

Development of a New Non-Invasive System for Fetal Hypoxia Diagnosis

J Lee¹, SP Cho², KJ Lee^{2,3}

¹Korea Institute of Oriental Medicine, Daejeon, Korea

²Yonsei University, Wonju, Korea

³Center for Emergency Medical Informatics, Seoul, Korea

Abstract

In this study, we have developed a new non-invasive system for fetal hypoxia diagnosis which provides systolic time interval (STI) parameters on the basis of analysis of electrical and mechanical heart activity together. For this we have worked on 1) the proper lead system for the acquisition of abdominal electrocardiogram (ECG), 2) the independent component analysis based signal processing and fetal ECG (FECG) separation, 3) the development of a hardware which consists of an abdominal ECG amplifying module and an ultrasound module and 4) the detection of characteristic points of FECG and Doppler signal and the extraction of diagnostic parameters. The developed system was evaluated by the clinical experiments in which 33 subjects were participated. The acquired STI by the system were distributed within the ranges from the well-established invasive results of other researchers. From this, we can conclude that the developed non-invasive fetal hypoxia diagnosis system is useful.

1. Introduction

Diagnostics of unborn baby is mainly aimed detection of occurrence of intrauterine hypoxia. Consequences resulting from fetal hypoxia appear in its heart activity [1]. In today perinatal medicine, non-invasive cardiotocography (CTG) is commonly used. A CTG is a record of the fetal heart rate (FHR) measured from a transducer on the abdomen. In addition to the fetal heart rate another transducer measures the uterine contractions over the fundus. A CTG makes possible the simultaneous observation of fetal heart rate. However, even with the high specificity, the CTG monitor has the low sensitivity [2]. There is also a method that uses systolic time interval (STI) which can be calculated with an invasively measured fetal electrocardiogram (FECG) and a Doppler shift of ultrasound beam reflected from moving valves of fetal heart. Even though it can provide high diagnostic sensitivity, it can not apply until the occurrence of uterine rupture.

In this paper, we propose a new non-invasive system

for fetal hypoxia diagnosis which provides STI parameters on the basis of analysis of electrical and mechanical heart activity together.

2. Methods

2.1. Electromechanical STI

Fig. 1 depicts the electrical and mechanical events that are occurring sequentially during one cardiac cycle. The electrical events include the P wave, QRS complex, ST segment, and T wave. The onset of the Q wave is usually used as a reference point for various measurements. The important mechanical events are the cardiac valvular motions. An interval between the Q wave on ECG and any mechanical event is defined as an electromechanical systolic time interval (STI). In Fig. 1, a, b, c, and d denotes the pre-ejection period (PEP), isovolumic contraction time (ICT), ventricular ejection time (VET), and electromechanical latent time (EMLT), respectively [3]. PEP, the useful diagnostic parameter of fetal hypoxia, can be calculated by inserting the scalp electrode and measuring the FECG only when the maternal amniotic membrane was ruptured during the end of the period of maternity [4]. If the FECG can be measured non-invasively, not only the fetal hypoxia can be monitored during the entire period of maternity but also the danger of invasive method can be avoided.

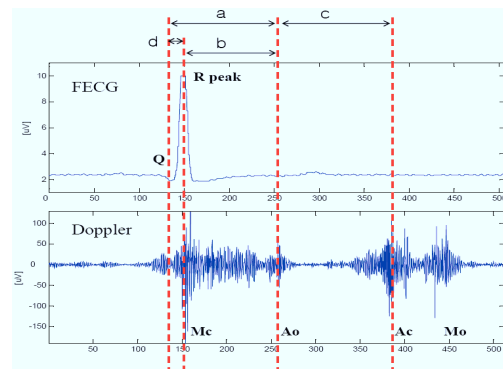


Figure 1. Electrical, mechanical events and STIs occurring during one cardiac cycle

2.2. Detection of electrical event

In this paper, we measured the 6-channel abdominal ECG and separated the FECG from abdominal ECG.

There is no approval standard of electrode position for non-invasive measurement of the FECG from abdominal ECG. Some lead systems were adopted for measuring the FECG, but the possibilities of measuring the FECG were low 30~60%. In this paper, we adopted the changeable lead system according to the position of fetus (LOT, ROT, ROP, LOP, ROA, LOA; L = left, R = right, O = occiput, A = anterior, T = transverse, P = posterior).

To separate the FECG from the maternal and other noise, we used the FastICA [5]. Fig. 2 shows the example of estimation of 6 independent components (ICs) from 6-channel abdominal ECG. To find out the FECG from these ICs, the autocorrelation function was applied. The autocorrelation function of IC ranging 2~4Hz (120~240bpm) was selected.

