

## OBSTETRICS

# Monitoring uterine activity during labor: a comparison of 3 methods

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**OBJECTIVE:** Tocodynamometry (Toco; strain gauge technology) provides contraction frequency and approximate duration of labor contractions but suffers frequent signal dropout, necessitating repositioning by a nurse, and may fail in obese patients. The alternative invasive intra-uterine pressure catheter (IUPC) is more reliable and adds contraction pressure information but requires ruptured membranes and introduces small risks of infection and abruption. Electrohysterography (EHG) reports the electrical activity of the uterus through electrodes placed on the maternal abdomen. This study compared all 3 methods of contraction detection simultaneously in laboring women.

**STUDY DESIGN:** Upon consent, laboring women were monitored simultaneously with Toco, EHG, and IUPC. Contraction curves were generated in real-time for the EHG, and all 3 curves were stored electronically. A contraction detection algorithm was used to compare frequency

and timing between methods. Seventy-three subjects were enrolled in the study; 14 were excluded due to hardware failure of 1 or more of the devices ( $n = 12$ ) or inadequate data collection duration ( $n = 2$ ).

**RESULTS:** In comparison with the gold-standard IUPC, EHG performed significantly better than Toco with regard to the Contractions Consistency Index (CCI). The mean CCI for EHG was  $0.88 \pm 0.17$  compared with  $0.69 \pm 0.27$  for Toco ( $P < .0001$ ). In contrast to Toco, EHG was not significantly affected by obesity.

**CONCLUSION:** Toco does not correlate well with the gold-standard IUPC and fails more frequently in obese patients. EHG provides a reliable noninvasive alternative, regardless of body habitus.

**Key words:** electrohysterography, electronic fetal monitoring, uterine activity monitoring

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Electronic fetal monitoring is used to assess both uterine activity (frequency of contractions) and fetal well-being (fetal heart rate pattern, especially in relation to contractions). The former is typically assessed noninvasively with a tocodynamometer (Toco): a strain gauge positioned over the maternal fundus, which responds to changes in uterine tension transmitted to the abdomen. The device identifies the frequency of

contractions, but not their intensity, and suffers both from misalignment following maternal movement and technical limitations in obese parturients. Currently the only alternative for Toco failure is the invasive intrauterine pressure catheter (IUPC), which carries inherent risks, most prominently infection.

In a comparison of Toco monitoring in obese (body mass index [BMI]  $>35$  kg/m<sup>2</sup>) and nonobese (BMI 20-25 kg/

m<sup>2</sup>) women, Ray et al<sup>1</sup> describe a 30% rate of “difficult monitoring” in the obese group (vs 0% in the nonobese), requiring a 26% rate of internal monitoring (vs 0% in the nonobese). Vanner and Gardosi<sup>2</sup> similarly reported poor-quality Toco during more than one quarter of the monitoring time in 36% of obese parturients (compared with 16% in nonobese).

Even in the nonobese, Toco suffers frequent failures. Bakker et al<sup>3</sup> described some period of inadequate registration (no tracing or unreliable pattern because of inadequate calibration) in 98% of 41 labors, for an average of 35% of stage 1 duration and 33% of stage 2. They also reported inadequate registration in 60% of 151 patients monitored with IUPC, for 28% of stage 1 and 30% of stage 2 durations.

Electrohysterography (EHG), the uterine electromyography, uses a different modality for monitoring uterine activity. Similar to observing an electrocardiograph rather than intracardiac pressures, EHG reports the electrical activity of the uterine muscle. This noninvasive monitor utilizes

