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Full length article

Detection of postpartum uterine activity with electrohysterography

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ABSTRACT

Objective: Uterine contractions are essential for childbirth, but also for expulsion of the placenta and for limiting postpartum blood loss. Postpartum hemorrhage is associated with almost 25% of the maternal deaths worldwide and the leading cause of maternal death in most low-income countries. Little is known about the physiology of the uterus postpartum, particularly due to the lack of an accurate measurement tool.

The primary objective of this pilot study is to explore the potential of using electrohysterography to detect postpartum uterine contractions.

If postpartum uterine activity can be objectified, this could contribute to understanding the physiology of the uterus and improve diagnosis and treatment of postpartum hemorrhage.

Study Design: In this observational study we included women aiming for a vaginal birth in two large maternity clinics in the Netherlands, Amphia Hospital Breda (group A, N2018-0161) and Máxima Medical Center Veldhoven (group B, N17.149). An electrode patch was placed on the maternal abdomen to record real-time electrical uterine activity until one hour postpartum continuously. In group A, the placement of the patch was lower than in group B.

For analysis, tracings were divided into five different phases (1: dilatation until start pushing, 2: from start pushing until childbirth, 3: from childbirth until placental expulsion, 4: first hour after placental expulsion and 5: after one hour postpartum). Readability, signal quality and contraction frequency per hour were assessed. Additionally, patient satisfaction was evaluated through a survey.

Results: In total 91 pregnant women were included of whom 45 in group A and 46 women in group B. Complete registrations were obtained throughout the five labor phases with very little artefacts or signal loss. The readability of the tracings decreased after childbirth. A significantly better readability was found in tracings where the patch placement was lower on the abdomen for phases 4 and 5. Contraction frequency was highest during phase 2 and decreased towards phase 5. Women rated the satisfaction with electrohysterography as high and mostly did not notice the patch.

Conclusion: It is possible to detect uterine activity postpartum with electrohysterography. Further investigation is recommended to improve diagnosis and treatment of postpartum hemorrhage.

Abbreviations: EHG, electrohysterography; PPH, postpartum hemorrhage; IUPC, intrauterine pressure catheter; TOCO, tocodynamometer.

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Introduction

Uterine contractions are essential for expulsion of the placenta and for limiting postpartum blood loss. Postpartum haemorrhage (PPH) is associated with almost 25 % of the maternal deaths worldwide and the leading cause of maternal death in most low-income countries [1,2]. Moreover, the incidence of PPH has increased during the last few years, especially in Western countries [3]. In most cases, PPH is caused by uterine atony, which can be treated with the administration of uterotonics. Although a relationship between uterine contractions and the amount of blood loss postpartum seems evident, very little research has been published about the physiology of uterine contractions in the postpartum period. These studies have used the intrauterine pressure catheter (IUPC), the external tocodynamometer (TOCO) or a device measuring electrical activity [4–6]. IUPC measures both frequency and intensity of contractions but it is an invasive method and complications as uterine perforation have been reported [7]. Moreover, postpartum measurements with IUPC are mostly inadequate or incomplete [4]. The catheter has often been squeezed out during childbirth and/ or placenta expulsion, which makes uterine monitoring after placenta expulsion more challenging. One study with IUPC used the umbilical cord as guide to reinsert the IUPC in the uterine cavity, to measure uterine contractions only prior to placenta expulsion [8].

Blood loss is mainly the result of atony, which can be the result of contained placental parts or intrauterine blood clots [2]. Frequent palpation of the uterine fundus can be applied to detect uterine atony but is subject to continuous presence and experience of caregivers. TOCO is still the standard method for uterine monitoring during labor, but in most cases TOCO is immediately removed after childbirth. Postpartum measurement is problematic as the external tension of the abdominal wall is diminished after delivery.

The researchers of previous studies concluded that a method for uterine monitoring postpartum is required to increase our knowledge about uterine contractions postpartum and related blood loss [5,6].

