

Uterine Monitoring Techniques from Patients' and Users' Perspectives

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Abstract

Keywords

- ▶ cardiotocography (MeSH)
- ▶ electrohysterograph
- ▶ external tocodynamometer
- ▶ intrauterine pressure catheter
- ▶ uterine contraction (MeSH)
- ▶ uterine monitoring (MeSH)
- ▶ patient preference (MeSH)
- ▶ user preference

Objective To evaluate preferences from patients and users on 3 uterine monitoring techniques, during labor.

Study Design Women in term labor were simultaneously monitored with the intrauterine pressure catheter, the external tocodynamometer, and the electrohysterograph. Postpartum, these women filled out a questionnaire evaluating their preferences and important aspects. Nurses completed a questionnaire evaluating users' preferences.

Results Of all 52 participating women, 80.8% preferred the electrohysterograph, 17.3% the intrauterine pressure catheter and 1.9% the external tocodynamometer. For these women, the electrohysterograph scored best regarding application and presence during labor ($p < 0.001$). Most important aspects were “least likely to harm” and “least discomfort”. Of 57 nurses, 40.4% preferred the electrohysterograph, 35.1% the external tocodynamometer, and 24.6% had no preference, or replied that their preference is subject to situation and patient.

Conclusion Patients prefer the electrohysterograph over the external tocodynamometer and the intrauterine pressure catheter, while healthcare providers report ambiguous results.

Annually, more than 5 million women give birth in the European Union. Most of them receive uterine monitoring during labor through the external tocodynamometer (TOCO), the intrauterine pressure catheter (IUPC), or the electrohysterograph (EHG). These techniques are compared in several studies that mainly focus on diagnostic values, interpretability, and labor outcomes.^{1–5} Only 1 article describes patients' and users' (i.e., healthcare provider) satisfaction of 2 securing methods (belts), both concerning external TOCO devices.⁶ Reports on users' and patients' preferences of all 3 uterine monitoring methods are still missing, while this topic is becoming more important nowadays.

Each uterine monitoring technique has advantages and limitations from patients' and users' perspectives. For example, TOCO measures changes of the abdominal wall noninvasively. It is generally applied by nursing staff and wireless connections are developed. A problem of this abdominal transducer is signal loss following maternal movements. With TOCO, a significant period of absent uterine activity monitoring (complete signal loss in 20 out of 42 minutes of registration) is described.⁷ To obtain a continuous registration of good quality, this method requires frequent repositioning of the transducer and tightening of the abdominal elastic belt. The alternative external method, EHG, measures

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uterine electrical activity noninvasively by abdominal electrodes that can be applied by the nursing staff.⁸ Due to the adhesive properties, these electrodes are potentially less-motion-sensitive than TOCO. For EHG, reduction of the skin impedance with abrasive sandpaper is necessary for proper data acquisition and the abdominal patch needs to be removed after the delivery.⁹ The current gold standard, IUPC, provides a direct and accurate measurement of the pressure changes inside the uterine cavity. Therefore, it can only be used, when the membranes are ruptured.¹⁰ Moreover, severe IUPC related complications have been described, such as placental or uterine wall perforation.¹¹ In addition, the invasive IUPC needs to be inserted by experienced obstetricians or midwives, who might not always be available.

In a separate paper, we described a study with simultaneous recordings of EHG, TOCO, and IUPC.⁵ Apart from the presented test characteristics, we wanted to gain insight into the patients' and users' preferences and characteristics, as well as they should be considered, when opting for uterine monitoring techniques. We hypothesize that both patients and users prefer EHG, since this method is noninvasive and less influenced by maternal movements.

Materials and Methods

We performed a prospective diagnostic accuracy study in the Máxima Medical Center, Veldhoven, the Netherlands. Term pregnant women carrying a singleton fetus in cephalic presentation were included. Once in active labor, eligible women were simultaneously connected to TOCO, IUPC, and EHG for 2 hours. Per patient we used 3 identical cardiotocography (CTG) monitors (Avalon FM30, Philips Healthcare, Eindhoven, the Netherlands) to store each real-time tocogram in the Electronic Patient System (Ezis, Chipsoft, Amsterdam, the Netherlands).

