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A validation of electrohysterography for uterine activity monitoring during labour

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Abstract

Objectives. Validation of electrohysterography (EHG) as a method for uterine activity monitoring during labour by comparing with intra-uterine pressure catheter (IUPC) recordings.

Design. Prospective observational study.

Setting. Labour ward in a tertiary centre in the Netherlands.

Population. Thirty-two women in labour.

Methods. Simultaneous recording of uterine activity with EHG and IUPC for at least 30 min.

Main outcome measures. Number of uterine contractions detected by both EHG and IUPC (sensitivity). Number of contractions detected by EHG only [positive predictive value (PPV)]. Correlation between contraction amplitude and duration measured by EHG and IUPC.

Results. EHG detects uterine contractions accurately: sensitivity = 94.5% (95%CI: 87.5–100), PPV = 88.3% (95%CI: 76.2–100). The correlation of contractions' duration and amplitude between both methods is $r = 0.31$ (95%CI: 0.23–0.39) and $r = 0.45$ (95%CI: 0.38–0.52), respectively.

Conclusions. EHG detects uterine contractions accurately during labour but the contraction's characteristics it measures are not directly comparable with that of IUPC.

Keywords: *Uterine activity monitoring, electrohysterography*

Introduction

Recording uterine activity is a standard component of obstetric care during labour. It informs on the adequacy of uterine activity and is, therefore, essential to assess progress of labour. It also gives information on fetal condition when combined with fetal heart rate recording. The two methods currently used, external tocodynamometry or internal monitoring using intra-uterine pressure catheters (IUPC) have disadvantages. Tocodynamometry is non-invasive and easy to use but its recording quality depends on correct positioning of the sensor on the maternal abdomen and is influenced by maternal movements and BMI [1–3]. IUPCs are invasive and have been associated in rare cases with intra-uterine infection, uterus perforation and placental abruption [1,4]. The search for an alternative has led to the investigation of methods measuring the uterus' electrical activity. This approach, denoted either uterine electromyography (uterine EMG) or electrohysterography (EHG) has been known for more than 50 years [5–7]. It is experiencing a renewed surge of interest recently thanks to technical improvements and because of indications that it could be able to discriminate between efficient and inefficient contractions. This distinction is particularly relevant in the context of threatened preterm labour [8–13].

Although promising results have been obtained on this issue, EHG is a method that is still under development. Studies focusing on signal analysis have shown that the EHG signal could be made to

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agree with IUPC measurements using algorithms of varying complexity [14–18]. Only few studies, however, have compared the performance of EHG to other methods of uterine activity monitoring under conditions representative of clinical practice [9,19]. The objective of this study is to further consolidate the validation of EHG by comparing it with the method of reference, IUPC, in clinical practice.

Methods

Population

Thirty-two women at term (gestational age ≥37 weeks and <42 weeks) admitted to the labour ward of the University Medical Centre, Utrecht, the Netherlands, for whom use of an IUPC was considered necessary following the local obstetrical protocol (induction of labour or labour augmentation). The study was approved by the institutional medical ethical committee.

Uterine activity registration

Once informed consent had been obtained, the five electrodes of the EHG apparatus (AN24 Maternal Heart rate/Fetal Heart Rate/EHG recorder, Monica Healthcare, Nottingham, UK) were positioned on the abdomen: two electrodes along the midline (at the side of the uterine fundus and above the symphysis), one on each side of the uterus and the ground electrode on the left flank. Skin impedance was reduced before placing the electrodes using abrading paper at the electrode placement site. Skin impedance was below 5 kV in all recordings. Data were analysed off line after computer download.

The aim was to register EHG and IUPC simultaneously for at least 30 min, although participants were free to stop prematurely or prolong the EHG registration.

Processing electrohysterography signal

The original raw electrophysiological signal from one pair of electrodes was processed to extract the EHG signal contained in one low-frequency band (0.1–0.9 Hz) and subsequently filtered using a low-pass filter (0.01 Hz) to provide an envelope of the signal comparable with the IUPC recording. This process is illustrated in Figure 1.