Electrohysterography (EHG) is a non-invasive technique for electrical activity monitoring of the myometrium, by translating this activity into an estimated IUPC signal to record a tocogram [9]. Previous research during the first stage of labor has shown that this technique performs better than external tocodynamometry and is less affected by obesity and maternal movements [10,11].

Therefore, we hypothesize that this method can also be of added value for postpartum monitoring of uterine contractions.

The main goal of this study is to investigate the possibility of detecting uterine contractions postpartum with EHG. If postpartum EHG measurement is feasible, the tracings will be assessed on readability and signal quality. Furthermore, we are interested in comparing different positioning of the EHG patch on the abdomen, changes in contraction frequency per hour between the different phases of labor and comparing women with PPH to women with average blood loss.

Material and methods

Material

A prospective observational cross-sectional study design was chosen to investigate the activity of the uterus postpartum. Women aiming for a vaginal birth, with a previous cesarean section, and/or induced labor, and/or BMI $>$ 30 kg/m^2, and/or women with inadequate registration with TOCO were eligible for inclusion. Exclusion criteria were water birth, skin diseases or allergies, and external or implanted electrical stimulator, as these were all incompatible with the measurement device. Postpartum registrations of less than one hour, or without monitoring of placental expulsion were excluded for analysis. PPH was defined as $>$ 1000 mL blood loss within 24 h after childbirth, estimated by weighing the disposable absorbing bed pads.

As this is an explorative study concerning proof of concept, a power calculation was not performed. Sample sizes of previous studies on postpartum monitoring were ranging from 19 to 44 [4–6]. For this study we aimed to collect at least 45 complete registrations in two different hospitals; Amphia hospital (group A) and Máxima Medical Centre (group B).

The study was registered as N17.149 (Máxima Medical Centre) and N2018-0161 (Amphia hospital). The research protocol was reviewed by the Medical Ethics Committee who declared that the rules laid down in the Medical Research Involving Human Subjects Act did not apply to this research.

All women in the Amphia hospital provided written informed consent. The medical ethics committee of Máxima Medical Centre decided that, since EHG was already used as standard method in this hospital, no informed consent procedure was required.

The EHG instrument (Fig. 1) consisted of a single patch with three electrodes connected to a translation device for data processing (Graphium and PUREtrace, respectively, Nemo Healthcare, Veldhoven, The Netherlands). The recorded data from the different electrodes were combined based on a physiological model of the myometrial conduction properties. In the translation module the signal is filtered at a frequency between 0.3 and 0.8 Hz to suppress electrical activity from other sources than the uterus. Subsequently, the signal is converted into a value that correlates with the IUP values, [9] and in real-time displayed on a CTG monitor at the labor ward (Avalon, FM30, Philips Healthcare, Eindhoven, the Netherlands). The EHG instrument is CE marked, FDA approved and validated in a previous study comparing EHG to TOCO and IUPC in the first and second stage of labor [10].

Before placement of the patch on the abdomen, the uterus was palpated to ensure proper location.

In group A the patch was placed next to or below the umbilicus, focusing on the postpartum period in which the uterine fundus is lower than during delivery. In group B the patch was placed next to or above the umbilicus, according to the standard protocol for intrapartum monitoring. Then the skin was scrubbed to decrease the impedance of the skin. Values below 5.0 Ω (measured with SIGGI II, MedCAT, Klazienaveen, Netherlands), were accepted.

We divided the tracings in five different phases: phase 1 one hour before childbirth until start pushing (also first phase of labor), phase 2 from start pushing until childbirth (also second phase of labor), phase 3 from childbirth until placenta expulsion, phase 4 from placenta expulsion until one hour after childbirth, and phase 5 the remaining registration starting from one hour after childbirth. For the primary outcome, all registrations were reviewed per phase. One researcher MvdB qualified the registrations for readability into: good (evident contraction pattern throughout phase), moderate (contraction pattern, but alternating with periods without recognizable pattern) and poor (no recognizable pattern), correlating with scores 3, 2, 1, respectively. Artefacts (recognized as small steep bar with flat top) and segments of signal loss (short technical interruptions) were counted to evaluate signal quality. The registrations were reviewed by a second researcher, KT.

