently when indicated. The diagnosis of labor arrest was made by the clinician using the following criteria: patient in active labor (according to the definition outlined previously) with no increase in dilation for at least 2 hours. Protracted labor was defined as a rate of cervical dilation ≤1 cm/h. In both cases oxytocin augmentation was started. A CD for labor arrest was generally performed if labor arrest persisted despite augmentation of labor with oxytocin during an additional 2 hours.[15,16]

Maternal, neonatal, and labor characteristics were collected from the patient's charts.

Uterine activity registration and analysis

Uterine activity was monitored using a portable maternal/fetal heart rate/EMG recorder (AN24, Monica Healthcare Ltd, Nottingham, United Kingdom) through 5 disposable electrodes that were positioned on the maternal abdomen in a standardized manner. The electrodes were positioned in the following way: 2 electrodes vertically along the midline, approximately 3-5 cm on both sides of the umbilicus; and 2 electrodes horizontally at the level of the umbilicus and symmetrical with respect to it, about 3-10 cm from the umbilicus. Finally, a (ground) electrode was placed on the left flank (Figure 1). Skin preparation before electrode placement ensured that skin impedance was <5 kΩ in all recordings. The raw abdominal EMG was recorded at 300 Hz and filtered in the 0.34- to 1-Hz bandwidth to obtain the uterine EMG. This procedure is similar to that reported by others in term of electrode placement and signal filtering.[11-13] Filtering in the 0.34- to 1-Hz bandwidth aims at removing heart rate artefacts >1 Hz and respiration artefacts <0.34 Hz. However, in contrast with the works cited previously, we developed an algorithm to identify contractions and compute the power density spectrum (PDS) due to the large number of contractions to be analyzed. This algorithm has been tested and described previously by comparing it against intrauterine pressure catheter measurements.[17]

PDS analysis was performed on each contraction and the peak frequency was used as a contraction characteristic to be linked with clinical outcomes (Appendix; definitions can be found in the Glossary). The signal processing steps are illustrated in Figure 2. This method of analysis has been one of the most predictive EMG parameters in both human and animal studies for prediction of true labor.[7,10,12,13,18,19] The investigators who analyzed the data were not blinded to the labor and delivery data. However, the numerical data of the EMG signal prevented subjective interpretation.

Statistical analysis

Data analysis was performed using software (SPSS, version 20.0; IBM Corp, Armonk, NY). The number of inclusions was estimated beforehand at 250 patients to result in around 10 CD for first-stage labor arrest, based on an expected rate of 4%. This was chosen such that in a univariate regression analysis the influence of 1 contraction parameter could be analyzed. It was difficult beforehand to estimate the degree of intercorrelation and intracorrelation due to the nested structure of the data and hence to perform a more precise power analysis. The study was terminated prematurely because 14 cases of CD for first-stage arrest had already been included.

The cohort was divided in different groups depending on the outcome. Patients with a CD for reasons other than first-stage labor arrest were excluded from analysis. Groups were defined as: group 1, women who delivered vaginally without labor augmentation; group 2, women who received labor augmentation because of protracted labor and who delivered vaginally; and group 3, women with a CD for first-stage labor arrest. The effect of labor augmentation on the mean PDS peak frequency was studied by a subanalysis of the contractions before (group a) and after (group b) administration of oxytocin. Due to the nested structure of the data with multiple measurements per subject, linear mixed models were used to evaluate the difference in peak depolarization frequencies between the different

groups. Intraclass correlation coefficients were calculated, to compare the variance of contraction characteristics within subjects to the variance between subjects. The following confounders were added to the model: maternal age, body mass index, gestational age, birthweight, cervical dilation, and epidural analgesia. The choice of these confounders was based on literature on confounders of labor outcome.[20-22] Interactions between the confounders and the different groups were studied. A Bonferroni correction was applied to the subanalysis because of multiple testing, by adjusting the level of significance to $P < .005$.