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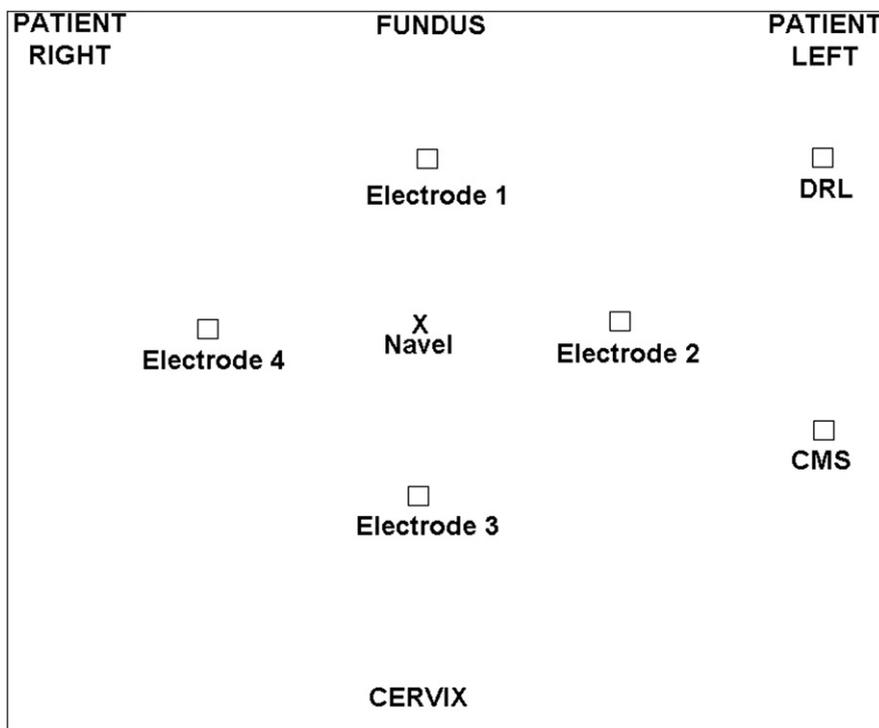
N.E. is president and M.T.N. and S.D. are employees of Convergent Engineering. T.Y.E. owns no stock or holds any position in the company but is married to N.E. and listed on patents filed for some of the technology described in this paper. The other authors report no conflict of interest.

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**FIGURE 1**  
**Electrode location**



CMS, common mode signal; DRL, driven right leg.

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surface electrodes applied to the maternal abdomen and a high-frequency, low-noise amplifier. Although prior studies have compared EHG with IUPC or Toco, to our knowledge this is the first study to compare EHG with both standard technologies in real time during active labor.

## MATERIALS AND METHODS

Adult patients admitted to labor and delivery in active labor with a singleton fetus in cephalic presentation and without bleeding, uterine scar, or contraindication to IUPC placement were eligible for inclusion. The study protocol was approved by our institutional review board, and all subjects provided written, informed consent. Following rupture of membranes (either spontaneous or artificial by obstetric indication), the EHG monitor was applied. In addition, if an IUPC was not already present, one was placed by the obstetrician. Data from the IUPC, Toco (using a second electronic fetal monitoring unit), and EHG were collected simultaneously via a laptop com-

puter. The patients' nurses were blinded to all but the IUPC output for uterine activity monitoring and interventions.

While a research data collector was available, monitoring continued through vaginal delivery or movement to the operating room for cesarean delivery.

Following skin preparation by gentle rubbing with an abrasive gel, 6.3 cm<sup>2</sup> Ag/AgCl<sub>2</sub> electrodes (Ambu, Glen Burnie, MD) were attached to the maternal abdomen (Figure 1). The electrodes were connected to the amplifier in a monopolar fashion with common reference and common mode rejection leads on the left side of the patient's abdomen, to reduce 60 Hz environmental noise. Electrode positions were modified slightly for each patient, as required by the location of the tocodynamometer and ultrasound fetal heart rate monitor. Impedance of each electrode was measured (as compared with the reference) (General Devices EIM-105 Prep-Check; General Devices, Ridgefield, NJ). Skin preparation was repeated as needed at each site until the

measured impedance was below 10 kΩ where possible.

The recorded signals were fed to a 4-channel, high-resolution, low-noise unipolar amplifier. All 4 signals were measured with respect to a reference electrode. The amplifier design used driven right-leg circuitry to reduce common mode noise between the patient and the amplifier common. The amplifier 3 dB bandwidth was 0.05–250 Hz.

Data from each patient included a uterine activity channel from 2 maternal-fetal monitors (Corometrics; GE Medical Systems, Waukesha, WI) sampled at 8 Hz with an 8 bit resolution. These cardiocographs reported the Toco- and IUPC-derived contraction curves. The data also included output from 4 abdominal EHG channels sampled at 500 Hz with a 24 bit resolution.