Contraction detection

Contractions were identified from both IUPC and EHG signals automatically using a simple algorithm. The algorithm identifies all maxima in the signal as potentially representing the top of a contraction. It discards maxima with an amplitude smaller than 5 mmHg (IUPC) or 10 μV (EHG) and those maxima much lower than others in the vicinity. The exact criteria being that a maximum should be higher than 3/4th of the standard deviation in the variation of amplitude of seven consecutive maxima. The remaining maxima represent uterine contractions. Their amplitude is given by the value of the maximum and their duration by 3/4th of the time between the two minima flanking the contraction peak. Contractions measured with EHG were considered to be matching those measured by IUPC if the peak of the EHG contraction was found within the duration of the IUPC contraction.

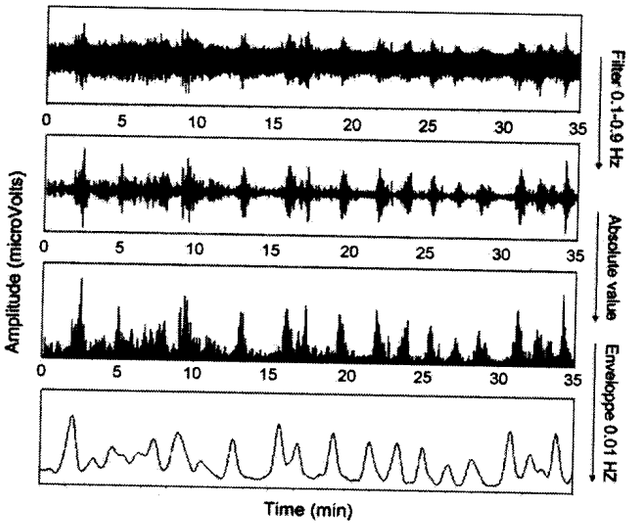

Figure 1. Illustration of the different step of signal processing applied to the raw electrophysiological signal. Top: raw signal. Second from top: signal after filtering (0.1–0.9 Hz) to extract uterine activity information. Third from top: absolute values of filtered signal. Bottom: Filtering with low-pass 0.01 Hz filter to obtain the envelope for comparison with IUPC signal.

Statistics

Statistical analyses were performed using SPSS 15.0 and OpenEpi 2.2. Correlation coefficients are calculated using Spearman's two-tailed test. Confidence intervals on means are calculated using a two-tailed *t*-test. Confidence intervals on medians are calculated by normal approximation method of large sample size theory.

Results

Characteristics of the 32 women participating in the study and of the uterine activity recordings are shown in Table I. The median recording time was 66.5 min [inter-quartile range (IQR) 51.6–78] with a median of 23 contractions per recording (IQR 18–30).

Slightly more than 50% of the recordings, 53%, were performed during the latent phase of the first stage of labour defined as a cervical dilatation ≤4 cm during the recording.

Contraction detection

Figure 2 shows the number of contractions measured by both methods in each recording. Overall, EHG shows a tendency to overestimate the number of contractions compared with IUPC. The proportion of contractions that are detected by both methods (sensitivity: number of contractions detected by both methods divided by the number of contractions detected by IUPC) and the proportion of contractions that are detected by EHG alone [positive predictive value (PPV): number of contractions detected by both methods divided by the number of contractions detected by EHG] are shown in Figure 3. In most recordings, a high value of both sensitivity and PPV was found, sensitivity being usually higher than PPV. Both values were correlated ($r=0.51$, $p<0.01$). The median of the sensitivity and PPV, calculated by pooling the means obtained for each recording using equal weight, irrespective of recording duration or number of contractions, were 94.5% (95%CI: 87.5–100) and 88.3% (95%CI: 76.2–100), respectively.

Table I. Characteristics of the study population and of the uterine activity recordings.

Study population ($N=32$)	
Age [mean (SD)]	31.2 (5.4)
BMI (kg/m^2) [mean (SD)]	27.2 (6.0)
Nullipara (%)	46.9
Indication for IUPC (%)	
Induction of labour	13 (40.6)
Augmentation of labour	17 (53.1)
Epidural anaesthesia	2 (6.3)
Cervical dilatation ≤4 cm during the recording (%)	53.1
Duration of recordings (min) [median (IQR)]	66.5 (51.6–78)
Nbr of contractions per recording [median (IQR)]	23 (18–30)

IQR, inter-quartile range.