First, after ultrasound localization of the placenta and during vaginal examination, a flexible sensor-tipped IUPC (Koala, Clinical Innovations, Murray, Utah, USA) was inserted in the amniotic cavity. This was done by an experienced physician or midwife, in presence of 1 of the researchers that checked proper placement after connection. Second, 1 of the researchers prepared the abdominal skin by abrasive paper to reduce skin impedance, and positioned the EHG patch (Graphium, Nemo Healthcare, Eindhoven, the Netherlands). The skin impedance was checked with the impedance meter (SIGGI II, MedCaT, Klazienaveen, the Netherlands). The preparation was considered adequate, when values were below 5k Ω . The EHG patch was then connected to the translation module for data processing (PUREtrace, Nemo Healthcare, Eindhoven, the Netherlands). Third, TOCO was placed at the uterine fundus and tied up with an elastic belt. For logistic reasons, TOCO was wirelessly connected to the CTG monitor. The researchers were present during each measurement, lasting from 30 minutes up to 2 hours, to annotate adjustments to any of the 3 techniques. TOCO signal quality was checked by the attending nurses every 30 minutes and the position of the TOCO was adjusted, if necessary. After 2 hours,

we removed TOCO and EHG, while IUPC remained in place until the end of the delivery.

Evaluation of patients' preferences was performed by a questionnaire filled out by the participating women within a few hours postpartum. The survey entailed 3 identical continuous scale questions for each uterine monitoring technique (IUPC, TOCO, and EHG) with a 100 mm scale corresponding to "not bothering at all" (0 mm) to "very bothering" (100 mm) regarding: (1–3) positioning, (4–6) presence during labor, and (7–9) removal. The actual value of the scale was not visible for the participants, but was calculated by the researchers afterwards. Additionally, this identical 0 to 100 mm scale was used to assess: (10) skin preparation for EHG and (11) transducer modifications during labor for TOCO. The survey entailed 4 multiple choice questions: (12) which of the 3 methods women preferred (EHG, TOCO, IUPC); (13) which factors of both external methods they considered as being most important (least difficult to position, least discomfort, least adjustments, least limitation of mobility, or least difficult to remove); (14) which external method women preferred (scale –50 to +50, corresponding to –50 for TOCO, 0 for neutral, and +50 for EHG); and (15) which aspects of uterine monitoring (either internal or external) they considered as being most important (costs, quality, discomfort, or potential harm). We also asked our participants, whether they experienced irritation, pain, discomfort, or dislocations with either 1 of the techniques. Finally, the women had the opportunity to leave other remarks or notes.

After completion of the validation study, EHG was introduced as standard alternative in our clinic. In case, TOCO was inadequate, EHG was applied by obstetric nurses that were trained by the main researchers on correct application. To evaluate user satisfaction, we asked all obstetric nurses that had been working with EHG, to fill out a questionnaire. This questionnaire entailed 9 continuous scale questions from 1 to 5, regarding their experiences with EHG: (1) sufficient knowledge of EHG, (2) sufficient competence with EHG, (3) usefulness of uterine palpation, (4) inconvenience due to performing skin preparation, (5) frequency of performing uterine palpation, (6) frequency of using the impedance meter, (7) repeating skin preparation, when the skin impedance is above 5 k Ω , (8) installing EHG without technical problems, (9) the prevalence of local skin irritation. The 5-point scale corresponded to 1 = "agree" and 5 = "disagree" for questions 1 to 3, to 1 = "very bothering" and 5 = "not bothering" for question 4, and to 1 = "always" and 5 = "never" for questions 5 to 9.

Furthermore, this user questionnaire entailed 6 additional questions regarding their experiences with external uterine monitoring techniques: (10) which technique is more time-consuming (TOCO, EHG, or no difference); (11) method of preference (TOCO, EHG, or no preference); (12) advantages of EHG (open question); (13) disadvantages of EHG (open question); (14) recommendation of EHG to colleagues working in another hospital, (rated from 0 = "not likely" to 10 = "very likely"); (15) frequency of weekly EHG usage in clinical practice (open question). For every question, there was the opportunity to write comments.

