Uterine Monitoring Techniques from Patients’ and Users’ Perspectives

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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.
uterine electrical activity noninvasively by abdominal electrodes that can be applied by the nursing staff. 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. The current gold standard, I UPC, 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. Moreover, severe I UPC related complications have been described, such as placental or uterine wall perforation. In addition, the invasive I UPC 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 I UPC. 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, I UPC, 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 tocardiogram 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 I UPC (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 5 kΩ. 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 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 I UPC 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 (I UPC, 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, I UPC); (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 kΩ, (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. 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. Mean with standard deviation (SD) for normally distributed continuous variables, or median with interquartile range (IQR) for non-normally 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. 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.

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

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n  =  52</th>
</tr>
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<tbody>
<tr>
<td>Maternal age (y)</td>
<td>31.7 ± 4.3</td>
</tr>
<tr>
<td>Race</td>
<td></td>
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<tr>
<td>Caucasian</td>
<td>48 (92.3%)</td>
</tr>
<tr>
<td>Other</td>
<td>4 (7.7%)</td>
</tr>
<tr>
<td>Parity</td>
<td></td>
</tr>
<tr>
<td>Nulliparous</td>
<td>29 (55.8%)</td>
</tr>
<tr>
<td>Multiparous</td>
<td>23 (44.2%)</td>
</tr>
<tr>
<td>Gestational age (wk + d)</td>
<td>39.3 ± 8.1</td>
</tr>
<tr>
<td>Body mass index (BMI, kg/m²)</td>
<td></td>
</tr>
<tr>
<td>Before pregnancy</td>
<td>29.2 ± 8.1</td>
</tr>
<tr>
<td>During measurement a</td>
<td>33.8 ± 7.4</td>
</tr>
<tr>
<td>Start of labor</td>
<td></td>
</tr>
<tr>
<td>Spontaneous onset</td>
<td>16 (30.8%)</td>
</tr>
<tr>
<td>Induction of labor</td>
<td>36 (69.2%)</td>
</tr>
<tr>
<td>Oxytocin usage</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>14 (26.9%)</td>
</tr>
<tr>
<td>Yes</td>
<td>38 (73.1%)</td>
</tr>
<tr>
<td>Labor analgesia</td>
<td></td>
</tr>
<tr>
<td>No analgesia</td>
<td>15 (28.9%)</td>
</tr>
<tr>
<td>Epidural analgesia</td>
<td>34 (65.4%)</td>
</tr>
<tr>
<td>Remifentanil</td>
<td>3 (5.8%)</td>
</tr>
<tr>
<td>Duration measurement (min)</td>
<td>104.4 ± 29.1</td>
</tr>
<tr>
<td>Cervical dilatation (cm)</td>
<td></td>
</tr>
<tr>
<td>Start measurement</td>
<td>4.0 (3–10)</td>
</tr>
<tr>
<td>Stop measurement</td>
<td>8.5 (3–10)</td>
</tr>
<tr>
<td>Mode of delivery</td>
<td></td>
</tr>
<tr>
<td>Spontaneous vaginal delivery</td>
<td>36 (69.2%)</td>
</tr>
<tr>
<td>Vacuum delivery</td>
<td>7 (13.5%)</td>
</tr>
<tr>
<td>Cesarean section</td>
<td>9 (17.3%)</td>
</tr>
</tbody>
</table>

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).
about discomfort (23.1%) and dislocations (28.8%) of TOCO, reported by only 3 women (5.8%). Several women complained
patch. In comparison, local skin irritation with TOCO was
irritation due to skin preparation and/or the abdominal EHG
system (mean 2.1
nurses (71.7%) reported no problems with application of this
method. However, when EHG was only compared with
removal of TOCO, we did
quired for EHG was assessed as minor, with a median of 6.6
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
considered themselves as competent in the use of EHG (mean
67.3% of nurses reported that they had suf
sisted as a body mass index
≥ 30 kg/m² during labor.

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

Table 2 Patients’ preferences regarding uterine monitoring
techniques

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

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 re
quired 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 con
cerning user satisfaction. Of them, 23 nurses (40.4%; 95% CI:
28.2–53.4%) chose EHG as preferred external method, com
pared 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 con
sidered 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)

<table>
<thead>
<tr>
<th></th>
<th>IUPC</th>
<th>TOCO</th>
<th>EHG</th>
<th>Significance</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application (n = 52)</td>
<td>30.6 (8.0–53.1)</td>
<td>10.0 (2.1–27.6)</td>
<td>2.1 (0.0–5.2)</td>
<td>( p = &lt; 0.001^a )</td>
<td>( p = 0.004^a )</td>
</tr>
<tr>
<td>Presence (n = 48)</td>
<td>8.3 (1.0–47.0)</td>
<td>42.0 (10.8–58.7)</td>
<td>2.1 (0.0–6.5)</td>
<td>( p = &lt; 0.001^a )</td>
<td>( p = &lt; 0.001^b )</td>
</tr>
<tr>
<td>Removal (n = 50)</td>
<td>5.2 (1.0–15.0)</td>
<td>3.1 (0.0–9.0)</td>
<td>10.0 (2.1–22.9)</td>
<td>( p = 0.052^a )</td>
<td>( p = 0.011^a )</td>
</tr>
</tbody>
</table>

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

Wilcoxon’s signed rank test.
Friedman’s test.
(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, and external EHG that was only recently validated for contraction monitoring. 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. 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. However, a Cochrane review reported no major complications in 977 women being exposed to IUPC. 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. EHG has a significant higher reported sensitivity: from 86 to 98%. 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, but also of the obstetrical caregiver, as oxytocin is often involved in obstetric litigation.