Contraction amplitude and duration

The amplitude and duration of the contractions detected by both EHG and IUPC were compared. Note that the amplitude of the contractions cannot be compared directly as one measures pressure (mmHg) with IUPC compared with electrical activity (μV) with EHG. A correlation coefficient was calculated in each recording by comparing the amplitude obtained by both methods in paired contractions. The results are plotted in Figure 4 as a function of the sensitivity obtained in each recording. The value of the correlation coefficient varied widely, from below 0.1 to 0.8. It is correlated to the sensitivity ($r=0.46$, $p<0.01$). Overall, the mean correlation coefficient for amplitude obtained by pooling the results obtained for each recording was 0.45 (95%CI: 0.38–0.52).

A similar approach was used to calculate the correlation coefficient for contraction duration between both methods (Figure 5). There also, the values of the correlation coefficient varied widely and were correlated to the sensitivity, albeit, less strongly

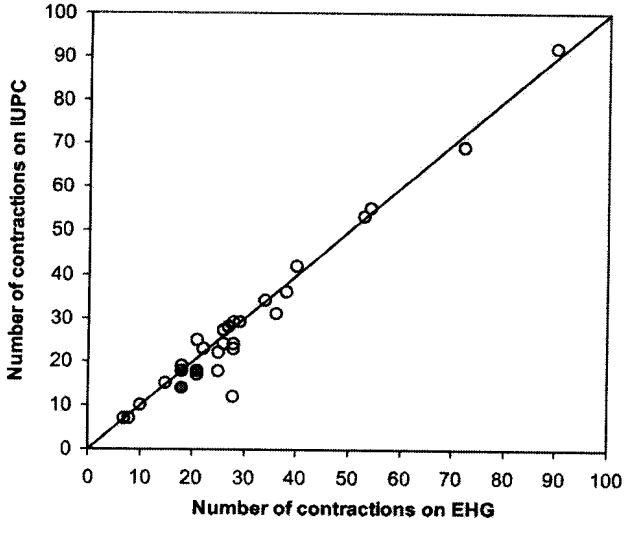

Figure 2. Number of contractions measured by EHG and IUPC for each recording. Grey circles indicate two recordings with this number of contractions. *median, otherwise mean.

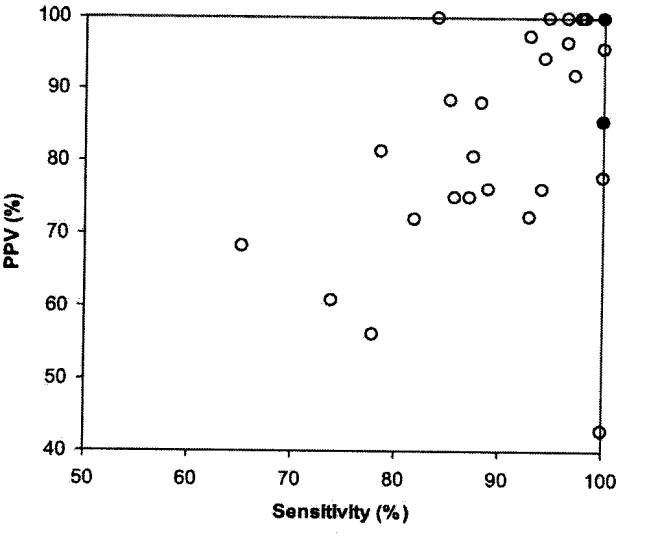

Figure 3. Sensitivity and positive predictive value obtained for each recording. The grey circle indicates two recordings with the same values, the black circle five.

($r = 0.38$, $p < 0.05$). The mean correlation coefficient for duration was 0.31 (95%CI: 0.23–0.39). Additionally, the agreement between both methods was evaluated by calculating the mean difference in contraction duration for each recording and comparing it to the mean duration of contractions for that recording. The mean difference is calculated by taking the mean of the absolute values of the difference in duration in each pair of contractions in the recording. This data is shown in Figure 6. The agreement between both methods was best for contractions of short duration but became poorer when contractions lasted longer. Overall the mean difference in contraction duration represented 27.3% (95%CI: 22.6–32.1) of the mean contraction duration.