Statistical Analysis

The sample size of 52 patients was based on a power analysis to validate the sensitivity of EHG, reported in our previous publication.⁵ We used SPSS (Statistical Package for Social Science) 23 statistics (IBM, New York, USA) for statistical evaluation. Descriptive statistics included frequencies with percentages and 95% confidence intervals (CI) for categorical data,^{12,13} mean with standard deviation (SD) for normally distributed continuous variables, or median with interquartile range (IQR) for nonnormally distributed continuous variables. Normality was checked visually using histograms, in addition to values for skewness and kurtosis between -1 and $+1$. Statistical significance was accepted at a 2-sided p -value below 0.05.

The results of the continuous scale questions regarding the placement, presence during labor and removal of the equipment were tested with the Wilcoxon's signed rank test for paired data, when comparing 2 techniques. The Friedman's test was used, when comparing all 3 techniques together. The patients' preferences for either 1 of the 3 techniques were tested by the Chi-squared test. Additionally, the patients' preferences were compared in subgroups based on obesity and labor analgesia. We hypothesized that patients without labor analgesia prefer TOCO over EHG and IUPC, because its wireless connection enables patients' mobility. Obese women might prefer IUPC over the external methods, as their increased abdominal adipose tissue significantly hampers their pregnancy and labor surveillance. These subgroup comparisons were tested with the Fisher's Exact test.

Frequencies, percentages, and 95%CI regarding users' preferences were calculated.^{12,13} For calculation of cumulative percentages, score 1 (totally agree) and 2 (agree) were summed up, or score 4 (disagree) and 5 (totally disagree).

Ethical Approval

The Institutional Review Board of Máxima Medical Center approved the protocol on 15 July 2014 (NL48951.015.14) and the study is registered in the Dutch trial register (NTR5894), <http://www.trialregister.nl/trialreg/admin/rctview.asp?TC=5894>.

Pregnant women were recruited in Máxima Medical Center (Veldhoven, the Netherlands). All measurements were performed by 2 researchers (K.M.J.T. and M.W.C.V), after informed consent was received.

Results

Patients' Preferences

From July 2014 to June 2016, 52 women participated in our study. All questionnaires were completed within 24 hours postpartum, except for 1 which was filled out within 1 week after the delivery. No questionnaires were lost to follow-up. Six patients did not fill out all questions regarding "the presence" (4 women) or "the removal" (2 women) of the 3 uterine monitoring techniques, therefore impeding comparison of these paired measurements. In addition, 1 woman did not answer the questions regarding the most important factor of the external methods. The patient characteristics are presented in ►Table 1.

Table 1 Sociodemographic and clinical characteristics of 52 women simultaneously monitored with the electrohysterograph, external tocodynamometer and intrauterine pressure catheter

Characteristic	n = 52
Maternal age (y)	31.7 ± 4.3
Race	
Caucasian	48 (92.3%)
Other	4 (7.7%)
Parity	
Nulliparous	29 (55.8%)
Multiparous	23 (44.2%)
Gestational age (wk + d)	39.3 ± 8.1
Body mass index (BMI, kg/m ²)	
Before pregnancy	29.2 ± 8.1
During measurement ^a	33.8 ± 7.4
Start of labor	
Spontaneous onset	16 (30.8%)
Induction of labor	36 (69.2%)
Oxytocin usage	
No	14 (26.9%)
Yes	38 (73.1%)
Labor analgesia	
No analgesia	15 (28.9%)
Epidural analgesia	34 (65.4%)
Remifentanyl	3 (5.8%)
Duration measurement (min)	104.4 ± 29.1
Cervical dilatation (cm)	
Start measurement	4.0 (3–10)
Stop measurement	8.5 (3–10)
Mode of delivery	
Spontaneous vaginal delivery	36 (69.2%)
Vacuum delivery	7 (13.5%)
Cesarean section	9 (17.3%)

Note: Data are mean ± standard deviation, median (range), n, or n (%) unless otherwise specified.

^aIn 3 women, body mass indices during labor are missing (values of 20, 42 and 48 before pregnancy).

Of the 52 women, 42 (80.8%; 95% CI; 68.4–89.8%) preferred uterine monitoring by EHG, 9 women (17.3%; 95% CI; 8.8–29.4%) preferred IUPC, and 1 woman (1.9%; 95% CI; 0.1–9.1%) preferred TOCO. This result was tested as a significant difference (►Table 2). The subgroup comparisons based on obesity (nonobese or obese) and labor analgesia (none, epidural analgesia or remifentanyl) reported no significant differences regarding the preferences of the women (►Table 2). Furthermore, we asked the women to choose between one of the external methods based on a continuous scale from -50 for TOCO to $+50$ for EHG. This revealed a strong preference for EHG, with an average score of 38.7.

