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Characterization of Maternal Body Movement During Sleep Before and After Parturition

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Abstract—**The purpose of this study was to characterize the different features of body movements for females before and after parturition. Body movement signal was measured by a piezoelectric sensor board which was deployed on the abdominal position beneath a mattress during sleep to monitor pressure changes around abdominal area. Body movement epochs were detected by an innovative algorithm based on Hilbert transform. Data were collected from two healthy pregnant females during sleep for 7 weeks before parturition and 6 weeks after parturition. The pressure signal was used to determine the duration and time interval of maternal movements. Characteristics of the detected body movements before and after parturition were investigated through their proportion. The results showed that before and after parturition, the body movement which features as 0~1 min in interval and 0~6 sec in duration has significant difference statistically. It is considered that these differences are highly correlated with the prenatal activities.**

I. Introduction

Detection of fetal movements is widely used in the study of prenatal health. In 1885, Preyer studied fetal movements both by placing his hands directly on the abdomen and by listening with a stethoscope [1]. In clinical practice, Doppler ultrasound and abdominal electrocardiography acquisition techniques are applied to detect fetal movements and measure the fetal heart rate. However, both techniques are not suitable for long term fetal activity monitoring. Many studies on fetal movement monitoring were conducted and various passive methods were developed. Zuckerwar et al. devised a sensor belt, which is made up of piezopolymer pressure sensors to monitor the fetal heart rate [2]. Ansourian et al. developed a PVDF (PolyVinyliDene Fluoride) sensor to pick up the maternal abdominal wall movements and to extract fetal breathing by autoregressive spectral estimation [3].

The previous studies are focused on the fetal movement monitoring. We propose another method to evaluate prenatal activities by maternal body movement measured during sleep. In some studies, the majority of women experience alterations in sleep during pregnancy [4]. Changes in sleep pattern and sleep duration are commonly reported, an associated with physical changes of pregnancy.

On the one hand, body movement plays the key functions in sleep-stage transition [5]. On the other hand, the body movement data which measured from abdominal position contains maternal movement and abdominal wall movement which caused by prenatal activities.

This paper aims at investigating the characterizations of maternal body movement before and after parturition, and confirming body movements as a potential index for maternal sleep assessment.

II. Method

A. Measurement Setup

Fetal movement is associated with changes in the fetal heart rate, fetal respiration activity and cyclic changes of behavioral state. All the movements lead to the changes of pressure on the maternal abdomen. In order to detect these pressure changes, the measurement system setup consists of a piezoelectric sensor board, a bedside box and an Internet database server as showed in Fig. 1. The piezoelectric board was deployed on the abdominal position beneath a mattress during sleep to monitor pressure changes around abdominal area. The bedside box amplifies and digitizes analog pressure signal, and transmits the digital data stream to a database server via Internet connection.

B. Setup for Algorithm Verification

A verification method of the detection algorithm was video recording by a web camera (Logicool Webcam Pro 9000). It was used to record the subject's sleep state as showed in Fig. 1. The actual body movement was checked by the video visually. Furthermore, the body movement duration and time interval were annotated once for the subject's body movement was record. The evaluation of the algorithm is to compare movement duration and time interval detected by bedside box and by web camera, respectively.

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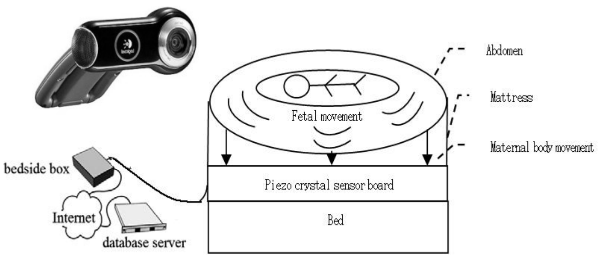

Fig. 1. Fetal moving around inside the uterus leads to the changes of pressure on the maternal abdomen. The sensor board monitors the pressure changes around abdominal area. The web camera was used to record the subject's sleep state.

C. Data Collection

After having been explained the purpose of this study, the volunteers consented to take part in, signed an informed consent agreement and collected daily vital signs. Data were collected from two healthy pregnant females during nighttime sleep over 13 weeks in their home environment. Data were digitized by the bedside box through a 16 bits ADC with a full range of -1 v to 1 v at 100Hz sampling rate.

D. Body Movement Detection

The body movement activities were collected from the piezoelectric sensor board. Three steps are involved in the pressure signal processing in order to detect the maternal abdominal wall movements precisely. Fig. 2. shows the flowchart of signal processing.