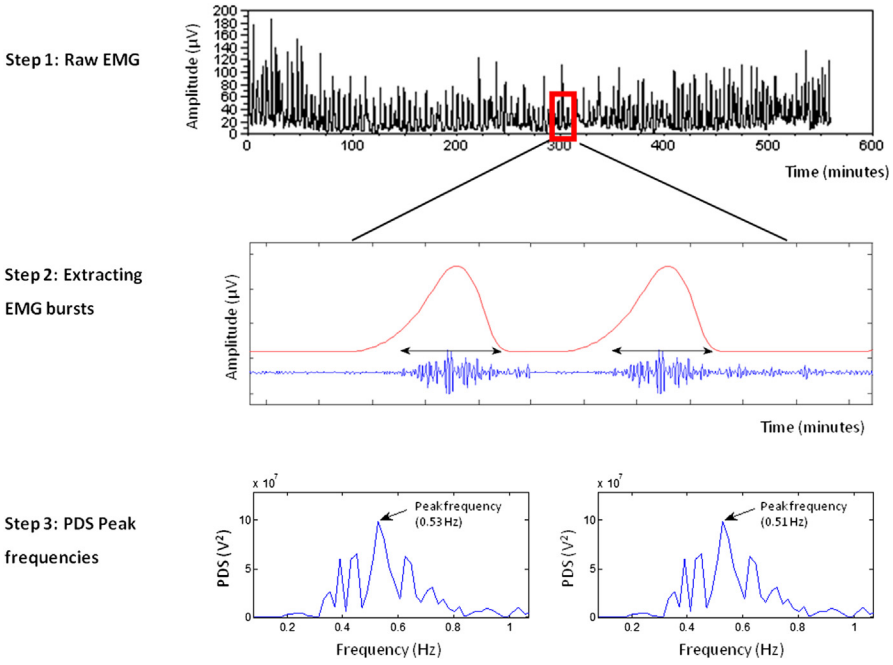
RESULTS

A total of 124 women were included, of whom 105 women delivered vaginally either spontaneously or instrumentally; 14 women delivered by CD during the first stage of labor because of arrest of dilation; another 5 women had a CD because of fetal distress (n = 2) or second-stage labor arrest (n = 3) (Figure 3 flowchart).

A total of 119 women were selected for analysis. Group 1 consisted of 32 women, group 2 of 73 women, and group 3 of 14 women. Table 1 shows the characteristics of the 3 groups. Table 2 displays the number of contractions, median peak frequency, and interquartile range per centimeter of cervical dilation for each group. In all groups the PDS peak frequency increased with increasing dilatation. The highest PDS values occurred in the CD group. In groups 2 and 3 all women received augmentation with oxytocin. The mean rate of cervical dilation in the hour before augmentation was 0.14 cm/h and the average cervical dilation at onset of oxytocin was 4.5 cm. Similarly labor arrest or very slow cervical dilation despite augmentation occurred in all cases in which a CD for first-stage labor arrest was performed (mean cervical dilation in the last 2 hours with augmentation was 0.16 cm/h). The mean cervical dilation at CD was 6 cm.

Figure 4 shows the mean peak frequencies with 95% confidence intervals (CIs) of groups 1, 2, and 3, with *P* values for differences between the groups. Interactions between the confounders and the groups showed no effect modification. In women delivering vaginally without or with augmentation (groups 1 and 2) the PDS peak frequency was significantly lower than in those with a CD for first-stage labor arrest (group 3). Of all confounders added to the model, only cervical dilation had a significant

FIGURE 2
EMG signal processing steps



Step 1: Raw EMG as recorded from maternal abdomen during labor. Step 2: EMG extraction; red line indicates uterine activity; blue line represents electrical burst/contraction. Step 3: For each burst/contraction peak frequency was calculated with PDS analysis.

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EMG, electromyography; *Hz*, hertz; *PDS*, power density spectrum; *μV*, micro Volt; *V*, volt.

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FIGURE 3
Flowchart delivery mode