For the secondary outcome a contraction annotation software tool (developed as internal application) was used to automatically extract uterine activity data (contraction duration) based on manual annotation. The annotation protocol was standardized by three researchers (KT, MvdB and MW, all experienced in the interpretation of EHG). All tracings were annotated per phase separately, as shown in Fig. 2. Within each phase, MvdB indicated start and end of contractions. Contraction frequency per hour was calculated by the annotation programme for each phase.

In the patient satisfaction survey women were asked whether they would recommend EHG to others, how they experienced placement of EHG, whether they were bothered by its presence and whether they were able to move around or change positions when connected to EHG. The surveys were handed out after birth and collected within a few days postpartum.

The patient's characteristics were collected from the hospital's

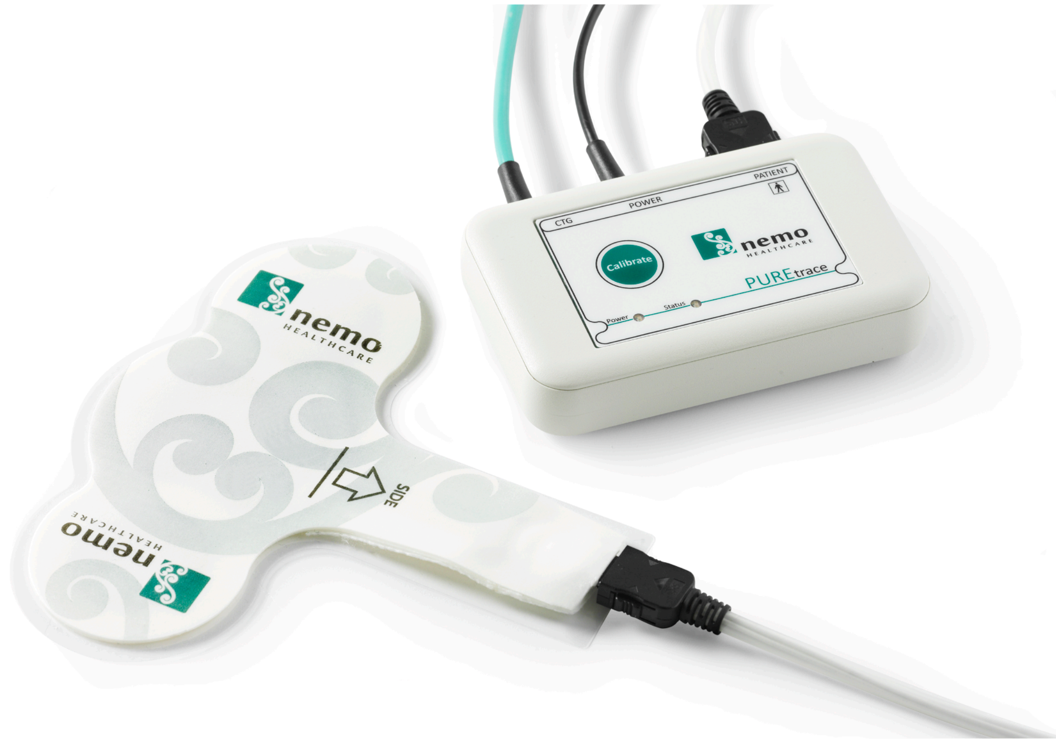

Fig. 1. Method electrohysterography (EHG). The EHG instrument, consisting of a single patch (Graphium) with three electrodes connected to a translation device (PURE-trace), Nemo Healthcare, Veldhoven, The Netherlands.

