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ECG Electrode Configuration to Extract Real Time FECG Signals

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Abstract

Monitoring fetal health early in pregnancy helps to avert possible fetal damage and even fetal death. Among various fetal monitoring techniques the invasive fetal scalp electrode method is the most accurate method at labor. However this method may cause risk to the baby if used for antepartum monitoring. The Non-invasive fetal ECG (NIFECG) is a simple and the next best method to extract fetal heart rate (FHR) before full term. NIFECG can extract the fetal morphology from the FECG signal which can aid in diagnosing fetal health ahead of delivery. This paper aims to locate the most optimum points to place the ECG electrodes on the maternal abdomen so as to get the best FECG signals. After reviewing few previous techniques, we proposed three schemes using a standard 12 lead ECG recorder. It was observed that the scheme 2 successfully displayed the average FHR as compared to the ultrasound report of a single subject. A further researching and experimental procedures are required in this abdominal ECG (aECG) placement electrode positioning schemes before a standardized electrode configuration which can be introduced in clinical practice

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1. Introduction

Fetal congenital heart defects may originate early in pregnancy although the baby may appear healthy at birth [1]. There is always an interest in the antepartum fetal monitoring which can provide the fetal's cardiac health efficiently

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in an automated way and at a lower cost. The FECG contains information of the cardiac defects which is embedded in the QRS morphology of the fetal cardiac signal such as the ST and QT changes, such that the derived FHR can indicate fetal distress [2]. This information is more accurate as compared to the sonographic methods [3,4]. Fetal monitoring analysis can also aid in averting possible irreversible neurological damage or even fetal death during labor [5]. Abnormal FHR patterns can possibly indicate decelerations, fetal asphyxia, fetal tachyarrhythmia and other related fetal health problems [6].

Fetal monitoring can be done using various methods such as echocardiography which is based on the standardized sonography and ultrasound method. Phonocardiography records the heart sounds and transforms it into electrical signals. Cardiotocography (normally refers to as CTG) measures the FHR along with the maternal uterine contractions [7]. Magnetocardiography (MCG) is a technique which uses devices such as SQUID to measure the magnetic fields of the heart signals. Although echocardiography is among the most commonly used technique today to record FHR, but MCG is considered to be accurate, however is difficult for ambulatory use and an expensive procedure [8]. FECG is another technique which can be used to monitor fetal cardiac signals. This method can be invasive or non-invasive. In the former type, a fetal scalp electrode is used during labor to acquire accurate fetal ECG waveforms however this technique cannot be used for antepartum procedures as it can be a risk to the fetus [9]. The non-invasive technique utilizes ECG electrodes on the maternal abdomen surface to acquire aECG. The ultrasound technique although a non-invasive method, requires skilful handling and virtually records FHR, but is sensitive to fetal and maternal movements and can misinterpret required signals as noise [10]. The ultrasound method produces average value and moreover does not give fetal beat – to – beat heart rate variability [11]. This technique can sometimes be uncomfortable for mothers for long term monitoring. However, the non-invasive FECG technique is well preferred for long term FHR monitoring, gives beat-to-beat cardiac analysis at low power requirements and at a low cost [9]. The major drawback this method has is the low signal to noise ratio (SNR) because it contains maternal ECG (MECG) and other noise elements such as power line interference (PLI), low frequency noise due to baseline wander, Electromyogram (EMG), motion artifacts, noise due to surface electrodes, etc [12]. The advantages of Ultrasound and FECG together can be used in conjunction to monitor FHR. With advanced signal processing techniques and biomedical engineering research, the SNR of the FECG can be enhanced by carefully acquiring the aECG from the maternal abdomen along with the maternal thoracic as reference MECG. After using appropriate filtering techniques to remove the above noise elements, the Non-invasive FECG (NIFECG) can be obtained by efficient detection and extraction methods.

