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Fetal heart rate monitoring: from Doppler to computerized analysis

Ji Young Kwon, In Yang Park

Department of Obstetrics and Gynecology, The Catholic University of Korea College of Medicine, Seoul, Korea

The monitoring of fetal heart rate (FHR) status is an important method to check well-being of the baby during labor. Since the electronic FHR monitoring was introduced 40 years ago, it has been expected to be an innovative screening test to detect fetuses who are becoming hypoxic and who may benefit from cesarean delivery or operative vaginal delivery. However, several randomized controlled trials have failed to prove that electronic FHR monitoring had any benefit of reducing the perinatal mortality and morbidity. Also it is now clear that the FHR monitoring had high intra- and inter-observer disagreements and increased the rate of cesarean delivery. Despite such limitations, the FHR monitoring is still one of the most important obstetric procedures in clinical practice, and the cardiotocogram is the most-used equipment. To supplement cardiotocogram, new methods of computerized FHR analysis and electrocardiogram have been developed, and several clinical researches have been currently performed. Computerized equipment makes us to analyze beat-to-beat variability and short term heart rate patterns. Furthermore, researches about multiparameters of FHR variability will be ongoing.

Keywords: Cardiotocography; Electrocardiography; Fetal heart rate; Monitoring; Perinatal mortality

Introduction

Fetal heart rate (FHR) monitoring is one of the most important procedures for preventing perinatal morbidity and mortality in the field of obstetrics. However, the electronic fetal monitoring during labor has been consistently doubted with respect to its efficacy. This is because it appeared to increase the rate of caesarian section and operative delivery without any substantial reduction of perinatal morbidity [1-5], and there is high intra- and inter-observer disagreement due to visual analysis of FHR tracings [6-8]. Despite such problems, the FHR monitoring is continuously used for pregnant women during labor by most obstetricians [9], and such widespread use of the FHR monitoring is also observed in Korea. Thus, at the moment, a research based clarification is necessary about merits and problems with the FHR monitoring, and false positive and negative rates when it is used as a screening method for low risk pregnancy.

Therefore, this paper will take a look at the screening validity of cardiotocogram (CTG), which is the most widely used for screening of compromised fetuses during labor. Also, it will introduce other various FHR monitoring methods designed for compensation of CTG, and the most recent advances in the field.

Background of FHR monitoring

When the FHR monitoring was introduced 40 years ago, this developed medical technology was expected to significantly reduce perinatal morbidity and mortality, such as fetal death

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Corresponding author: In Yang Park
Department of Obstetrics and Gynecology, The Catholic University of Korea College of Medicine, 222 Banpo-daero, Seocho-gu, Seoul 06591, Korea
Tel: +82-2-2258-2813 Fax: +82-2-595-1549
E-mail: oooooobbbbb@catholic.ac.kr
http://orcid.org/0000-0002-9458-2886

or cerebral palsy. The fetal brain controls the FHR in terms of sympathetic and parasympathetic forces [10]. Thus, under a hypoxic fetal condition, the sympathovagal balance of fetuses suffered several changes, and in response to this, FHR variability showed different pattern compared with those under normal condition [11]. With this background, the FHR monitoring came to be used to determine whether fetuses are well oxygenated. The FHR monitoring can be undertaken intermittently using a hand-held Doppler device. Intermittent auscultation was a main method in FHR monitoring before CTG was used. Fifteen minutes is recommended as a proper frequency for auscultation during labor and at least 5 minutes for auscultation during the second stage of labor [12]. For continuous monitoring, a CTG is a popular method. CTG is an equipment with which the baby's FHR and the mother's uterine contraction can be recorded electronically on a paper. The FHR is acquired using an ultrasound transducer and the uterine contraction was acquired by pressure transducer. It is also possible to perform FHR monitoring by attaching a scalp electrode directly to the presenting part, the fetal head, which is possible after rupturing the amnion. This is known as internal fetal electrocardiogram monitoring. After the introduction of CTG, by the 2000s, the FHR monitoring was performed in more than 85% of labor rooms in the USA [9], and also CTG monitoring is used in most labor rooms nowadays in Korea.

FHR interpretation: a summary of the 2008 NICHD workshop

In 2008, National Institute of Child Health and Human Development (NICHD) research Planning Workshop made recommendations for standard classification system for FHR tracing [2]. The workshop recommended that a full description of a FHR tracing including baseline rate, baseline variability, accelerations, decelerations, and changes or trends over time as well as a qualitative and quantitative description of uterine contractions. Also, a new categorization system to group FHR tracings into 3 categories was proposed [2,13].

Additionally, the workshop introduced, for the first time, 2 key statements regarding standardized FHR interpretation based on 2 components of a FHR tracing: "moderate FHR variability reliably predicts the absence of fetal metabolic acidemia at the time it is observed" and "the presence of FHR acceleration (either spontaneous or stimulated) reliably predicts the absence of fetal metabolic acidemia" [2,13]. In particular, the workshop clarified that the converse is not true. Minimize or absent FHR variability alone does not appear to predict the presence of fetal hypoxemia or metabolic acidemia and the absence of acceleration does not reliably predict fetal metabolic acidemia.