Fig. 2. Contraction annotation procedure phase 1 until phase 5. Phase 1 = first phase of labor (dilatation). Phase 2 = second phase of labor (pushing). Phase 3 = childbirth until placenta expulsion. Phase 4 = after placenta expulsion until 1 h postpartum. Phase 5= > 1 h postpartum.

electronic patient record.

Methods

Statistical analysis was performed using SPSS 26 statistics (IBM, New York, USA). Descriptive analyses were used for all variables. Continuous variables were described as mean with standard deviation (SD) if normally distributed, and as median with interquartile range (IQR) if not normally distributed.

Differences in categorial variables (readability) between phases were statistically tested using a McNemar-Bowker Test. A One-Sample Chi-Square Test was used to test proportions against a fixed proportion. To compare two groups with categorical variables a Pearson Chi-Square Test was used, or the Fishers Exact Test in case of small numbers. A difference in continuous variables (artefacts, signal loss) between phases was tested using a Wilcoxon Signed Ranks Test. Comparing two groups, the Mann Whitney *U* test was applied. To investigate whether there was a demonstrable link between the number of artefacts per hour and the readability, a Kruskal-Wallis Test was done. Two-sided p-values below 0.05 were considered statistically significant. Since this was an explorative study, we did not correct p-values for multiple testing.

Results

A total of 91 pregnant women were included in the study between September 2018 and January 2019. In group A 45 postpartum registrations that lasted for at least one hour were included and in group B 46 women (receiving the patch according protocol). Women were excluded in case the registration could not be continued postpartum, e.g. due to operative interventions like secondary cesarean section, manual placenta removal or repair of tears.

Baseline characteristics of both groups are represented in Table 1. There was a significant difference between group A and B regarding gestational age ($p = 0.01$) and duration of first phase of labor ($p = 0.02$). These small differences could be explained by a more high-risk patient population in group B.

Complete registrations were obtained throughout the different phases. Fig. 3 shows the readability of the tracings for each phase per group. A good readability was observed in most cases during first and second phase of labor. After childbirth, readability reduced significantly.

In phase 4 ($p = 0.004$) and phase 5 ($p = 0.016$) there was a significantly better readability in group A as compared to group B, whereas the other phases were not significantly different between both groups.

The number of artefacts is displayed in Table 2. Significantly more artefacts per hour were observed during phase 3 as compared to the other phases. The least artefacts were seen in phase 1 and phase 5. Comparing group A and B, no significant differences were found regarding artefacts.

The Kruskal-Wallis test showed that there was no significant demonstrable link between artefacts per hour and the readability for every phase. The incidence of signal loss was very low for all phases.

Contraction frequency was highest during phase 2 and then decreased until phase 5, as shown in Fig. 4. The median contraction frequency in phase 4 and 5 was lower in the subgroup who developed PPH, but these differences were not statistically significant.

In total 66 women filled out the patient satisfaction survey, of whom 63 would recommend EHG to other women (95.5 %). They were less bothered by EHG, also, they noticed that their mobility was less compromised. Regarding the postpartum period, most women (72.9 %) experienced no inconvenience from the presence of the patch. Reasons why women did not recommend EHG were irritation of the skin (1,5%) or a more accurate registration with external TOCO prior to placement of the patch (3 %).

Comment

Findings

This study shows that it is possible to measure postpartum uterine contractions with EHG even after the expulsion of the placenta, with little artefacts and signal loss.

There is a significant variation between the different phases before and after childbirth. The readability of the tracings decreases after childbirth. We hypothesize that the decrease in readability can be partly attributed to differences in uterine activity postpartum when compared to intrapartum and therefore must be interpreted differently than an intrapartum EHG. It is striking that the measurements in group A phases 4 and 5 have a significantly better readability. This may be linked to the location of the patch, which was placed lower on the abdomen in group A, and thus closer to the location of the postpartum uterus. However, signal loss and artefacts did not differ significantly between groups. In both groups most artefacts were observed between childbirth and expulsion of the placenta, which could be caused by manipulation during controlled cord traction. Least artefacts were seen in phase 5, also the sacred hour postpartum.