The extracted FECG from the aECG is very small, about 5 times less in amplitude compared to the MECG and is sometimes embedded in the noise signals [10]. The maximum amplitude for FECG can record $60 \mu\text{V}$ while the MECG ranges from 100 to $150 \mu\text{V}$ [9]. Although the frequency bandwidth range of the FECG is 0.05 – 100 Hz it interestingly overlaps with the MECG [5]. While FECG has been estimated to be $\frac{1}{4}$ of the total signal energy [9], the normal FHR ranges from 120 – 140 bpm and comparatively the MHR ranges from 70 – 100 bpm [12]. Fig. 1 illustrates the invasive scalp FECG along with one of the aECG channels from the PhysioNetadfecgdb database [13,14] while Fig 2 shows the two maternal thoracic channels of the PhysioNetnifecgdb record [15] along with 3 to 4 channels of the non-invasive electrode signals placed on the mothers abdomen. The above signals clearly show the amplitude and frequency of the maternal and fetal signals.

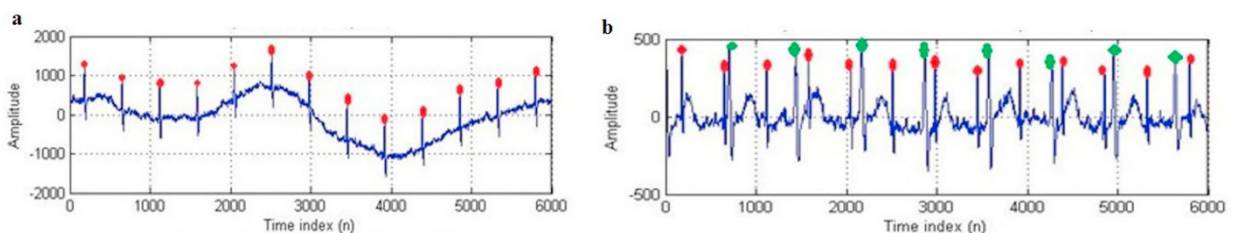


Fig. 1. a) Invasive fetal scalp ECG (the red dots indicate the fetal R peaks); b) One of the abdominal channel from the PhysioNetadfecgdb database [14] (the green dots indicate the maternal R peaks). The FECG signal amplitude in this database is relatively good.

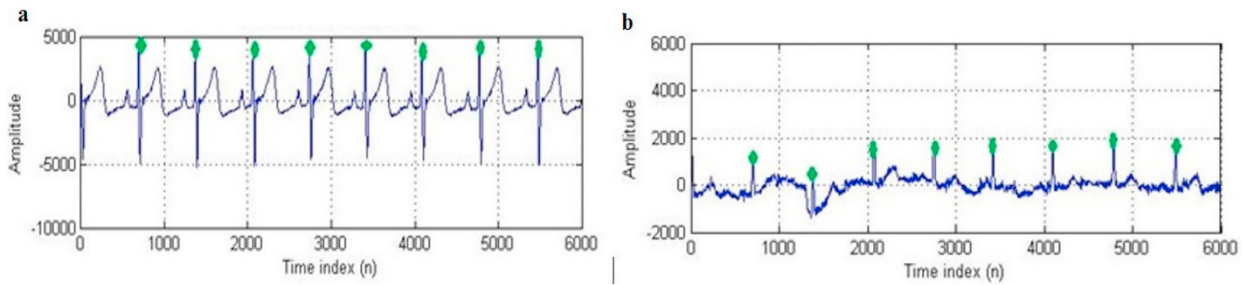


Fig. 2. a) Maternal thoracic ECG (the green dots indicate the maternal R peaks); b) One of the abdominal channel from the PhysioNetnifecgdb database [15]. The FECG and noise amplitude is very small compared to MECG signal.