All results are summarized in Table II. We performed statistical analyses to identify factors influencing the agreement between EHG and IUPC. Age and BMI of the patients were not correlated to sensitivity, PPV, or correlation coefficients for amplitude or duration of contractions. Furthermore, we did not find significant differences in the proportion of recordings with a sensitivity or PPV above 90% or correlation coefficients above 0.5 between nullipara and multipara, between induction and augmentation of labour and between recordings performed before or after 5 cm of cervical dilatation. We could not identify, on the basis of this limited set

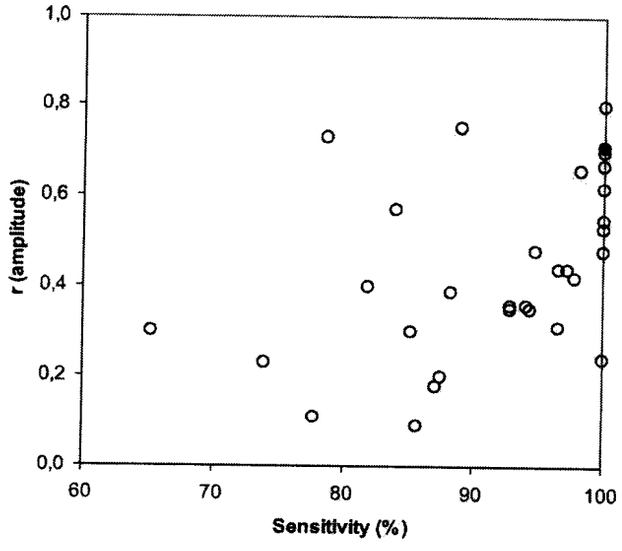

Figure 4. Correlation coefficient of the contractions' amplitude between EHG and IUPC for each recording plotted as a function of the sensitivity obtained in that recording. The grey circle indicates two recordings with the same values.

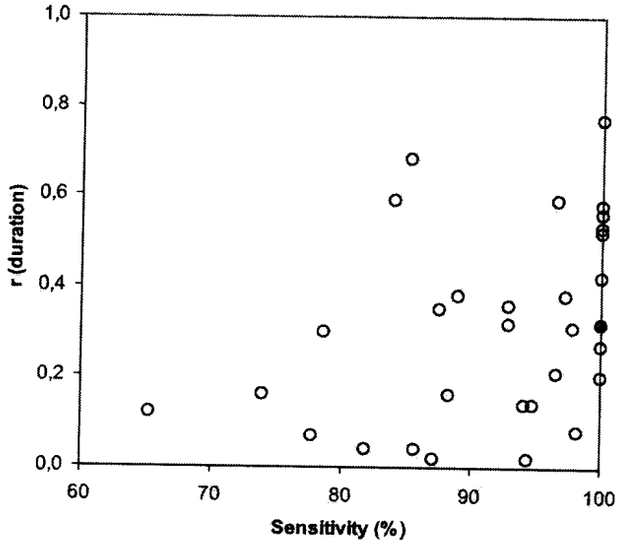

Figure 5. Correlation coefficient of the contractions' duration between EHG and IUPC for each recording plotted as a function of the sensitivity obtained in that recording. The grey circle indicates two recordings with the same values.

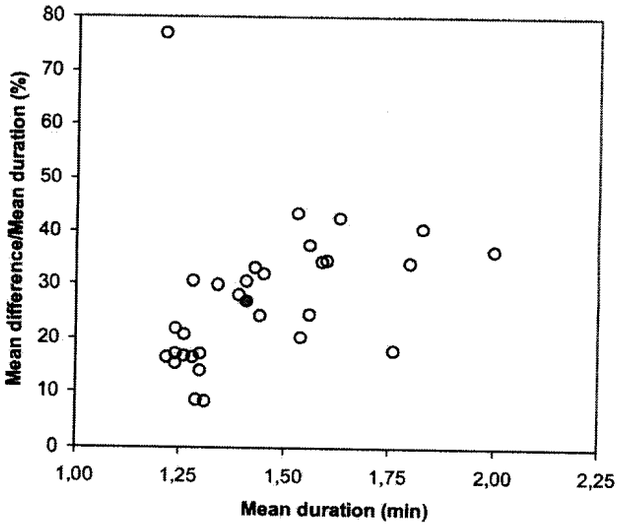

Figure 6. Agreement between EHG and IUPC in terms of contraction duration. The mean difference between contraction duration normalized on the mean duration of the contractions is plotted for each recording as a function of the mean duration of the contractions in this recording. The grey circle indicates two recordings with the same values.

Table II. Results.