Regarding phase 4 and 5, the median contraction frequency was lower in a group with PPH compared to a group with average blood loss. As the group with PPH was small (9 women), there was great variation and differences were not significant.

Postpartum contraction measurements can also be considered by using IUPC or TOCO. Yet, both methods have drawbacks. Schorn et al. and Akin et al. report that the IUPC is often squeezed out during placenta expulsion [4,8]. A Japanese study from Masuzawa et al. described measurements of two hours postpartum with the external TOCO [5].

Table 1
Baseline characteristics.

Patient characteristic	Group An = 45	Group B n = 46	P-value
Maternal age[**] **(y)**	30.6 ± 4.7	31.3 ± 4.2	0.47 [a]
Body Mass index (kg/m²)[***]	29.4 [27.0–32.2]	29.9 [26.9–35.8]	0.67[b]
Etnicity			0.16[c]
Caucasion	43 (95.6)	39 (84.4)	
Other	2 (4.4)	7 (15.2)	
Parity			0.92 [d]
Nulliparous	22 (48.9)	22 (47.8)	
Multiparous	23 (51.1)	24 (52.2)	
Gestational age (week + days)	39 + 5 (36 + 1—42 + 0)	39 + 0 (36 + 6—41 + 3)	0.01 [a]
Obstetric history			
Caesarean section i.a.	3 (6.7)	1 (2.2)	0.36[c]
Vacuum delivery i.a.	0 (0.0)	1 (2.2)	1.00[c]
PPH i.a.	5 (11.1)	4 (8.7)	0.74[c]
Induction of labor	30 (66.7)	27 (58.7)	0.43 [d]
Oxytocin augmentation	35 (77.8)	41 (89.1)	0.14 [d]
Labor Analgesia			0.09[c]
No analgesia	10 (22.2)	3 (6.5)	
Epidural analgesia	32 (71.1)	40 (87.0)	
Remifentanil	3 (6.7)	3 (6.5)	
Duration of labor			
Duration of 1st phase	350.0 [204.5–647.5]	476.5 [375.3–784]	0.02[b]
Duration of 2nd phase	17.0 [6.0–61.0]	17.5 [9.75–45.5]	0.82[b]
Duration of 3rd phase	11.0 [8.0–14.5]	11.0 [7.75–16.25]	0.80[b]
Mode of delivery			0.67[c]
Spontaneous	42 (93.3)	44 (95.7)	
Vacuum delivery	3 (6.7)	2 (4.3)	
Fever during labor	5 (11.1)	7 (15.2)	0.56 [d]
Manual placental removal	1 (2.2)	2 (4.3)	
Medication			
Oxytocin	41 (91.1)	41 (89.1)	
Oxytocin, Methergin	0 (0.0)	2 (4.3)	0.21[c]
Oxytocin, Methergin, tranexamic acid	4 (8.9)	1 (2.2)	
Oxytoncin, Sulprostone, tranexamic acid	0 (0.0)	1 (2.2)	
Oxytocin,Sulprostone, Methergin, tranexamic acid	0 (0.0)	1 (2.2)	
Perineum			0.92[c]
Intact	15 (33.3)	14 (30.4)	
1st degree tear	7 (15.6)	6 (13.0)	
2nd degree tear	13 (28.9)	12 (26.1)	
3rd degree tear	0 (0.0)	1 (2.2)	
Episiotomy	10 (22.2)	13 (28.3)	
Vaginal blood loss (mL)	300 [200–470]	300 [200–500]	0.46[b]
Neonatal birth weight	3452.4 ± 523.9	3474.4 ± 474.3	0.83 [a]
Twin birth	0 (0.0)	1 (2.2)	1.00[c]

Legend:*Results are represented as n (%), mean ± SD, mean (range) or median [IQR].
[**] Age at time of event***Body Mass index at time of event.
[a] T-test.
[b] Mann Whitney U.
[c] Fishers Exact.
[d] Chi-Square test.