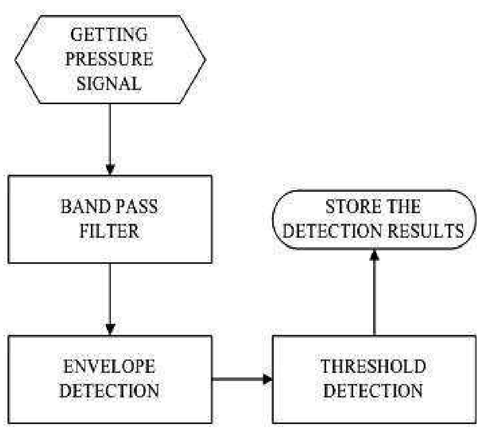

Fig. 2. The flowchart of pressure signal processing.

The pressure signal during sleep is readily affected by sleep pattern or other factors. Therefore, the preprocessing is very necessary for the body movement detection. According to the characteristics of pressure signal which measured from abdomen position, FIR band pass filter and envelope detection were used in preprocessing.

1) FIR band pass filter: The FIR band pass filter is commonly used in ECG signal preprocessing. Because the pressure signal measured from abdomen position consists of pulse component, the FIR band pass filter is also suitable in eliminating the baseline drift and saturated output signal. Fig. 3 shows the raw pressure signal and filtered pressure signal from upper to lower subplot, respectively.

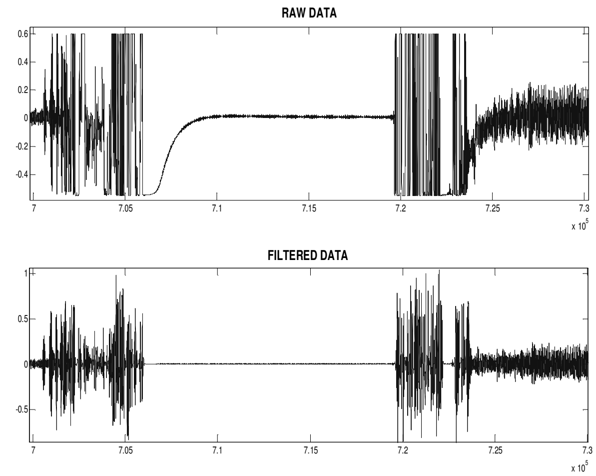

Fig. 3. The result of band pass filter. The raw pressure signal, as shown in upper subplot, is measured on the abdomen position, the lower subplot is filtered data.

2) Envelope detection: The drawback of threshold detection method is easily influenced by the pressure signal's amplitude. Furthermore the range of movement signal is from -1v to 1v which will substantially affect detection accuracy. On the other hand, the envelope detection is used to calculate the filtered signal's amplitude envelope. An efficient method for envelope detection is based on Hilbert transform. The envelope is the square root of the energies of the original and the Hilbert transformed signals. Fig. 4. shows the raw pressure signal, band pass filtered signal and envelope detected signal from upper to lower subplot, respectively.

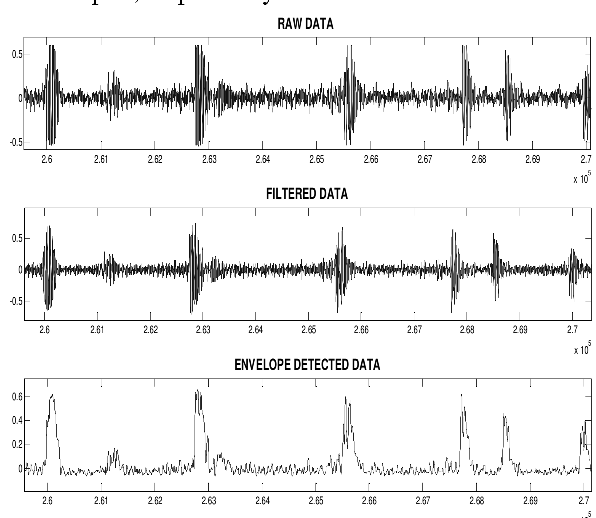

Fig. 4. The raw pressure signal, band pass filtered signal and envelope detected signal from upper to lower subplot, respectively.

3) Body movement epoch detection: The body movements are detected by a threshold method. The extremely high point, whose absolute value is 4 times larger than the standard deviation of the preceding detected artifact-free raw signal, is found in the raw pressure signal [6] as the onset point of the body movement epoch. If the duration of large signal from each onset point was longer than 500 ms, this duration is defined as body movement duration. Fig. 5.

shows the detected results of body movement epochs before and after parturition.