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. TOCO required frequent adjustments during labor, such as repositioning of the transducer and tightening of the elastic belt. TOCO required frequent adjustments during labor, such as repositioning of the transducer and tightening of the elastic belt. EHG has a significantly higher reported sensitivity: from 86 to 98%. 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. 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, but also of the obstetrical caregiver, as oxytocin is often involved in obstetric litigation.

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.

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>
<thead>
<tr>
<th><strong>Table 4</strong> Advantages and limitations of currently available uterine monitoring techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technical characteristics:</strong></td>
</tr>
<tr>
<td>Used technique</td>
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<tr>
<td>Value of the measurement</td>
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<tr>
<td>Internal or external</td>
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<tr>
<td>Invasiveness</td>
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<td>Application of technique</td>
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<tr>
<td>Placed by</td>
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<td>Reusability</td>
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<td>Wired or wireless</td>
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<td>Potential risks or side-effects</td>
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<td>Diagnostic values:</td>
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<tr>
<td>Accuracy of method</td>
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<tr>
<td>Sensitivity contraction detection</td>
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<tr>
<td>Sensitivity in obese women(^a)</td>
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<tr>
<td>Performance influenced by second stage of labor</td>
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<tr>
<td>Users’ and patients’ preferences</td>
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<tr>
<td>Intrauterine pressure catheter</td>
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<td>Difficulty positioning</td>
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<td>Users’ preference</td>
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<td>Application</td>
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<td>Presence during labor</td>
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<td>Removal</td>
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<td>Patients’ preference</td>
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\(^a\)Source references are\(^{3,5,19-21}\)
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 can be used 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 adhesive 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**
The study has been financially supported by the Dutch Foundation “Stichting De Weijerhorst” and the Horizon2020 grant, the European Framework Program for Research and Innovation (Project number 719500). Author S.G.O. initiated the scientific research from Nemo Healthcare and from where the described EHG device have originated. There are no financial relationships between Nemo Healthcare and any of the authors.

**Acknowledgments**
None.

**References**
12 Rothman KJ, Boice JD. Epidemiological Analysis with a Program-
mable Calculator. USA: NIH Publication; 1979
13 Wilson EB. Probable inference, the law of succession, and statis-
14 Fetal monitoring. Guidelines; perinatology. Dutch Society for
Obstetrics and Gynecology. Version 30. 2015
15 Ayres-de-Campos D, Spong C, Chandrakaran E. FIGO consensus
guideline on intrapartum fetal monitoring. Int J Gynaecol Obstet
2015;131((01):13–24
16 American College of Obstetrics and Gynecology Committee on
Practice Bulletins-Obstetrics. ACOG practice bulletin number 49,
December 2003: dystocia and augmentation of labor. Obstet
Gynecol 2003;102(49):1445–1454
17 Namm JP. Primum Non Nocere: Ethical Implications in Medical
18 Rood KM. Complications associated with insertion of intrauterine
pressure catheters: an unusual case of uterine hypertonicity and
uterine perforation resulting in fetal distress after insertion of an
intrauterine pressure catheter. Case Rep Obstet Gynecol 2012;
2012:517461
19 Euliano TY, Nguyen MT, Darmanjian S, Busowski JD, Euliano N, Gregg
AR. Monitoring uterine activity during labor: clinician interpretation
of electrohysterography versus intrauterine pressure catheter and
Prediction of intrauterine pressure waveform from transabdomi-
(12):811–816
22 Simpson KR, James DC. Effects of oxytocin-induced uterine
hyperstimulation during labor on fetal oxygen status and fetal
e5
23 Bakker PCAM, van Geijn HP. Uterine activity: implications for the
24 Cohen WR, Schifrin BS. Medical negligence lawsuits relating to
25 Lawrence A, Lewis L, Hofmeyr GJ, Dowswell T, Styles C. Maternal
positions and mobility during first stage labour. Cochrane Data-
base Syst Rev 2013. Doi: 10.1002/14651858.CD003934.pub4
26 Reinhard J, Hayes-Gill BR, Schiermeier S, et al. Uterine activity
monitoring during a multi-centre, blinded two-way trial of
external tocdynamometry against electrohysterography. Z
Geburtshilfe Neonatol 2011;215(05):199–204
and Schuster; 2003