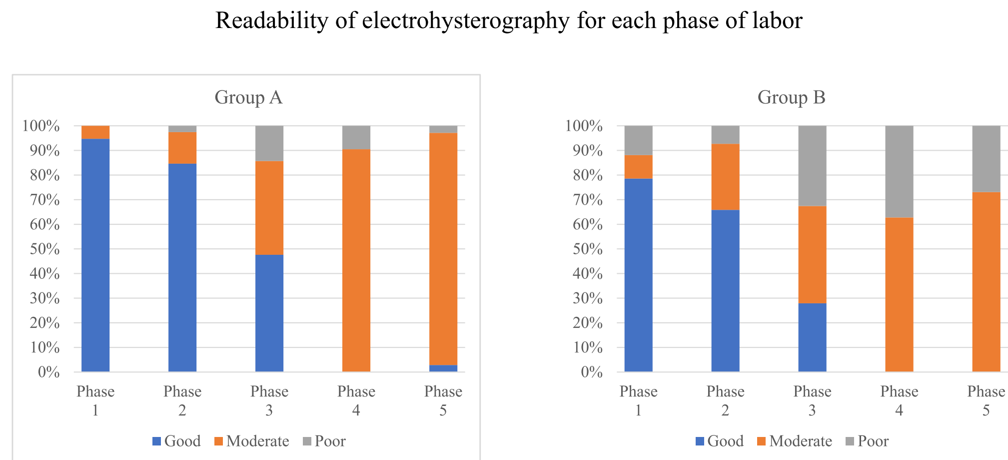

Fig. 3. Readability of electrohysterography for each phase of labor. Phase 1 = first phase of labor (dilatation). Phase 2 = second phase of labor (pushing). Phase 3 = childbirth until placenta expulsion. Phase 4 = after placenta expulsion until 1 h postpartum. Phase 5= >1 h postpartum. Readability is significantly different between all phases within group (McNemar-Bowker test and One sample Chi-Square test). Comparing group A and B, there is a significant difference in phase 4 ($p = 0.004$ Pearson Chi-Square Test) and 5 ($p = 0.016$, Fisher exact Test).

Table 2
Number of artefacts / hour for every phase of labor.

Artefacts / hour	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Group A	0.0 [0.0–1.4]	3.5 [0.0–10.4]	14.8 [8.4–22.9]	4.7 [1.2–9.3]	0.7 [0.0–4.4]
Group B	0.0 [0.0–2.7]	1.3 [0.0–6.4]	15.0 [5.5–22.5]	3.8 [1.3–8.8]	0.0 [0.0–5.6]

Legend:Results are represented as median [IQR].

However, the average BMI of their population is much lower (19.1 kg/m^2) then in Western countries and therefore more suited to measure uterine activity with TOCO. Moreover, they describe that some of the contractile waves were not identifiable and they also suggested to do future examination with a more accurate method for uterine monitoring. In women with BMI > 30 kg/m^2), the sensitivity of EHG is higher than TOCO during the first and second stage of labor [11]. We expect that this will not be any different postpartum.

Strengths and limitations

We succeeded in retrieving all complete registrations which we aimed for. However, some registrations less than one hour postpartum, including situations with PPH and manual placenta removal, were excluded because registration could not be continued in the operation room. It would be interesting to study EHG specifically in these clinical conditions to investigate whether the EHG signal deviates from physiologic postpartum recordings.