To produce the EHG contraction curve, the 4 EHG signals were downsampled at 20 Hz, band pass filtered between 0.2 and 1 Hz to eliminate low- and high-frequency noise while preserving the main contraction power, and combined based on their signal-to-noise ratio. The output was then downsampled at 8 Hz and normalized to scale the signal from 0 to 100 units. All 3 uterine activity curves were displayed in real time to the data collector and stored electronically for subsequent analysis.

Contraction location was statistically computed. Contractions were rejected if duration was less than 45 seconds or longer than 180 seconds, amplitude less than 10 mm Hg (IUPC) or less than 10 units (Toco and EHG), and amplitude less than 40% or greater than 350% of the median of the last 10 contractions. To evaluate contraction consistency, we used a modification of the Contractions Consistency Index (CCI) defined by Jezewski et al<sup>4</sup> to compare EHG and Toco each to the gold standard, IUPC:

$$CCI = \frac{N_C}{\frac{1}{2}(N_T + N_E)}$$

where  $N_T$  is the number of contractions detected by IUPC,  $N_E$  is the number detected in the EHG or Toco signal, and  $N_C$

is the number of consistent contractions. Contractions were consistent when the peak of a contraction from the EHG or Toco signal was within  $\pm 30$  seconds of the peak of a contraction from the IUPC signal.

In addition to the overall CCI score, a running window CCI (15 minutes) was also computed for each combination of patient and device to determine the percentage of time the CCI was below 0.75 during data collection. Recordings below that threshold were considered noisy with increased time of low contraction consistency between methods.

Descriptive statistics and graphical methods were used to summarize subject characteristics and examine variable distributions. Performance characteristics including CCI, positive predictive value (PPV; true positives/[true positives + false positives]) and sensitivity (true positives/[true positives + false negatives]) were calculated for each participant. True positives are consistent contractions, false positives are contractions detected in Toco/EHG curve and not in IUPC curve, and false negatives are contractions detected in IUPC and not in Toco/EHG curve.

The EHG and Toco means were compared using 2-sided paired Student *t* tests. Contraction timing (peak, onset, offset, and duration) were also compared in the manner described in the previous text. Pearson correlation coefficient estimates were used to examine the relationship between BMI and CCI, PPV, and sensitivity. We also used 2-sided, 2-sample Student *t* tests to compare obese women (BMI  $>35$  kg/m<sup>2</sup>) with nonobese women for CCI, percentage CCI less than 0.75, correlation, PPV, and sensitivity. With a sample size of 59, there is sufficient power (0.80) to detect a 0.37 SD unit difference between means and a correlation of 0.35 or larger. A *P*  $<$  .05 was considered statistically significant. Analyses were performed using SAS (version 9.1), and R (version 2.12.0) (SAS Institute, Cary, NC).

## RESULTS

A total of 73 patients were enrolled in the study. Of these, 14 were excluded be-

**TABLE 1**  
**Subject characteristics (n = 59)**

Variable	Mean	SD	Range
Body weight, lb	204.6	57.6	122–384
BMI	34.3	8.6	23.1–61.4
Gestational age	39	1.7	33–42
Duration of monitoring, min	137	65.8	48.6–345.9
IUPC contractions	38.3	19.2	8–95
EHG contractions	37.7	19.6	8–94
Toco contractions	26.4	16.0	1–64

BMI, body mass index; EHG, electrohysterography; IUPC, intrauterine pressure catheter; Toco, tocodynamometry.

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cause of the following: IUPC never functioned (n = 5), Toco failed (n = 2), the amplifier battery was problematic (n = 2), practitioners failed to follow protocol with electrode selection/placement (n = 2), duration of monitoring was inadequate (n = 2), and a period in which both Toco and IUPC functioned simultaneously was lacking. The mean BMI of the excluded group was 34.4 kg/m<sup>2</sup>, similar to the included group.