CTG monitoring for fetal assessment during labor

The basic purpose of continuous intrapartum CTG monitoring is to reduce fatal complications like perinatal death and neonatal hypoxic brain injuries. However, a Cochran review in 2013 confirmed that the continuous CTG monitoring had no significant merits against perinatal death [4]. This review performed a meta-analysis of 12 randomized controlled studies that have compared outcomes from a group of continuous CTG monitoring during labor and another group of intermittent auscultation with 33,681 women participating in the studies. The meta-analysis showed that there were no significant differences between the two groups in the indexes of the perinatal mortality (risk ratio [RR], 0.86; 95% confidence interval [CI], 0.59 to 1.24; n=33,513, 11 trials), the incidence of cerebral palsy (RR, 1.75; 95% CI, 0.84 to 3.63; n=13.252, 2 trials), and the incidence of cord blood acidosis. There were also no effects of improvement of newborn outcomes of continuous CTG monitoring observed in 6 studies that involved women at increased risk of complications [4].

For mothers in a condition in which adverse outcomes like meconium-stained amniotic fluids and preeclampsia, electronic FHR monitoring can clearly be an important method to determine the possibility of pregnancy maintenance. However, it is the case that the CTG monitoring, which should be employed for screening newborns with adverse outcomes from asymptomatic women, is widely used without verification of its efficacy. Grimes and Peipert investigated the poor predictive value of CTG monitoring thoroughly [14]. According to their report [14], given that the sensitivity of the electronic FHR monitoring to the prediction of fetal death is 57% and its specificity 69% [15], its positive predictive value for fetal death with the very low prevalence, 50 per 100,000 [16] is zero percent. On the other hand, its negative predictive value reaches 100%. Such a phenomenon is an inevitable limitation of the screening test of conditions with very a low prevalence like fetal

death. It is because too many false-positive findings should be undergone for just a very few true-positive results. In the case of another serious averse outcome, cerebral palsy, the positive predictive value of the electronic FHR monitoring is still close to zero percent though its prevalence, 2 per 1,000 [17], is higher than fetal death. Only when fetal acidemia is a target adverse outcome, a positive predictive value of 37% could be achieved [18]. However, this study had a weakness in that it sets up high criteria for fetal acidemia including an umbilical cord arterial pH of 7.15 and an incidence rate of 10%. The clinical trend is to set up criteria for pathologic fetal acidemia at umbilical cord arterial pH values lower than 7.0 or 7.05 [19].

The high false positive rate of the elective FHR monitoring had after all caused unnecessary interventions. According to Cochran analysis in 2013 [4], the group of the continuous CTG monitoring had a significantly increase rate of caesarian section than the group of intermittent auscultation (average RR, 1.63; 95% CI, 1.29 to 2.07; 18,861 women, 11 trials). Also, the continuous CTG is related with increased instrumental vaginal birth (average RR, 1.15; 95% CI, 1.01 o 1.33; 18,615 women, 10 trials). Given that the increased rate of caesarean section was after all due to increase of cesarean section with an indication of non-reassuring FHR, the introduction of CTG monitoring seems to be responsible for the adverse effect on modern obstetrics.

Obstetricians' opinions of intrapartum fetal monitoring

Although there have been several reports from recent research that the electronic FHR monitoring has no benefits but rather increases the rate of cesarean section, it is continuously widely used in actual clinical practices. According to some questionnaire surveys on obstetricians about FHR monitoring use, Obstetricians appear to use the CTG monitoring because the trace provides a hard copy 'proof' that the baby is not compromised whilst in their care [20]. That is to say, the obstetricians greatly depend on the CTG monitoring as they believe that it will protect them when they are faced with severe criticisms and legal actions in some cases of birth of compromised baby. Also, it is because they feel that they need more time and human resources with intermittent auscultation than with CTG under busy clinical environments where medical staffs get more wanted over time [20]. After all, though the purpose of the introduction of CTG is to predict compromised fetuses, the greater reason why it is actually used clinically is that the negative predictive ability of the FHR monitoring that can reassure medical staffs and pregnant women that there are no problems with the fetus in the uterus.

Current guidelines

American College of Obstetricians and Gynecologists (ACOG) considered continuous FHR monitoring to be equivalent to intermittent auscultation during labor [2] and recommended the former in some high-risk pregnancies, both before and during labor [21,22]. The Royal College of Obstetricians and Gynecologists (RCOG) and the British National Institute of Clinical Excellence do not recommend the use of continuous FHR monitoring in low-risk pregnancies but recommend this in all high-risk pregnancies [23,24]. In regard to additional testes, the ACOG and the RCOG do not recommend fetal pulse oximetry in routine clinical practice [2,23]. Fetal blood sampling can be used as further test when FHR monitoring is unreassuring.

Other additional monitoring methods to predict compromised fetuses

Some other FHR monitoring methods have been developed and tried in clinical practice in order to make up the low screening validity of CTG. The most representative of them include computerized FHR analysis [25,26] fetal scalp blood sampling for pH or lactate estimation [27] and fetal electrocardiogram (ECG) monitoring [28,29].