1.1. Challenges in extracting NIFECG

As seen in the Fig.1 the SNR of the NIFECG is quite low as compared to the MECG due to the size of the fetal heart and the conducting media between the fetal heart and the surface electrodes [5]. The maternal skin and muscle tissue acts as a volume conductor whose conductivity changes with the gestation age [1]. A poor conductivity is displayed by the vernixcaseosa during the 28th to 32nd gestation week, wherein the NIFECG is negligible. However the recording is possible well after the 37th gestational week as the vernixcaseosa dissolves [16]. Another concern is the fetal movement based on the gestational age which is constantly changing from the 1st trimester to labour. The FECG signal improves as the gestational age increases due to the fetal amplitude and frequency increases thereby increases the signal to noise ratio (SNR) [17]. Another challenge for the biomedical signal processing engineers and researchers is to avoid confusion between FHR and MHR computation after extracting the aECG signal. Today the biggest boon is to derive significant fetal morphological parameters from the NIFECG signals to extract various fetal parameters such as QRS morphology, shortening of QT, ST intervals [18] etc, that will enable fetal diagnosis at an early stage in pregnancy. In the market there are already various FHR monitors which detect FHR recordings such as, Monica AN24 monitor, Nottingham, UK, Meridian M100/M1000 monitors from MindChild Medical, Nemo Healthcare, Netherlands and PregSense, Israel [1]. The motivation to research and to build efficient FHR monitors to provide a complete set of fetal information to the clinician has not ended. This area of biomedical study is an ongoing process among many researchers today.

1.2. Electrode placement for NIFECG

A few pointers were considered before setting up the configuration of the electrode placement over the surface of the maternal's abdomen. An ultrasound of the maternal abdomen can be done to investigate the presentation of the fetus in the womb as the position of the fetus varies with the gestation age right up to labor. Knowing the position of the fetus would enhance the chances of extracting better FECG waveforms. Care should be taken that at least one strong maternal thoracic signal can be recorded from the mother as a reference MECG signal to be used for certain extraction algorithms synced with other aECG channels. Abdominal ECG signals from one channel to multichannel can be used as per the requirement for the fetal detection techniques such as ANFIS [19,20], ICA [21] etc. The aECG database can be sampled at 1 KHz with an ADC resolution of 16 bits and the recording time can range from 18 minutes (antepartum) to at least 30 minutes (at labor). These durations will be able to capture the various fetal conditions especially as the FECG are quasiperiodic in nature and the fetus is constantly moving in the uterus during labor. The aECG recordings can be taken from a group of subjects over a known gestation period starting at 20th week and follow up till labor. These measurements can be compared with the patient's clinical information using other methods such as CTG and ultrasound.

2. Methodology

The procedure used here is to locate bipolar ECG electrodes on the surface of the pregnant mother's abdomen. The concept used here is based on the single dipole vector described in [22]. The combination of all cardiac vectors emitting from the maternal or fetal heart is considered to be a single source dipole vector represented by P_m and P_f respectively. The vector r is the distance between the two source vectors P_m and P_f as shown in the Fig 3. A good quality FECG signal largely depends upon the configuration and placement of the electrodes on the *mother's* abdomen. Although a set standard of the electrode configuration is not yet derived [18], few authors in this biomedical field proposed various procedures and measurements to derive good quality aECG signals.

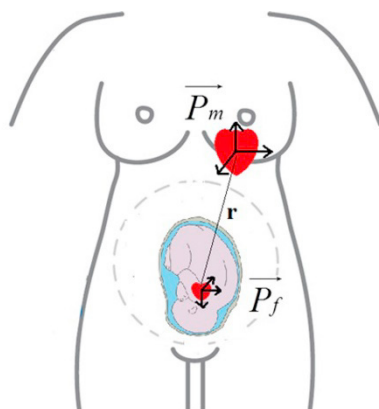


Fig. 3. Maternal and fetal dipole vector represented by P_m and P_f respectively. Vector r is the distance between the two source vectors P_m and P_f .

2.1 Existing electrode configurations

Some researchers would depend on prior knowledge of the position of the fetus using ultrasound, some would go by the normal position of the fetus as vertex (head down) which is at the end of the third trimester. Some authors would cover the entire abdomen area with electrodes so as to pick the maximum fetal cardiac signals or some would use a proper strategy to locate and place the ECG electrodes. Configurations by different authors are listed and reviewed in [18, 23] in Fig 4, where GND is considered as the inactive electrode representing common ground.

Type 1: [5 electrodes] The four active bipolar ECG electrodes are placed in the circular fashion keeping the reference electrode at the pubic area as shown in Fig 4a. This configuration is used by the fetal monitor device, Monica Healthcare Ltd AN24 (Nottingham, UK) [24].