Demographic characteristics of the subjects are listed in Table 1. Thirty-nine of 59 delivered vaginally (66%). Table 2 displays the summary statistics for EHG and Toco, each compared with the gold standard, IUPC. Significant differences were identified between the 2 techniques for most of the variables under study. The EHG technique identified a higher number of consistent contractions and

had a higher CCI (EHG mean, 0.88; 95% confidence interval [CI], 0.83–0.92) than the Toco (mean of 0.69; 95% CI 0.61–0.76; *P*  $<$  .0001). Correspondingly, the percentage of time the CCI was less than 0.75 differed significantly between the 2 methods, occurring an average of 17% (95% CI, 10–24), with EHG compared with 46% (95% CI, 37–55) with Toco (*P* = .0001). Waveform matching, as quantified by correlation, was superior with EHG, resulting in a mean correlation of 0.62 (95% CI, 0.56–0.68) compared with 0.38 (95% CI, 0.30–0.45) for Toco (*P*  $<$  .0001). PPV did not differ significantly for the 2 methods (EHG mean, 0.89; 95% CI, 0.85–0.92, Toco mean, 0.86; 95% CI, 0.81–0.92; *P* = .37). Sensitivity was significantly higher for EHG (*P*  $<$  .0001).

**TABLE 2**  
**Comparison of operating characteristics for contraction detection comparing EHG with IUPC and Toco vs IUPC (n = 59)**

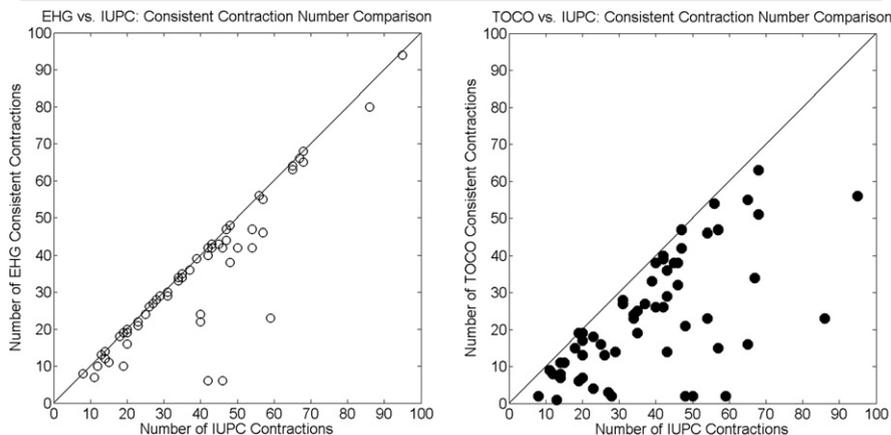
Variable	EHG vs IUPC		Toco vs IUPC		Difference		<i>P</i> value <sup>a</sup>
	Mean	SD	Mean	SD	Mean	SD	
Consistent CTX	33.8	19.4	23.5	16.2	10.4	16.3	$<$ .0001
CCI	0.88	0.17	0.69	0.27	0.19	0.33	$<$ .0001
CCI $<$ 0.75, %	16.7	26.7	46.1	34.0	–29.4	44.2	.0001
Correlation	0.62	0.24	0.38	0.28	0.25	0.35	$<$ .0001
PPV	0.89	0.14	0.86	0.19	0.03	0.24	.37
Sensitivity	0.89	0.20	0.62	0.29	0.27	0.37	$<$ .0001

CCI, Contractions Consistency Index; CTX, contractions; EHG, electrohysterography; IUPC, intrauterine pressure catheter; PPV, positive predictive value; Toco, tocodynamometry.

<sup>a</sup> Two sided paired Student *t* test.

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**FIGURE 2**  
Plot of consistent contractions per patient for both methodologies EHG vs IUPC and Toco vs IUPC



Each dot corresponds to 1 subject. Those near the diagonal indicate the noninvasive method is equivalent to IUPC; those below the diagonal indicate superiority of IUPC.

EHG, electrohysterography; IUPC, intrauterine pressure catheter; Toco, tocodynamometry.

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Figure 2 shows the number of consistent contractions for each subject for EHG and Toco compared with the number of contractions detected in IUPC. Points on or near the diagonal represent good correlation with the gold standard.

Comparing contraction timing for women who had at least 4 consistent contractions with both noninvasive techniques (n = 52), Toco detected contractions at nearly the same time as IUPC (contraction delay mean across patients of  $-1.2 \pm 4.5$  seconds) and EHG was slightly delayed (contraction delay mean across patients of  $2.5 \pm 2.6$  seconds). A similar relationship was

observed for the detection of onset. Offset was nearly identical in all methods. Variability of offset detection (SD) was greater with Toco. As suggested by the reported differences, contraction duration was slightly less (4.5 seconds) with EHG relative to IUPC and slightly greater using Toco (1.7 seconds).