The poor inter- and intra-observer reliabilities in the interpretation of FHR tracings have been known as one of the major drawbacks of the CTG monitoring [2,6,7]. For example, when 4 obstetricians examine 50 CTGs, the agreement was reported as only 22% of the cases [30]. The visual interpretation of CTG traces seems to be a major cause. Computerized CTG is a method to analyze FHR patterns in terms of a computer algorithm to improve CTG interpretation by making up poor inter and intra-observer. However, precise analysis with computerized CTG also appeared not to be helpful to improve perinatal outcomes.

Fetal scalp sampling, as an adjunctive test along with CTG, may reduce unnecessary interventions without jeopardizing

fetal outcomes. Cesarean rates from studies comparing CTG with intermittent auscultation were higher in cases without fetal scalp sampling (RR, 1.79; 95% CI, 1.41 to 2.27) than in cases with (RR, 1.26; 95% CI, 1.05 to 1.51) [31]. However, to analysis pH in fetal scalp blood, a relatively large amount of blood (30 to 50 μL) was necessary and sampling failure rate of 11% to 20% have been reported. So Lactate analysis has been attended because of smaller amount of sampling (5 μL) and fewer failure rate than pH analysis. However, scalp sampling has weakness in that it is an uncomfortable procedure for the mother and must require stab incision on the fetal scalp [27].

To address these challenges in intrapartum fetal monitoring, technology has been developed to monitor the fetal ECG waveform during labor in the 1990s. FHR obtained from an electrode clipped into the baby's scalp can provide information of fetal ECG [28]. The fetal ECG, like the adult ECG, display P, QRS, and T wave corresponding to electrical events in the heart during each beat. The most recent Cochran review [29], including 6 trials (16,295 women) showed that in comparison to continuous electronic FHR monitoring alone, the use of adjunctive ST waveform analysis made no significant difference to primary outcomes: birth by cesarean section (RR, 0.99; 95 % CI, 0.91 to 1.08), the number of babies with severe metabolic acidosis at birth (RR, 0.78; 95% CI, 0.44 to 1.37), or babies with neonatal encephalopathy (RR, 0.54; 95% CI, 0.24 to 1.25) however, there were fewer operative vaginal deliveries (RR, 0.89; 95% CI, 0.81 to 0.98) and admission to special care unit (RR, 0.89; 95% CI, 0.81 to 0.99) [29]. A recent large multicenter randomized trial of fetal ECG ST-segment analysis also did not improve perinatal outcomes such as neonatal death, fetal death, low Apgar score at 5 minutes, intubation at delivery and neonatal encephalopathy or decrease cesarean section [31]. Use of fetal ECG analysis rather than CTG can be a little helpful to improvement of labor prognosis in continuous electronic FHR monitoring during labor. However, even with such a merit, the disadvantage of having to use an internal scalp electrode, after membrane rupture, for ECG waveform recordings should be considered.

Computerized fetal heart beat analysis

Recent research efforts have focused on computerized interpretation of electronic FHR tracking and specific components of electronic FHR tracings that may be more useful such as multiparameter analaysis of FHR variability. The parameters assessed on FHR signals included time domain parameters, frequency domain parameters and the complexity parameters [32]. FHR values can highly oscillate in time. Therefore, FHR variation contains information on the neural events controlling fetal heart. For example, spectral analysis determines the energy in specific frequency components of heart rate variability [33]. Low frequency range is related to modulation of the sympathetic and parasympathetic nervous systems, and the high frequency ranges is related to parasympathetic modulation [34]. Several studies presented that the spectral power of FHR variability are related to fetal acidemia during labor [35,36]. Additionally, Entropy analysis of heart rate that measures the correction and persistence of a signal is a nonlinear mathematical approach to quantify the irregularity and complexity of a system [37]. Using the complexity parameters including approximate entropy (ApEn), sample entropy, multiscale entropy, several studies presented the specific change according the fetal conditions [38]. Most updated method of FHR analysis is entropy analysis of FHR. Generally, activities of none biological system go to stabilization state, but the activity of FHR goes to unstable state because the fetus is biologic system. If some unknown causes make fetus distress state, the activity of FHR is changed to low entropy state. ApEn quantifies the complexity of FHR variability. Low ApEn values correspond to lower complexity while higher ApEn indicates higher complexity [39]. All mathematical equations have been described in detail elsewhere [40].

Conclusion

At the moment, after 10 years that have seen widespread use of CTG in clinical practices, limitations of FHR monitoring have been revealed and novel FHR monitoring methods have been presented to restore such problems. Several studies showed that CTG increases caesarean sections without being able to reduce catastrophic perinatal events and to prevent cases of cerebral palsy, but to the contrary, in clinical practices, it is expected to continue to be used continuously for the purpose of the reassurance that there are no problems with the baby at least during monitoring. Thus, additional FHR monitoring methods need to be developed that can reduce the false positive rate for prediction of compromised babies. In recent

future, the adjunctive techniques such as fetal electrocardiogram analysis and computerized FHR interpretation system may come into wide use. In addition, researches that apply multiparameters of FHR variability for screening of fetal well-being will be ongoing.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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