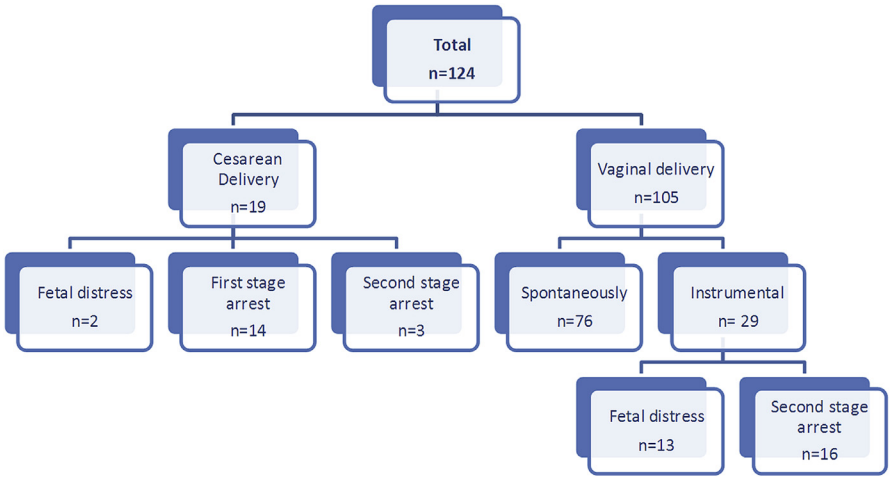

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TABLE 1
Subject characteristics group 1-3

Characteristics	Group 1 (n = 32) Mean (minimum-maximum)/ no. (%)	Group 2 (n = 73) Mean (minimum-maximum)/ no. (%)	Group 3 (n = 14) Mean (minimum-maximum)/ no. (%)
Maternal			
Age, y	32 (24-42)	31 (19-40)	32 (26-39)
BMI	26 (19-40)	27 (21-38)	29 (18-42)
Gestational age, d	279 (259-292)	280 (261-293)	285 (268-296)
Labor			
Cervical dilatation at admission, cm	6 (1-9)	5 (0.5-9)	5 (2-8)
Duration rupture of membranes, h	10 (2-34)	15 (3-69)	15 (5-26)
Duration labor, h	8 (3-23)	12 (3-22)	15 (9-26)
Labor augmentation (oxytocin)	0 (0%)	73 (100%)	14 (100%)
AROM	17 (53%)	38 (52%)	6 (43%)
Epidural analgesia	12 (38%)	61 (84%)	12 (86%)
Indication transfer			
Maternal[a]	13 (41%)	17 (23%)	—
Fetal[b]	12 (37.5%)	17 (23%)	6 (43%)
Labor arrest	4 (12.5%)	15 (21%)	4 (28.5%)
Analgesia request	3 (9%)	24 (33%)	4 (28.5%)
Registration uterine activity			
Duration registration, min	219 (48-543)	363 (30-928)	370 (133-824)
No. of contractions measured (first stage)	79 (20-218)	142 (14-377)	143 (38-296)
Total no. of contractions measured	2537	10,333	1996
Without oxytocin	2537	2282	220
With oxytocin	—	8051	1776
Neonatal			
Female	17 (53%)	32 (44%)	7 (50%)
Birthweight	3405 (2330-4280)	3500 (2395-4560)	3848 (3400-4460)
Apgar 1 min[c]	9 (4-10)	9 (3-10)	9 (3-10)
Apgar 5 min[c]	10 (7-10)	10 (8-10)	10 (9-10)
Umbilical artery blood pH	7.19 (7.02-7.30)	7.23 (7.05-7.35)	7.3 (7.23-7.37)

AROM, Artificial rupture of membranes; *BMI*, body mass index; *group 1*, vaginal delivery without oxytocin; *group 2*, vaginal delivery with oxytocin; *group 3*, cesarean delivery for first-stage labor arrest.

[a] Main maternal indications: diabetes, hypertensive disorders, maternal disease; [b] Main fetal indications: growth restriction, meconium, oligohydramnios; [c] Displayed in median (minimum-maximum).

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effect ($P = .000$), by increasing PDS peak frequency with 0.008 Hz (95% CI, 0.007−0.009) per centimeter dilation.

The results of the subanalysis of the contractions before and after oxytocin administration are displayed in Figure 5. The number of contractions measured is shown in Table 1.

In the women who eventually delivered vaginally after augmentation (group 2), the PDS peak frequency before the start of oxytocin (group 2a) was slightly higher (nonsignificant) than in the women delivering vaginally without augmentation (group 1). In these women the PDS peak frequency increased significantly after the start of oxytocin (group 2b). In the women delivering by CD

for first-stage arrest the PDS peak frequency before oxytocin administration was nonsignificantly higher (after Bonferroni correction) than in group 1 ($P = .020$) and group 2a ($P = .056$), ie, as compared to women who delivered vaginally without augmentation and in those before the start of oxytocin who subsequently responded to oxytocin. In group 3 the increase in PDS peak frequency after the start of oxytocin was not significant, but the number of contractions considered in group 3a was limited (Table 1). Again, of all confounders, only cervical dilation had a significant effect ($P = .000$), by increasing PDS peak frequency with 0.007 Hz (95% CI, 0.006–0.008) per centimeter dilation.