Table 2 Patients' preferences regarding uterine monitoring techniques

	IUPC	TOCO	EHG	Significance
Overall (n = 52)	9 (17.3%)	1 (1.9%)	42 (80.8%)	p < 0.001 ^a
Maternal obesity				
Nonobese (n = 20)	5 (25.0%)	0 (0.0%)	15 (75.0%)	p = 0.452 ^b
Obese (n = 32)	4 (12.5%)	1 (3.1%)	27 (84.4%)	
Labor analgesia				
No (n = 15)	1 (6.7%)	1 (6.7%)	13 (86.6%)	p = 0.226 ^b
Epidural (n = 34)	7 (20.6%)	0 (0.0%)	27 (79.4%)	
Remifentanyl (n = 3)	1 (33.3%)	0 (0.0%)	2 (66.7%)	

Note: Data are n (%); maternal obesity was defined as a body mass index of ≥ 30 kg/m² during labor.

^aChi-squared test.

^bFisher's Exact test.

On a continuous scale from 0 to 100, "application of EHG" was scored as being least bothering, with significant differences between all 3 methods (►Table 3). Regarding the "presence during labor", patients were significantly more bothered by TOCO than by IUPC or EHG. No significant differences were found between the 3 methods regarding "removal of equipment". However, when EHG was only compared with TOCO, we did find a significant difference in favor of TOCO (►Table 3). The discomfort due to the skin preparation required for EHG was assessed as minor, with a median of 6.6 (IQR; 2.0–21.9), although 8 patients (15.4%) did report local irritation due to skin preparation and/or the abdominal EHG patch. In comparison, local skin irritation with TOCO was reported by only 3 women (5.8%). Several women complained about discomfort (23.1%) and dislocations (28.8%) of TOCO, which was not reported for EHG. For IUPC, 3 women (5.8%)

reported dislocations, 2 women (3.8%) experienced discomfort and 1 woman (1.9%) experienced pain.

Considering uterine monitoring in general (internal and external), "least likely to harm" was reported as most important factor by 51.9% of the women, "best quality" by 25.0% and "least discomfort" by 23.1%. Furthermore, when considering the characteristics of the external methods (n = 51), 60.8% of the participants considered "least discomfort" as an important factor for external uterine monitoring, followed by "least limitation of mobility" with 27.5%, "least difficult to position" with 5.9% and "least adjustments" with 5.9%.

Users' Preferences

In April 2017, all obstetric nurses that had been working with EHG (57 nurses, 100%) completed the questionnaire concerning user satisfaction. Of them, 23 nurses (40.4%; 95% CI; 28.2–53.4%) chose EHG as preferred external method, compared with 20 nurses (35.1%; 95% CI; 23.6–48.1%) choosing TOCO. Furthermore, 14 nurses (24.6%; 95% CI; 14.7–36.9%) had no preference or replied that their preference was subject to situation and patient.

Regarding their experiences with EHG on a 5-point scale, 67.3% of nurses reported that they had sufficient knowledge about EHG (mean 2.1 ± 1.3) and 73.7% of all nurses considered themselves as competent in the use of EHG (mean 2.2 ± 1.0). Most nurses also confirmed that they palpate the uterus to ensure optimal localization of EHG (subdivided into helpfulness 87.3% [mean 1.6 ± 1.0] and frequency 86.8% [mean 1.6 ± 1.0]). Only 13.2% of nurses reported to use the impedance meter to check the impedance after skin preparation (mean 4.4 ± 1.2). However, the nurses that do use the impedance meter also repeat skin preparation, when the impedance appeared to be too high (mean 1.5 ± 0.7). Most nurses (71.7%) reported no problems with application of this EHG system (mean 2.1 ± 0.8). EHG was considered most time-consuming by 60.4% of nurses, compared with 22.6% that found TOCO more time-consuming, the remaining 17.0% was neutral. The users' questionnaire revealed indifferent results regarding the inconvenience of skin preparation

Table 3 Assessment of the application, presence and removal of intrauterine pressure catheter (IUPC), external tocodynamometer (TOCO) and electrohysterograph (EHG)