Type 2: [8 electrodes] There are two configurations using 8 electrodes, in Fig 4b a triangular shape structure covers the lower area of the abdomen [22] while in Fig 4c, two smaller circles are used above and below the navel and at the lower part of the abdomen for better FECG and uterine measurements [25]. The aECG recordings were taken from 8 women at labor.

Type 3: [10 electrodes] The authors used three placement schemes in this configuration to record each measure for a duration of 24 seconds using the standard 12-lead ECG machine, made by Nihon Kohden Corporation [26]. In all the three schemes, six active electrodes were placed in a hexagonal structure keeping the navel at the centre with a radius of 10 cm as shown in Fig 4d. Two of the limb electrodes F and R were placed at the uterus fundus and pubic respectively for all the three schemes. The remaining two limb electrodes L and N (reference) were moved for the three schemes, namely (i) scheme 1: L = right flank; N = below the navel (ii) scheme 2: L = left flank; N = below the navel (iii) scheme 3: N = right flank; L = below the navel.

Type 4: [14 electrodes] The authors used AD Instruments, New Zealand to collect a 20 minute data from 10 different subjects aged between 21 to 33 and having gestational period between 20 to 28 weeks [27]. Channel 1 was

set for the thoracic reference MEEG while from the active electrodes 2 to 8 which are placed on the circumference, only 6 to 8 abdominal leads were used for fetal signal processing as seen in Fig 4e.

Type 5: [32 electrodes] The authors used MindChild Meridian fetal monitoring System, USA [28] which uses a configuration using 32 electrodes as shown in Fig.4f. The electrodes cover the entire abdomen, sides and back. Electrodes marked in blue show the corresponding good signal quality while active electrodes in red have low signal quality [29]. Although the coverage of the fetal cardiac signal is maximum the subjects may find it uncomfortable to use the electrode belt array for daily monitoring. In the case when a belt array of 72 electrodes is used for monitoring, the extracted information can be redundant and time consuming [30]. A smaller set of electrodes of 8 to 10 sensor electrodes is sufficient to obtain the required fetal information.

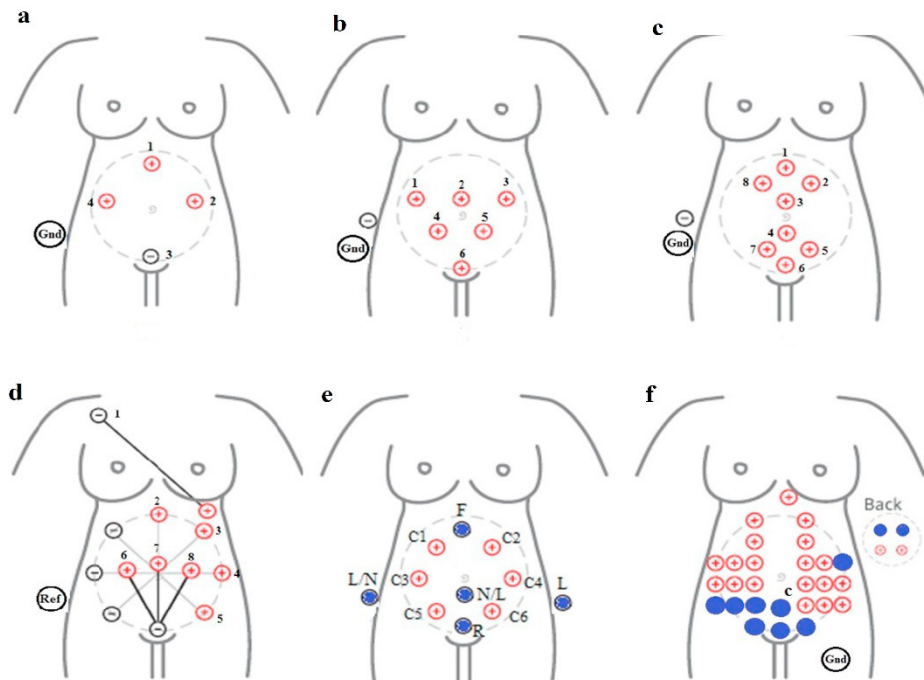


Fig. 4. Various electrode configurations used by authors [18,23] (a) Type 1: [5 electrodes] Monica Healthcare Ltd AN24 [24] (b) and (c) Type 2: [8 electrodes] [22,25] (d) Type 3: [10 electrodes] [26,33] (e) Type 4: [14 electrodes] [27] (f) Type 4: [32 electrodes] [29].