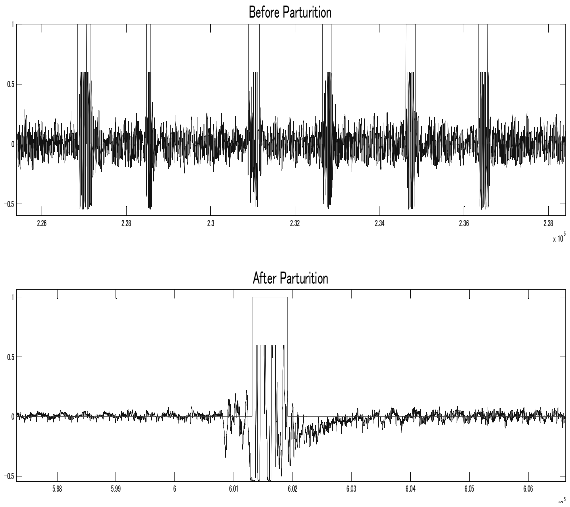

Fig.5. The measured raw pressure signal and detected body movement epochs. The raw pressure signal, as shown in upper subplot was measured before parturition. The lower subplot was measured after parturition. The square windows indicate the detected body movement durations.

E. Performance Assessment for Body Movement Detection

There are two methods were used to body movement analysis. The one is positive predictivity; the other is one-way analysis of variance.

1) Positive predictivity: The positive predictive value is the most important measure of a diagnostic method as it reflects the probability that a positive test reflects the underlying condition being tested for. Two values are defined as: number of true positive (TP) and number of false positive (FP).

A true positive means the body movement detection algorithm detects body movement correctly. A false positive means body movement did not exist but the algorithm detected. The formula for calculating positive predictivity (PP) is showed in (1)

$$PP = \frac{TruePositive}{TruePositive + FalsePositive} \quad (1)$$

2) One-way analysis of variance: The one-way analysis of variance (one-way ANOVA) was used to assess the characterization of body movements before and after parturition. In addition, two parameters, each day's proportion distributions of body movement duration and body movement interval, are defined to evaluate each day's body movement characteristics. In order to meet the assumptions of one-way ANOVA, all the proportion data were tested by homogeneity of variance test before one-way ANOVA analysis.

III. RESULT

A. The result of positive predictivity

By comparing body movement detection by algorithm with those by web camera visually, the mean value of PP is about 83%. Fig. 6 illustrates comparative result of one night body movement detected by both methods. The upper subplot was body movements detected by detection algorithm. The lower one was acquired by web camera.

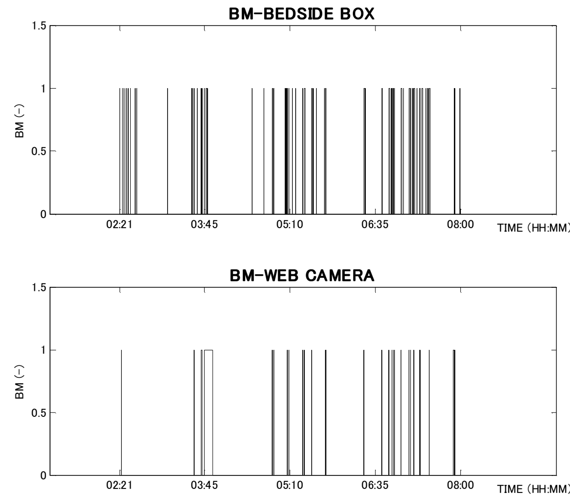

Fig.6. A typical one night's sample of binarization by using detection algorithm (upper) and web camera (lower) to identify body movement.

B. The result of one-way analysis of variance:

According to the fetal movement duration classification [7], the body movement duration (BMD) was divided into 7 segments. The duration of each segment is as follows: 0 to 1, 1 to 2, 2 to 3, 3 to 4, 4 to 5, 5 to 6, and above 6 sec. The body movement interval (BMI) was also divided into 7 segments. The interval of each segment is as follows: 0 to 1, 1 to 2, 2 to 3, 3 to 4, 4 to 5, 5 to 6, and above 6 min. Figures 7 to 10 illustrate the mean value and standard deviation of body movement duration/interval proportions, they are showed as a vertical black bar and a short error line. Each bar indicates the mean value before parturition or after parturition. As showed in figures 7 and 8, the two subjects have the same proportion of average body movement duration proportion. In the BMD segments shorter than 6 sec, the average proportions before parturition are nearly 10% higher than the value after parturition. Conversely, in the BMD segments longer than or equal to 6 sec, the average proportion after parturition is nearly 10% higher than the value before parturition. In the segments of shorter than 6 sec, the result of one-way ANOVA analysis shows that the σ values of two subjects' average proportion were less than 0.05. It suggested that there was a significant difference between before and after parturition in these segments. With respect to body movement interval, the similar result was obtained in the segment of 0 to 1 min. Therefore, it is considered that before parturition the body movement which has 0 to 1 min interval and 0 to 6 sec duration is highly correlated with pregnancy.