	IUPC	TOCO	EHG	Significance	Significance
Application (n = 52)	30.6 (8.0–53.1) 30.6 (8.0–53.1) –	10.0 (2.1–27.6) – 10.0 (2.1–27.6)	– 2.1 (0.0–5.2) 2.1 (0.0–5.2)	p < 0.001 ^a p < 0.001 ^a p < 0.001 ^a	p < 0.001 ^b
Presence (n = 48)	8.3 (1.0–47.0) 8.3 (1.0–47.0) –	42.0 (10.8–58.7) – 42.0 (10.8–58.7)	– 2.1 (0.0–6.5) 2.1 (0.0–6.5)	p = 0.004 ^a p < 0.001 ^a p < 0.001 ^a	p < 0.001 ^b
Removal (n = 50)	5.2 (1.0–15.0) 5.2 (1.0–15.0) –	3.1 (0.0–9.0) – 3.1 (0.0–9.0)	– 10.0 (2.1–22.9) 10.0 (2.1–22.9)	p = 0.052 ^a p = 0.583 ^a p = 0.011 ^a	p = 0.188 ^b

Note: Data are median with (interquartile ranges); the continuous scale ranged from 0 to 100, corresponding to "not bothering at all" to "very bothering."

^aWilcoxon's signed rank test.

^bFriedman's test.

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(mean 3.4 ± 1.2) and local irritation due to EHG (mean of 3.3 ± 1.0), whereas in the open answers 35.1% of the nurses observed skin redness and 19.3% skin irritation.

The most reported advantage of EHG was a more constant and reliable registration, which especially holds in case of obesity and with changing maternal position (64.9% of the respondents). In addition, 24.6% of the nurses considered the improved patient satisfaction to be an advantage. The main disadvantage, reported by 54.4% of the nurses, was a decreased mobility of patients by cables of EHG. The fact that this EHG method cannot be used in bath or shower was reported as a disadvantage by 28.1% of the nurses. Finally, the users would recommend this EHG method to colleagues with a score of 6.3 ± 2.0 out of 10.

Discussion

This is the first study evaluating patients' and users' preferences of 3 uterine monitoring techniques; the internal IUPC, which is the current gold standard though not routinely used, the external TOCO, which is the method of first choice,^{14–16} and external EHG that was only recently validated for contraction monitoring.⁵ Patients strongly preferred EHG over TOCO and IUPC. EHG is considered as the most comfortable method regarding both placement and presence during labor. On the contrary, preferences of healthcare providers were ambiguous.

A strength of the evaluation on patients' preferences is the unique situation: all patients received all 3 methods, so they are most eligible to evaluate their preferences. Another strength of our study is that we had little missing data. Almost all women filled out the questionnaires directly postpartum or within a few hours, which resulted in a complete database. We also had a high response rate to evaluate users' preferences as every obstetric nurse completed the questionnaire.

One limitation of this study was that there were no validated questionnaires available to evaluate neither patients' nor users' preferences on uterine monitoring techniques, so we developed customized questionnaires for this purpose. Another limitation might be that we collected the patients' questionnaire this short after a life-event, which could influence the outcomes. However, we expect that the mutual comparison is minimally affected, since the comparison includes all 3 methods applied to the same woman at the same time. Finally, both patients and users were aware that EHG was the newly introduced technique, which may have caused bias.

Safety

One of the main principles in medicine is “*primum non nocere*”, i.e. first do no harm.¹⁷ Our results underline this statement as most women preferred the aspect “least likely to harm” above comfort, quality and costs.

On the one hand, noninvasive external monitoring methods are therefore preferred above invasive methods to monitor the uterine activity pattern.

Extra membranous placement of IUPC is not uncommon (reported incidence is 23–38%) and potential risks following

improper IUPC placement include perforation of the placenta, the uterus, or fetal blood vessels.^{11,18} However, a Cochrane review reported no major complications in 977 women being exposed to IUPC.¹ Therefore, IUPC-related complications are rare, yet can be very severe.