	Median* or mean (95% CI)	IQR or SD
Sensitivity (%)	94.5* (87.5–100)	86.8–100
Positive predictive value (%)	88.3* (76.2–100)	75.9–100
Correlation coefficient for the contractions' amplitude, r_a	0.45 (0.38–0.52)	0.20
Correlation coefficient for the contractions' duration, r_d	0.31 (0.23–0.39)	0.21
Normalized mean difference in contraction duration (%)	27.3 (22.6–32.1)	13.1

*denoted a median

of data, the conditions for which agreement between EHG and IUPC can be expected to be poor. On the other hand, the fact that the agreement between IUPC and EHG does not seem to depend on BMI is an important finding given the rise of obesity in western countries and confirms previous reports [19].

Discussion

Our study shows that EHG detects uterine contractions accurately during labour but that the correlation between the two methods regarding contraction's characteristics (amplitude and duration) is moderate.

The high rate of concordance between EHG and IUPC concerning the occurrence of uterine contractions found in this study confirms results published previously in a smaller study [19]. The sensitivity and PPV values found in that study were 97.2% and 90.6%, respectively. This is slightly higher than the findings in our cohort. However, the values in that study were calculated by pooling the contractions of all registrations together. This means that a long registration with very good agreement could influence the overall results. Our study shows that EHG can detect most of the contractions that an IUPC would detect and 'adds' a small number of bursts of uterine electrical activity that do not seem to lead to an increase in intra-uterine pressure. This is due either to the existence of bursts of electrical activity in the uterus that are not coordinated enough to give rise to a contraction, or to noise from, for instance, abdominal muscles being mistaken for a uterine contraction. The latter hypothesis seems more likely given the fact that sensitivity and PPV are correlated. In other words, there are relatively few extra contractions in those recordings of good quality where a large proportion of the IUPC contractions are detected by EHG. Overall, EHG shows the tendency to detect a slightly higher number of contractions than IUPC.

The comparison of contractions' amplitude measured by both methods is difficult because of the different nature of the signal measured. EHG monitors the process by which contractions are formed whereas IUPCs measure the end result of that process. Intra-uterine pressure, for instance, depends strongly on the synchronisation of myometrial activity. Only synchronized contractions will lead to high intrauterine pressures. On the other hand, even unsynchronized contractions from myometrial cells can be associated with a high total electrical energy and, therefore, high readings with EHG. Moreover, the absolute value of the electrical signal does not have to be linearly related to intra-uterine pressure but may contain a non-linear component. One study has reported a good correlation between the total energy of a burst and intra-uterine pressure ($r=0.762$, $p=0.002$) [9]. This is not confirmed by our study although we only considered the maximum amplitude and not the total energy. However, an additional analysis using the product of the maximum amplitude and contraction duration as a surrogate for the total energy did not improve the correlation coefficient.

Similarly, there is no compelling reason to consider that the duration of the depolarization phase in the uterus should directly be related to the duration of its effect in terms of intra-uterine pressure. Uterine activity might start or end with a period of unsynchronized depolarisation which would not lead to a rise in intra-uterine pressure but be recorded by EHG. Long IUPC contractions are likely to represent merging double contractions. The electrical activity of the uterus might not show the same sustained character. The increasing lack of agreement between IUPC and EHG with increasing contraction's duration found in this study supports this view. Our findings do not agree with that of Euliano et al. [19] who reported that 'contraction lengths closely approximated those calculated from the IUPC signal'. It is, however, difficult to compare their analysis with ours given the fact that they pooled the results of all contractions whereas we considered each recording separately.

Overall, the correlation found between EHG and IUPC is nevertheless comparable or slightly better than that found between IUPC and external tocodynamometry. Miles et al. [2] reported a correlation coefficient of only 0.26 for the contraction amplitude and 0.27 for the contraction duration whereas there the physiological basis of the measurement methods are more similar.

EHG has been studied for more than 50 years but there is still no uniform way of acquiring and processing the electrical signal coming from the uterus. This lack of uniformity and the varying definitions for uterine contractions form a limitation of any study aiming to validate the method, the present one included. We have tried to limit the influence of having had to define our own set of criteria by applying them consistently to EHG and IUPC recordings. Additionally, the method has been tested under conditions representative of common clinical practice with prolonged recording time at each stage of labour. Bearing these limitations in mind, the agreement between the detection rate found in this study and the only other study comparable in design, is noteworthy [19].

The method now seems accurate enough for one to be confident that the EHG signal represents uterine activity. One should bear in mind, though, that signals of different nature are measured