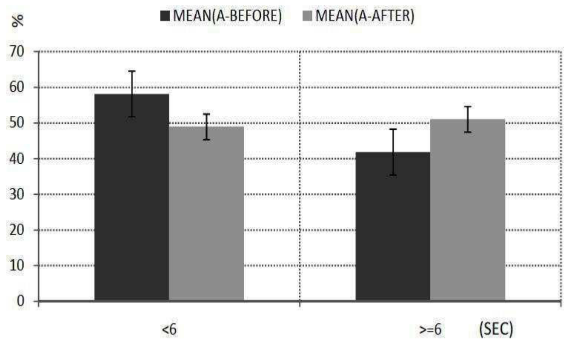

Fig. 7. Subject A's mean value and standard deviation of body movement duration proportions before and after parturition.

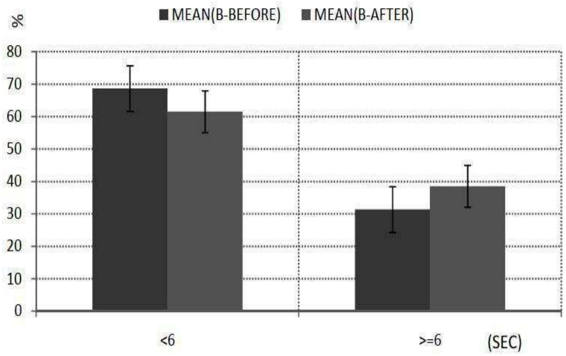

Fig. 8. Subject B's mean value and standard deviation of body movement duration proportions before and after parturition.

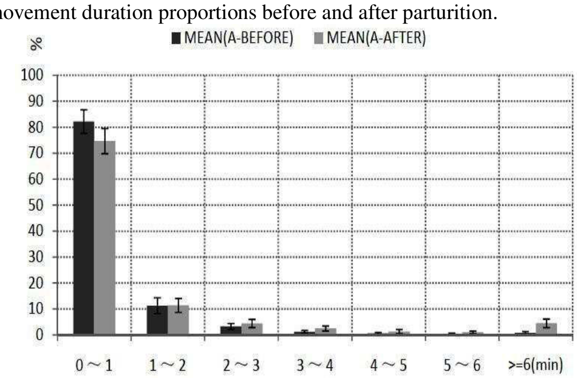

Fig. 9. Subject A's mean value and standard deviation of body movement interval proportions before and after parturition.

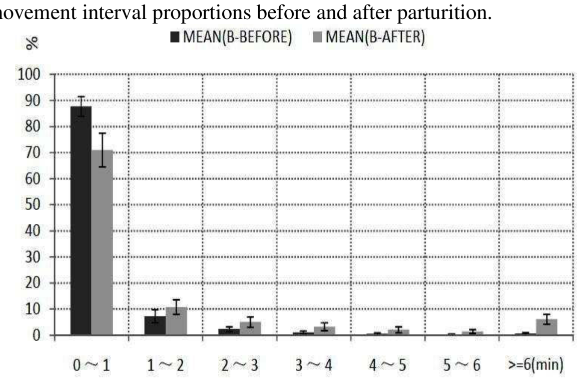

Fig. 10. Subject B's mean value and standard deviation of body movement interval proportions before and after parturition.

IV. DISCUSSION

The accuracy of proportion analysis largely depends on the body movement detection algorithm. Firstly, body movement duration was divided into 7 segments. But as the result shows, the proportion distribution only lies within the range of 5 to 6 sec and above 6 sec. The potential reason is the threshold value of body movement epoch detection. The best threshold parameters should be chosen by reference of PSG.

Due to the body movement was measured from fetus' third trimester to 1 month postpartum. According to Kathryn A. Lee et al.'s research, deep sleep was diminished throughout pregnancy compared with baseline and postpartum. The third trimester has the lowest mean value of deep sleep time proportion during pregnancy [8]. Therefore during third trimester the pregnant women have the lowest sleep quality. After parturition, the sleep quality will gradually improved by time. The character of body movement which has 0 to 1 min interval and 0 to 6 sec duration reflects the difference of prepregnancy and postpartum obviously. Although the physiological meaning is not confirmed yet, this kind of body movement is considered highly correlated with prenatal activities.

V. CONCLUSIONS

This study collected body movement signal from two healthy pregnant females during nighttime sleep over 13 weeks in their home environment, and investigated the different features of body movements for females before and after parturition. The results showed that before and after parturition, the body movement which features as 0~1 min in interval and 0~6 sec in duration has significant difference statistically. Therefore, it is considered that these differences are highly correlated with the prenatal activities.

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