TABLE 2
Contraction characteristics by cervical dilation

Characteristic	Cervical dilation, cm	No. of contractions	Median PDS PF, Hz	IQR
Vaginal delivery without labor augmentation				
	0-2	48	0.45	0.39–0.51
	2-4	131	0.49	0.41–0.55
	4-6	324	0.49	0.43–0.57
	6-8	677	0.49	0.41–0.57
	8-10	1357	0.51	0.45–0.59
Vaginal delivery with labor augmentation[a]				
	0-2	28	0.41	0.39–0.45
	2-4	537	0.45	0.39–0.53
	4-6	1423	0.49	0.43–0.57
	6-8	2033	0.51	0.45–0.59
	8-10	4030	0.53	0.47–0.59
Cesarean delivery for first-stage labor arrest				
	0-2	5	0.39	0.35–0.46
	2-4	386	0.55	0.49–0.63
	4-6	834	0.55	0.47–0.63
	6-8	583	0.59	0.49–0.64
	8-10	188	0.55	0.43–0.66

IQR, interquartile range; *PDS*, power density spectrum; *PF*, peak frequency.

[a] Contractions after starting oxytocin.

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Comment

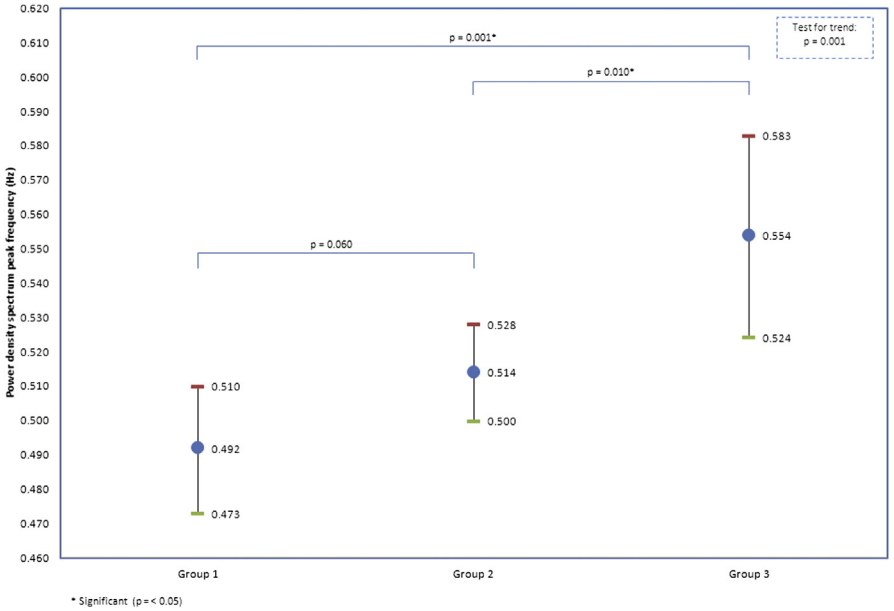
This study showed that the PDS peak frequency of contractions leading to CD despite augmentation was significantly different from that of contractions in women delivering vaginally with or without protracted labor. Augmentation increased the mean PDS peak frequency when comparing contractions before and after start of oxytocin. This increase was only significant in women who eventually delivered vaginally. In women who delivered vaginally after augmentation, the contractions before augmentation were similar to those of women not needing augmentation, whereby PDS values increased significantly after the start of oxytocin. In women eventually having a CD, PDS values were already increased before augmentation (nonsignificant) and further increased thereafter.