Pearson correlation coefficients were used to assess the relationship between BMI and performance characteristics (CCI, PPV, and sensitivity) of EHG and Toco. The results are displayed in Table 3. A significant negative correlation was detected for BMI and sensitivity as measured by Toco, indicating that higher BMI values correspond to less sensitive Toco results. A similar magnitude of correlation was estimated for EHG; however, this was of borderline statistical significance ( $P = .07$ ). These relationships are illustrated in Figure 3, including best linear fit lines for the 2 methods.

It is important to note the negative slope for both, corresponding to the negative correlations and indicating that sensitivity falls when BMI is higher. Table 4 displays the comparison of obese with nonobese women. There were no statistically significant differences be-

tween these groups for EHG considering CCI, percentage CCI less than 0.75, correlation, PPV, and sensitivity. This was not the case for Toco, which indicated significantly lowered sensitivity in obese subjects.

**COMMENT**

This study documents the superiority of EHG to Toco in uterine activity monitoring. Normal, spontaneous labor generally proceeds without intervention. In this setting, external electronic fetal monitoring documenting contraction frequency and fetal response to labor, generally suffices, and brief periods of signal dropout are of little concern. When labor is induced or augmented or fetal well-being is of concern (eg because of intrauterine growth restriction or maternal preeclampsia), signal quality rises in importance.<sup>5</sup>

The IUPC provides quantitative information regarding contraction intensity not available from the Toco. Use of EHG to infer intrauterine pressure remains an area of research with some promising results<sup>6,7</sup> but was not a goal of this study. In fact, the availability of IUPC data does not affect labor outcome.<sup>8-10</sup>

Recent EHG studies have documented the technology's utility in the diagnosis of preterm labor<sup>11-13</sup> and have compared EHG with Toco<sup>10,14,15</sup> and IUPC<sup>14,16</sup> for term labor. The primary strength of the current study is the simultaneous comparison of all 3 technologies in the labor setting. Using IUPC as the gold standard, our results confirm the superiority of EHG over Toco for uterine activity monitoring in laboring women, regardless of body habitus. CCI and sensitivity were higher for EHG compared with Toco, whereas PPV was similar. This suggests EHG is more reliable in terms of signal quality.

As noted in the introductory text, several research groups, including our own,<sup>14</sup> have identified obesity as a risk factor for failure of Toco monitoring. In the current study, CCI was affected by obesity for both noninvasive technologies, but for Toco it fell to 0.60 in this subgroup, compared with 0.82 for

**TABLE 3**  
Correlation coefficient estimates (n = 59)

Variable	EHG	Toco
CCI	-0.20 (0.13)	-0.23 (0.09)
PPV	-0.10 (0.44)	0.10 (0.43)
Sensitivity	-0.23 (0.07)	-0.26 (0.04)

Listed are Pearson correlation coefficient and P value of test for significant correlation.

BMI, body mass index; CCI, Contractions Consistency Index; EHG, electrohysterography; PPV, positive predictive value; Toco, tocodynamometry.

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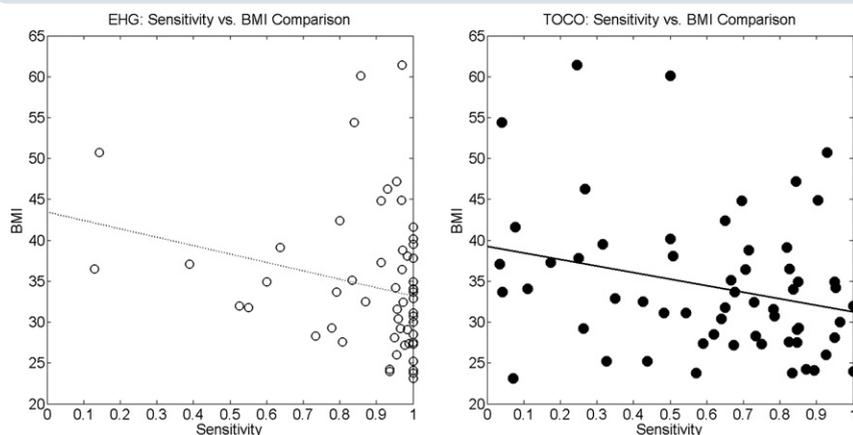
EHG ( $P = .03$ ). Similarly, the percentage time CCI less than 0.75 increased to more than half the monitoring time (56.0%) for Toco in obese parturients but remained less than one-quarter (24.2%) for EHG ( $P = .01$ ).