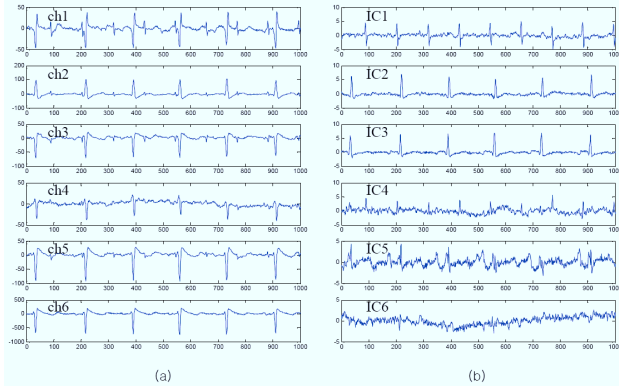


Figure 2. An example of extracted ICs from 6-channel abdominal ECG; (a) The 6-channel abdominal ECG; (b) 6 extracted ICs from (a) by ICA

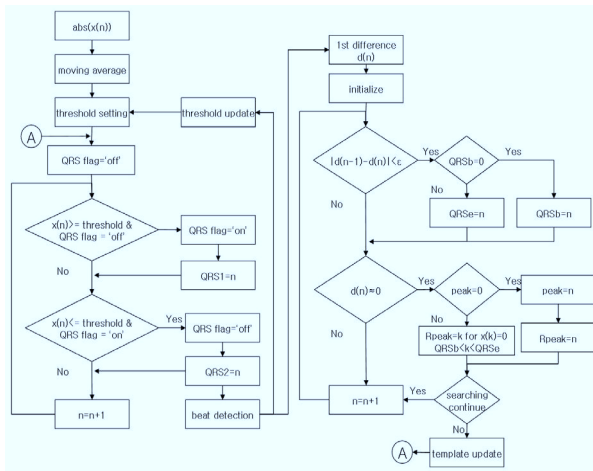


Figure 3. Flowchart for the parameter calculation of FECG

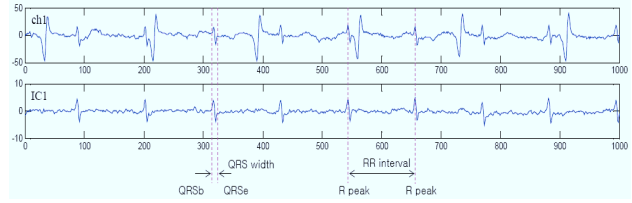


Figure 4. Comparison of extracted parameters from abdominal ECG and IC corresponding to FECG

Fig. 3 shows flow chart for the parameters calculation of FECG. At the first, the absolute value of selected IC was calculated and moving averaged with 52msec width (mean width of fetal QRS complex) and then the beat detection process was accomplished [6]. After the beat detection, the starting and ending point of QRS complex and R-peak were detected. As shown in Fig. 3, the threshold and template were updated at every beat detection procedure. Fig. 4 shows the abdominal ECG (ch1), FECG (IC1) and the result of parameters measured from FECG.

2.3. Detection of mechanical events

To calculate the STIs, the mechanical events using Doppler shift of ultrasound beam reflected from moving valves of fetal heart are necessary along with the parameters from FECG related with the electrical activity of fetal heart.

The closing and opening of mitral and semilunar valve (Mc, Mo, Ac and Ao) were detected using the moving average filtered Doppler signal. Fig. 5 shows the moving average filtered Doppler signal during one heart beat for three different window sizes, 800, 200 and 100, respectively. As shown in Fig. 5, 800-point moving average filter (MA800) can be used for detecting a period of one beat, and 200-point moving average filter (MA200) can be used for separating into two segments. First segment include Mc, Ao and second segment include Ac, Mo, respectively. 100-point moving average filter (MA100) can be used for detecting each event (Mc, Ao, Ac and Mo).

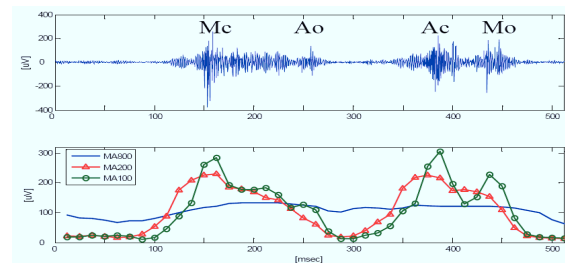


Figure 5. Comparison of Doppler signal and moving average filtered signals by 3 different window sizes

3. Experimental results and discussions

3.1. Hypoxia diagnostic system

The proposed system consists of abdominal ECG module, ultrasound module, MP150 (Biopac Systems, U.S.A.) and laptop PC. The MP150 was used to digitalize the ECG and Doppler signal. The ECG and Doppler signal were digitized with a frequency of 500Hz and 2000Hz, respectively and 16-bit resolution.