Previous studies on EMG in the context of preterm labor have shown that PDS values increased in women at risk for delivery at short term.[11-13] PDS values in the latter group were comparable to those observed by us in the group of women delivering vaginally without augmentation. The increase in PDS values in preterm threatened labor has been explained by an accelerated development of gap junctions resulting in an increased synchronization of myocyte activity.[7,11,12,18] The fact that augmentation with oxytocin also increased PDS values (this study) might be explained by the same mechanism. In this context, it is interesting to note that tocolysis with nifedipine in case of preterm contractions has been shown to lower PDS values.[23] There seems, however, to be a limit beyond which an increase in PDS peak frequency is not efficient anymore. This may reflect an increase in lactic acidosis due to a prolonged exposition to oxytocin as has been shown in other studies.[24] Women who do not respond to augmentation seem to have higher PDS values even before starting augmentation, perhaps reflecting the presence of a certain degree of lactic acidosis. It would be of great interest to study the relationship between intrapartum EMG and in vitro analysis of myometrium contractility to test this hypothesis. If our results were to be replicated and correlated to lactic acidosis, one may argue that a temporary arrest of contractions using a tocolytic drug may restore adequate metabolization. Similarly, dextrose administration might improve uterine contractility and shorten the duration of labor in such cases.[25]

Finally, the evidence that early and high-dose oxytocin augmentation rather than late and/or low-dose augmentation shortens the duration of labor,[26] also suggests that augmentation is more effective if given before impaired metabolization of the myometrium.

One of the challenges in current obstetrics is to prevent the first CD to subsequently prevent later fetal and maternal morbidity. Most of the CDs in this cohort were performed because of first-stage labor arrest (14 of 19 CD). Considering the high rate of augmentation in our cohort and in general obstetrical practice, uterotonics alone are not an efficient strategy. The results

FIGURE 4
Mean PDS peak frequencies as function of clinical outcome



Mean PDS peak frequencies for groups 1-3, with 5-95% confidence intervals and *P* values, calculated with linear mixed model analysis. Test for trend analysis. $P = .001$.

PDS, power density spectrum.

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reported here need to be replicated before alternative treatment strategies can be studied but they point toward a more selective use of uterotonics and open the way for testing of alternative strategies in a selected group of patients who beforehand have a low susceptibility of responding to augmentation.

Comparison of EMG with conventional registration methods has shown that EMG during labor shows a strong correlation with the invasive gold standard intrauterine pressure monitoring.[17,27,28] EMG also performs much better than external tocodynamometry, which does not correlate well with intrauterine pressure recording.[29]

This is the first study using EMG to measure PDS peak frequencies in protracted labor in term nulliparous women with a spontaneous onset. It is also the first study to distinguish between contraction characteristics before and after start of augmentation. Comparison with previous studies is therefore indirect. As mentioned earlier, the PDS values measured in women delivering vaginally without augmentation were comparable to those measured in women at high risk of preterm labor in other studies.[11-13] Euliano et al[30] used EMG in a different way but in a similar population and with a similar research question. They showed that the spatial propagation of contractions differed between patients delivering vaginally and patients delivering by CD because of labor arrest. It would be interesting to see whether secondary analysis of their data focused on the frequency content of the contractions yielded similar results as those described by us. Unfortunately we can not replicate their analysis as the distance between the electrodes was only specified in a general way and was not measured accurately.