2.2 Our Proposed schemes

We proposed three schemes for the electrode placements using the standard 12-lead ECG machine by Kallows Engineering, Goa India [31]. This configuration is based on the lead configuration for a commercial 5 lead fetal ECG as per the IEC 60601-2-51 standard [32] wherein the right leg lead (black) is placed on the right thigh and the other four leads are arrayed around the fetus. With proper consent from the subject, it was reported that the young mother was 24 years old with the gestational age of 34 weeks, 5 days and as per the clinical impression: a live fetus in cephalic presentation. At the clinic, the nurses cleaned the abdominal skin with alcohol to avoid dry skin around the area where the surface electrodes would be placed. The removal of grease would further enhance the conductivity of the electrodes. We placed the limb leads around the fetus to get good strength differential leads (I, II and III) as well as placing four of the precordial leads whose voltages will be with respect to the spot we have labelled as WCT. Finally, we placed V5 and V6 on the mother's upper arms to get some strong maternal ECG references as seen in Fig 5a for scheme 1. We inverted this configuration for the scheme 2 (so that RA, LA are shifted down and LL is at the top) for the difference in fetus orientation (head up vs. head down). The scheme 3 is similar to scheme 2 except that the V5 and V6 are placed at the maternal thoracic area to compare the MEEG signals from both the schemes. An eighteen minute recording was done for each of the electrode positions shown in Fig 5.

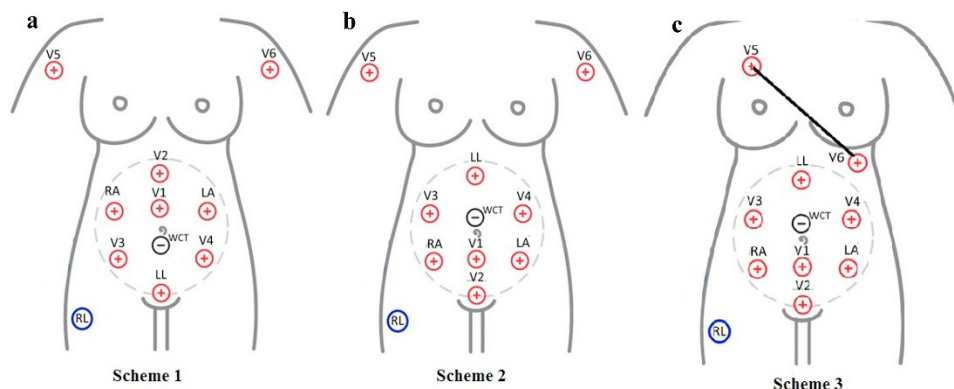


Fig. 5. Proposed three schemes based on the positions of the pre cordial active electrodes (V1 –V6) and the four limb electrodes (RA, LA, LL). RL is placed on the right thigh as a reference electrode. WCT is the virtual reference point for the V1-V6 leads.

3. Experimental Results

Measurements were performed on a 24 year old single pregnant woman, with gestation period of 34 weeks. The experiment was conducted in three modes by using the standard 12 lead resting ECG recorder called Mobmon. The device had the capability to send the live ECG streams to the remote doctor's phone. Initially we tested the scheme 1 thoroughly for few minutes before we could set to record each scheme for 18 minutes each. The largest fetal ECG amplitudes are recorded during the 2nd scheme giving an average FHR value as 132 bpm which was similar to the CTG recordings taken an hour before. The maternal signals were stronger than the FECG for the other two schemes which displayed the mother's heart rate values only. The recordings of the three schemes 1, 2 and 3 are displayed in Fig 6 (a), (b) and (c) respectively, while the CTG reading of the subject is seen in Fig 6 (d).