On the other hand, inadequate external uterine monitoring could also be considered as unsafe for mother and child. The widely used TOCO is noninvasive but has a low reported sensitivity: from 46 to 74% thereby missing a significant number of contractions.^{19,20} EHG has a significant higher reported sensitivity: from 86 to 98%.^{3–5,19–21} Inadequate uterine monitoring can result in fetal distress and cesarean delivery due to insufficient relaxation time to reoxygenate the placental tissue in case of (missed) hypertonia or hyper stimulation of the uterus.^{22,23} Especially during induction or augmentation of labor, the uterine activity pattern should be closely monitored to improve the safety of not only mother and child,¹⁶ but also of the obstetrical caregiver, as oxytocin is often involved in obstetric litigation.²⁴

Comfort

Of the external methods, patients preferred the technique with the “least discomfort” (60.8%) during labor above mobility, adjustments, positioning, and removing. TOCO required frequent adjustments during labor, such as repositioning of the transducer and tightening of the elastic belt, resulting in discomfort reported by 23.1% of our participants. Patients also reported to be least bothered by the presence of EHG during labor compared with TOCO and IUPC. However, a potential discomfort of EHG could be temporarily skin reactions following skin preparation and/or the abdominal patch, which has been reported by 15.4% of patients. Another issue concerning comfort is for the equipment to be waterproof, in case patients prefer having a bath or shower during labor. The studied EHG method was not waterproof, and IUPC catheters were also not suitable for use in water. The telemetry variant of TOCO could be used in both shower and bath, and is therefore most suitable for these patients. When waterproof EHG methods will be available, patients' comfort could be further improved.

Mobility

Next to comfort, our participants considered mobility as an important factor during labor. Research has also shown that walking and upright positions positively influence the progress of labor.²⁵

With IUPC, mobility is seriously hampered as these women are confined to bed because the catheter can fall out, when they walk around. Eight out of 9 (88.9%) women that chose IUPC as their preferred method, had labor analgesia and were thus being confined to bed already. Both external methods (EHG and TOCO) can provide more mobility than IUPC. Cables for both EHG and TOCO are long enough to walk around the bed but mobility is still compromised. Therefore, wireless connections are preferred to further improve mobility. TOCO can be wireless (although not all hospitals have the availability of wireless systems), while most real-time EHG systems do not (yet) provide wireless connections. On the contrary, EHG can enhance mobility

during labor compared with TOCO due to the adhesive properties of the contact electrodes, which are less sensitive to position.

Time-Efficiency

Novel techniques used at the labor ward should not only be preferred by patients, but should also be user-friendly. The results of our user questionnaire revealed ambiguous results, regarding their preference for EHG (40.4%) or TOCO (35.1%). Less experienced nurses found the use of EHG more time-consuming than TOCO. Especially, the impedance meter was considered as difficult to use and a time-consuming step to integrate in clinical practice. However, Euliano et al suggested that the usage of EHG could reduce nursing time.¹⁹

Our more experienced nurses also recognized the time-saving aspect of EHG as it needs to be applied only once per patient, due to its adhesive properties. Thus, while initiating the measurement might be more time-consuming, this could be compensated by reduced interference time during the measurement. In contrast, TOCO needs to be repositioned several times during labor, especially after maternal movements. To assess this hypothesis, we annotated all adjustments during the measurements. We checked signal quality every 30 minutes during the 2-hour registration period: on average, TOCO needed to be repositioned twice due to signal loss. Within the same time frame, EHG required 1 adjustment on average such as calibration or reset baseline (zero) on the CTG monitor. IUPC required less

Table 4 Advantages and limitations of currently available uterine monitoring techniques