Adequate monitoring in the obese parturient has special importance, considering their increased risk for labor complications.<sup>17</sup> Ray et al<sup>1</sup> noted a 32% incidence of complications (postpartum hemorrhage, third-degree tears and extension of episiotomy, and shoulder dystocia) in obese patients vs 6% in controls. Even without such complications, obese patients undergo a longer duration of labor and have a higher incidence of cesarean delivery.<sup>18,19</sup>

The combination of longer labor, which entails more cervical examinations, a high rate of induction/augmentation, and difficult noninvasive monitoring requiring the use of IUPC and/or fetal scalp electrode, places obese parturients at significantly greater risk of developing infection.<sup>17</sup> Once infected, dysfunctional uterine contractility further prolongs labor and increases the cesarean risk.<sup>20</sup> Furthermore, chorioamnionitis is associated with increased risks for uterine atony, maternal blood transfusion, septic pelvic thrombophlebitis and pelvic abscess as well as poor neonatal outcome.<sup>21</sup> EHG monitoring for uterine activity may lessen these complications by reducing the need for intra-uterine monitoring and by providing reliable contraction information early in labor that may reduce the need for repetitive cervical examinations and perhaps enhance the safe titration of oxytocin.

Although there is little reason to expect variable performance by location, a weakness of this study is its performance at a single site. Another potential weakness is that subjects underwent IUPC placement for obstetric indication. Although not specifically documented by the obstetricians, often this indication is an inadequate Toco tracing, thereby potentially biasing our results in favor of EHG yet also confirming its superiority in these patients.

**FIGURE 3**  
**Plot of sensitivity vs BMI**



Open dots and dashed line (best linear fit) represent EHG observations; filled dots and solid line represent Toco observations. As BMI increases, sensitivity decreases for both technologies; however, the relationship is steeper for Toco.

BMI, body mass index; EHG, electrohysterography; Toco, tocodynamometry.

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Important in all discussions of novel technology is the cost-benefit ratio. Benefits such as reduced nursing interventions for Toco failures, improved patient comfort, and fewer IUPC-induced infectious complications are difficult to quantify. The recurring physical cost of Toco is in the occasional replacement of the sensors and the inexpensive disposable belts. An IUPC certainly has increased per-patient acquisition costs. EHG sensors consist primarily of electrodes and therefore may be priced between the cost of the Toco and IUPC. A design goal

would include interacting directly with existing electronic fetal monitoring systems to ease the cost of adoption. Training for nurses should be minimal and consist only of appropriate skin preparation and electrode application.

This study suggests that EHG is superior to Toco for noninvasive uterine activity monitoring. An ongoing study will evaluate whether this translates to superior clinical use: clinicians and nurses will evaluate fetal heart rate/uterine activity strips from all 3 technologies and compare interpretability.

**TABLE 4**  
**Comparison of obese and nonobese women**

Variable	Toco			EHG		
	Nonobese (n = 38)	Obese (n = 21)	P value	Nonobese (n = 38)	Obese (n = 21)	P value
CCI	0.74 (0.25)	0.60 (0.30)	.06	0.91 (0.11)	0.82 (0.24)	.11
CCI <0.75, %	40.7 (32.2)	56.0 (35.6)	.09	12.6 (19.1)	24.2 (36.1)	.11
Correlation	0.41 (0.28)	0.32 (0.29)	.25	0.65 (0.22)	0.57 (0.26)	.22
PPV	0.85 (0.20)	0.88 (0.18)	.51	0.91 (0.11)	0.85 (0.19)	.22
Sensitivity	0.67 (0.26)	0.51 (0.30)	.03	0.93 (0.13)	0.82 (0.27)	.10

Listed are mean (SD) and 2 sample, 2-sided Student t test P value.

CCI, Contractions Consistency Index; EHG, electrohysterography; PPV, positive predictive value; Toco, tocodynamometry.

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