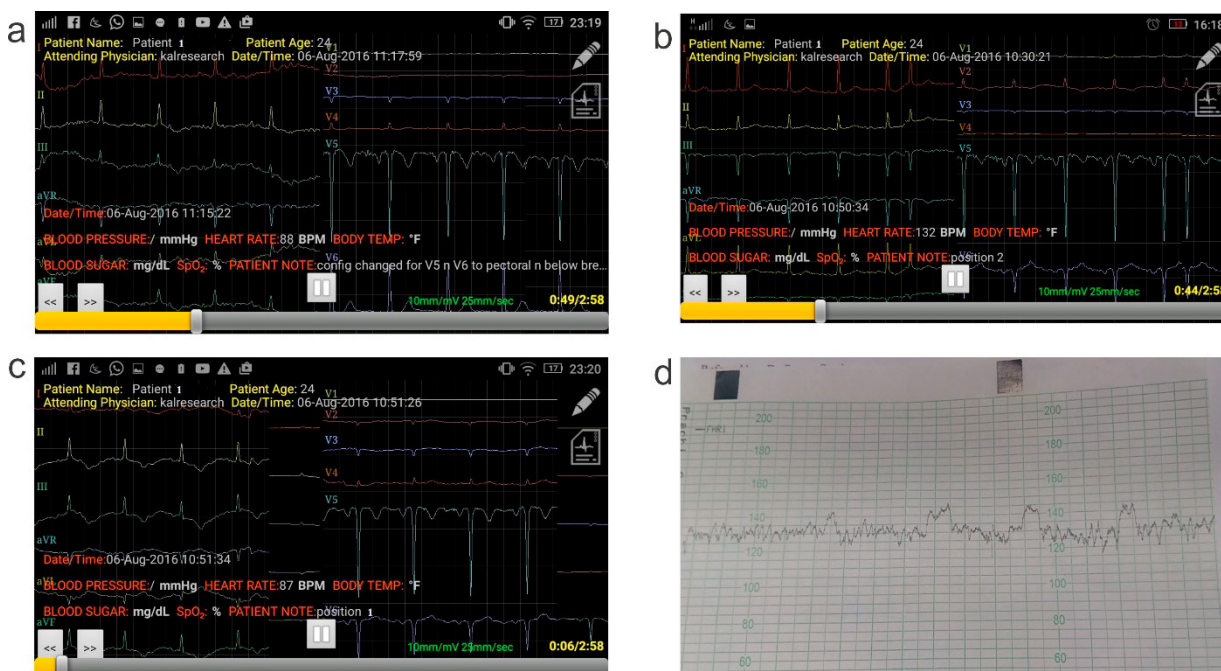


Fig. 6. (a) , (b) and (c) show the aECG recordings using the Mobmon 12 lead resting ECG recorder for the scheme 1, 2 and 3 respectively. Fig 6(d) shows the CTG recording of the subject taken earlier to the aECG recording.

4. Conclusion

In this paper, the experimental recordings had been conducted to collect the aECG signal from a single pregnant woman to access the best electrode position configuration. It was noted in our experiment that the fetus was too small and the small heart was extremely weak and thus the FECG signals were very small compared to the maternal signals picked through the aECG. This maternal-fetal amplitude ratio is almost the same in the case of the nifecgdb (online database records). Wherein the MECG amplitude is very large compared to the fetal amplitude. Moreover the noise overrides the aECG signals, making it even more difficult for the separation of fetal signals from the aECG. The best recordings would be of a near full term mother with a normal size baby. It was observed that the scheme 2 gave the best results whose average FHR value was closer to the average FHR taken using CTG, while the schemes 1 and 3 gave MHR values. This could have been because the leads may have been placed very close to each other. In our next experiment, the distance of leads (inter electrode distance) from WCT can be varied and also around the abdominal circumference. More positions can be researched so that we get equivalent height to the baby's ECG peak in our database before processing the raw measurements so as to isolate FECG from the MECG. As for the future work and to strength our proposed schemes so as to obtain better quality FECG signals, we propose at least 25 subjects to be examined from the 37th gestation week for all three schemes, especially scheme 2 for a duration period of 18 minutes each. The fetal heart rate variability from the CTG reading (from the clinic) and using our method can be compared for each subject. The status of the fetal health for all the above subjects can be monitored weekly up to delivery, and can be correlated with the health status of the new born baby at birth.

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