Technical characteristics:	Intrauterine pressure catheter (IUPC)	External tocodynamometer (TOCO)	Electrohysterograph (EHG)
Used technique	Sensor-tipped or transducer catheters measuring changes of the intrauterine pressure	Gauge transducer measuring shape changes of the abdominal wall	Abdominal electrodes measuring the electrical activity of the uterine muscle
Value of the measurement	Millimeters of mercury	Relative TOCO units	MicroVolts
Internal or external	Internal	External	External
Invasiveness	Invasive	Noninvasive	Noninvasive
Application of technique	During vaginal examination	Abdominal positioning	Abdominal positioning
Placed by	Only physicians or midwives	Any obstetrical caregiver	Any obstetrical caregiver
Reusability	Disposable	Reusable	Disposable
Wired or wireless	Wired, direct connection is essential	Some hospitals have a wireless TOCO (telemetry)	Most do not (yet) provide wireless connection
Potential risks or side-effects	Moderate, < 1:1,000, rare though severe complications (placental/uterine perforation)	Very low, skin reactions due to the transducer or elastic band around the abdomen	Low, skin reactions due to skin preparation or the abdominal electrodes
Diagnostic values:	Intrauterine pressure catheter	External tocodynamometer	Electrohysterograph
Accuracy of method	Very high	Moderate	High
Sensitivity contraction detection	> 95%	46–74% ^a	86–98% ^a
Sensitivity in obese women ^a	> 95%	46–51% ^a	82–97% ^a
Performance influenced by second stage of labor	Low, the catheter can be expulsed	Low, sensitivity might increase as pushing improves the uterine contact	Moderate, potentially more technical artifacts due to pushing
Users' and patients' preferences	Intrauterine pressure catheter	External tocodynamometer	Electrohysterograph
Difficulty positioning	Moderate, ultrasound for placental localization and vaginal examination	Very low, can be easily placed and adjusted throughout labor	Low, adequate skin preparation is necessary
Users' preference	x	35%	40%
Application	Moderate, score 31	Low, score 10	Very low, score 2
Presence during labor	Low, score 8	Moderate, score 42	Very low, score 2
Removal	Very low, score 5	Very low, score 3	Low, score 10
Patients' preference	17%	2%	81%

Note: Scale: very low, low, moderate, high, very high; 0–100: 0 = not bothering, 100 = very bothering x; not assessed.

^aSource references are^{3,5,19–21}

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adjustments (on average 0.5 per 2-hour registration), including resetting baseline, flushing and repositioning of the catheter. In 3 cases the IUPC was expelled and in 2 of these cases a new catheter had to be inserted.

Another important factor considering time-efficiency is, whether the method can be applied throughout the different stages of labor (term/preterm labor, first/second stage, with/without ruptured membranes). The IUPC can only be inserted, when membranes are ruptured, which is not always the situation during the early stage of labor or during preterm labor. During second stage of labor the IUPC catheter can be pushed out. On the contrary, both EHG and TOCO do not require ruptured membranes. These techniques can already be applied in the early beginning of (preterm) labor and they stay positioned throughout labor and delivery. For women, this will be more convenient and for nurses this could improve workflow. Another factor that could influence time-efficiency is interpretability of uterine monitoring techniques. The adhesive properties of EHG enable a more continuous CTG registration of good quality that could be less time-consuming during labor. Previous studies have also shown that EHG registrations have a higher interpretability and are easier to interpret than TOCO.^{4,19,26}

Individualized Choice of Monitoring Method

Most of above described factors depend on type of patient and situation. Therefore, these factors should be considered, when choosing a suitable method for uterine monitoring. Patients that benefit most from registration with EHG, TOCO, or IUPC could be selected. An overview of these method-specific characteristics is presented in ►Table 4.

Implementation

The nurses of our hospital have been working with EHG for a couple of years now. As they were the first to work with this real-time method worldwide, they are the so-called “early adopters” in the “technology adoption life cycle” of the innovation theory described by Rogers.²⁷ As for many innovations, there is still a chasm to be crossed. We expect that wide implementation of this technology may take some time. Experience needs to grow and investment in training is important. All future users should be trained on key aspects of EHG. Correct patch localization is important for proper interface with the myometrium and adequate skin preparation with abrasive sandpaper is essential for an accurate EHG signal. However, abrading too firm might evoke dermatologic reactions. Therefore, an impedance meter is useful to check impedances and guide users in preparation and application. As this step is considered time-consuming, it would be interesting to implement direct feedback on the EHG monitor with respect to skin impedance. Finally, for a successful implementation, it is essential that obstetricians will be trained in interpretation of EHG signals as well.

Conclusion and Future Perspectives

Current uterine monitoring techniques have some disadvantages. EHG is therefore being evaluated as a promising new

method that is both safe and reliable. Patients prefer EHG over TOCO and IUPC, although the opinion of healthcare providers is inconclusive.

For future designs of EHG devices, we would recommend a waterproof and wireless system, enabling a more continuous and mobile monitoring. Integrating an impedance meter is also advised. These adjustments could further improve patients' and users' satisfaction, which is necessary for successful implementation in clinic. The effect of EHG application on obstetric and perinatal outcome and related cost-effectiveness should be further evaluated.

Conflict of Interest

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