3.2. Data acquisition

The developed system was evaluated by the clinical experiment in which 33 healthy gravidas were participated and the clinical experiments were done in Wonju 21C obstetrics and gynecology (Korea), during 3 month, in 2005. The participants were 32~41 weeks pregnant and were prescribed the non-stress test (NST) by physician in which measuring the FHR during the resting state. The participants were divided into two groups. The changeable lead system was applied to the first group (20 participants) and general lead system that did not consider the fetus position was applied to the second group (13 participants). For the first group, we could measure the FECG of 13 from 20 participants (65%). For the second group, we could measure the FECG of 3 from 13 participants (23%). The changeable lead system based on the fetus position was effective to measure the FECG.

3.3. Calculation of STIs

The STIs (EMLT, ICT, VET and PEP) were calculated for the successful measurement of FECG. Each STI can be derived by the following equation:

$$\begin{aligned}
 PET &= T_{A_s} - T_{Q_{onset}} \\
 ICT &= T_{A_s} - T_{M_c} \\
 VET &= T_{A_i} - T_{A_s} \\
 EMLT &= T_{M_c} - T_{Q_{onset}}
 \end{aligned}
 \tag{1}$$

The max, min and mean value of calculated STIs are shown in Fig. 6. The maximum, minimum, mean value and standard deviation of PEP, which is the most extensively studied STI and known as a sensitive indicator of myocardial performance, were 60msec, 77msec, 67msec and 5.23msec, respectively. The mean values and standard deviations of EMLT, ICT, VET and VET/PEP were 18.09ms (SD = 4.43), 49.23ms (SD = 4.77), 153ms (SD = 13.46), 0.41 (SD = 0.018). From these STIs, standard deviation of VET/PEP(x 100) had the lowest value, 1.87, compared to the other STIs (ICT=4.77, PEP=5.23, VET=13.46). This means that VET/PEP has the smallest change than other STIs of

normal fetus. It should be noted that VET/PEP is most possible parameter to estimate the fetal state based on the Charles' research (normal range of VET/PEP: 0.40-0.52, abnormal range: ≥ 0.9) [2].

3.4. Analysis

The best evaluation method is to compare the calculated STIs with invasively measured STIs from same subject. However, we compared the calculated STIs with the previous results of other researchers because of difficulty of practical comparison. Among the STIs PEP was selected. To compare the PEP, we used the normal ranges of invasive results of Bartling, Organ and Doig [7-10]. Fig. 7 shows the calculated PEP(*) and normal ranges of previous researchers. The upper and lower limit mean the range of 5~95% of Murata's PEP.

There were five subjects that had PEP exceeding the upper limit, but they were distributed within normal ranges of Bartling, Organ and Doig.

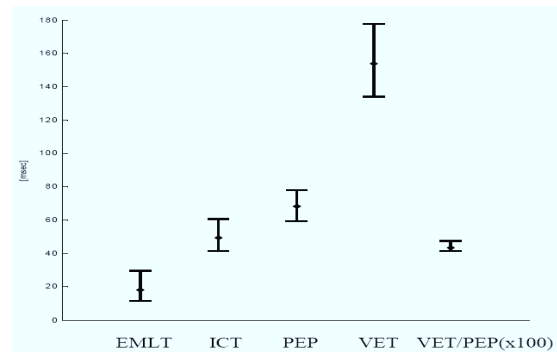


Figure 6. Statistical distributions of STIs

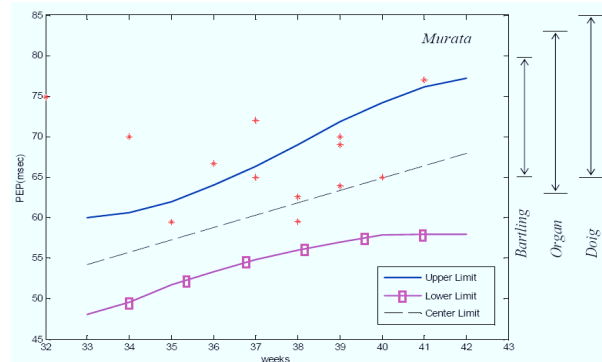


Figure 7. Results of clinical experiment and the comparison of its range with that of other researchers

4. Conclusions

We have developed a new non-invasive system for fetal hypoxia diagnosis which provides STI parameters on the basis of analysis of electrical and mechanical heart

activity together. Consequently, we suggested an effective lead system which for the acquisition of abdominal ECG by considering the fetal position. And, we found that the FECG was able to be separated successfully and the moving average technique was suitable for the Doppler signal. The acquired STIs from participants by the system were distributed within the ranges from the well-established invasive results of other researchers. The developed system showed the possibility of the non-invasive diagnosis for fetal hypoxia.

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Address for correspondence

Name: Prof. KJ Lee

Full postal address: 234, Maeji, Heungup, Wonju, Gangwon, 220-710, Korea

E-mail address: lkj5809@yonsei.ac.kr