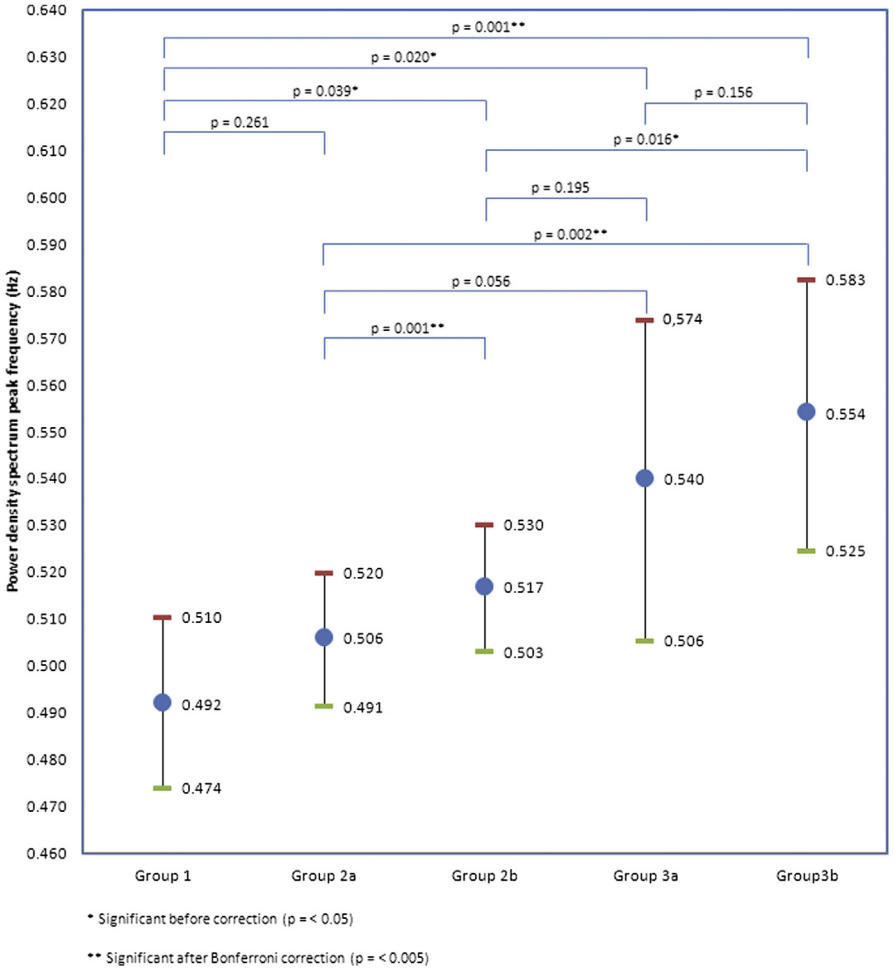
A limitation of our study is the limited number of patients with a CD for first-stage labor arrest. Division of the group for subanalysis of the effect of augmentation on contraction characteristics also resulted in small numbers of contractions (n = 220). Subsequently the interpretation of the data becomes more speculative. The intracase variance in contractions characteristics was, however, much larger than the intercase variance. This suggests limited dependence between contractions due to clustering and implies that a linear mixed model with a larger number of confounders could be used than would have been possible based on the number of cases solely. The linear mixed model analysis enabled us to respect the repeated measures structure in time of the data and to analyze the effect of possible confounders.

Another limitation of this study is the high rate of protracted labor (70%). This largely reflects the context of Dutch obstetrical care in which low-risk pregnant women deliver under the care of the midwife or general practitioner, and high-risk women deliver under the care of the obstetrician. The study population therefore represents a selected, high-risk population, in which risk factors for protracted labor such as increased maternal age, diabetes, and obesity are more prevalent. Nationwide data on the rate of labor augmentation in term nulliparous women delivering under the care of the gynecologist are comparable: 59% in 2011 and 64% in the region of the participating centers.[31] The same holds for the high incidence of CD (15%) and vaginal instrumental delivery (23%). Again these figures are comparable to nationwide data, with an incidence of 13% for CD and 28% for vaginal instrumental delivery, respectively.[31]

The strength of this study is that it is to date the largest prospective study on EMG in labor. It includes a homogeneous population, solely nulliparous women, cervical assessment at set times, and a standard augmentation protocol. Next to that, this is the first study in which the effect of augmentation on contraction characteristics was studied by comparing contractions before and after the start of oxytocin administration.

The next step would be to replicate the current findings in a larger study powered to detect the differences between contractions before augmentation in women delivering vaginally and in women undergoing a CD for labor

FIGURE 5
Effect of labor augmentation on mean PDS peak frequencies



Mean PDS peak frequencies for groups 1-3b, with 5-95% confidence intervals and *P* values, calculated with linear mixed model analysis.

PDS, power density spectrum.

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arrest. An additional aspect would be to couple intrapartum recordings to in vitro analysis to test the hypothesis of a link between increase in PDS peak frequency and lactic acidosis and impaired in vitro contractility. If the results are replicated and a threshold above which labor augmentation is likely to fail can be identified, a randomized controlled trial could be designed testing alternative strategies for these patients. ■

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APPENDIX

Glossary

Power density spectral analysis: analysis of the frequency content of a complex signal. The standard amplitude as a function of time domain is transformed in an amplitude as a function of frequency domain. This domain is denoted by the power density spectrum.

Peak frequency: frequency at which the largest-amplitude component of the power density spectrum occurs.