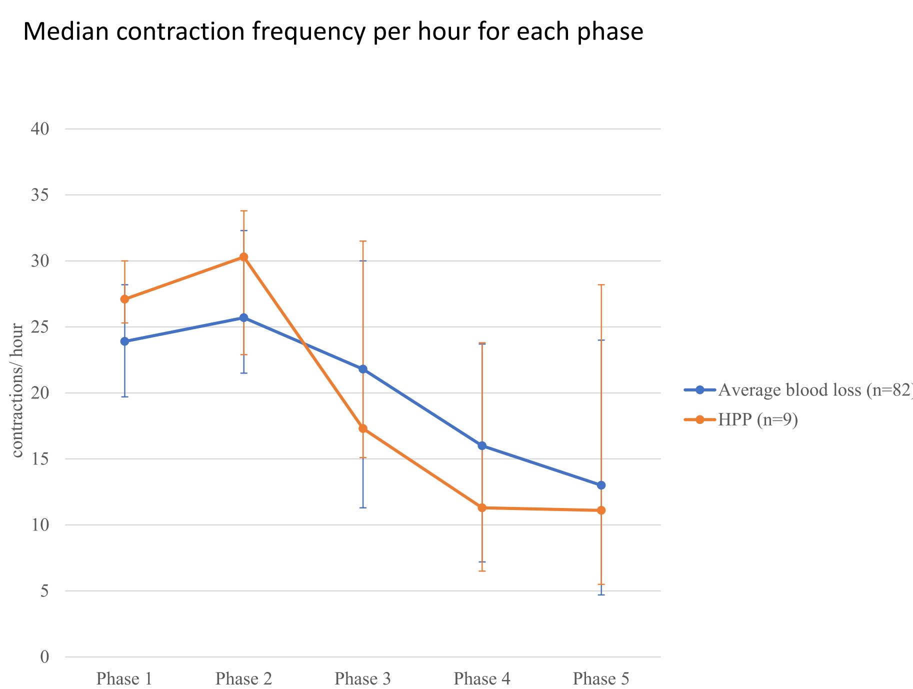

Fig. 4. Median contraction frequency per hour for each phase. Phase 1 = first phase of labor (dilatation). Phase 2 = second phase of labor (pushing). Phase 3 = childbirth until placenta expulsion. Phase 4 = after placenta expulsion until 1 h postpartum. Phase 5= >1 h postpartum. Differences between subgroup PPH vs. average blood loss were not significant in all phases (Mann Whitney *U* test).

Clinical implications

EHG signals after childbirth should be interpreted differently compared to the intrapartum period as the characteristics of the uterine activity change after childbirth and placental expulsion. With increasing experience in EHG postpartum, EHG readability and interpretation will also further improve. Computerized analysis could be of added value to recognize different patterns in postpartum EHG monitoring and to include other parameters such as the amplitude or area under the curve. Also raw unfiltered, unprocessed EHG signals could be studied, e.g. with spectral analysis for frequency content.

Quality of postpartum registrations might be further improved by adjusting the patch lower on the abdomen, i.e. closer to the uterine fundus, or using multiple electrodes.

Research implications

For future research we recommend to gain more experience with continuous registrations after childbirth, both in uncomplicated and complicated postpartum episodes, such as cases with HPP and/or manual placental removal. With a recently introduced new design of wireless EHG, (combined with fetal ECG), continuous registration even in OR is feasible.

Since most patients were not bothered by the application of EHG postpartum, it is justified to set up further research on this topic.

Moreover, it would be interesting to investigate different factors that could influence uterine activity postpartum such as uterine massage, breast feeding (oxytocin release), administration of oxytocin, different oxytocica (methergine, prostaglandins, carbetocine) and cesarean section.

Conclusion

This study shows that with EHG it is possible to objectify uterine activity both during and after the third stage of labor, which may be of value in clinical practice and future research.

This could provide more insight and knowledge into the (patho) physiology of uterine contractions postpartum.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [S.G. Oei initiated the scientific research from which Nemo Healthcare and the evaluated EHG device have originated].

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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