Invention of ultrasonic Doppler fetal actocardiograph to continuously record fetal heart rate and movements

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Abstract

Aim: Fetal movement Doppler signal was added to fetal heart rate (FHR) in controversy case of cardiotocogram (CTG) diagnosis. Method: An ultrasonic Doppler FHR monitor was remodeled by the author. As fetal chest Doppler signal was mixed up with the signals of various movements, and fetal movement Doppler was 20-50 Hz when ultrasound was 2 MHz, a band pass filter extracted fetal movement Doppler signal, and 100 Hz high-pass filter detected the signal to record FHR, thus FHR and fetal movement were traced with single ultrasound probe. Uterine contraction was traced with external tocodynamometer. Results: The amplitude of spiky fetal movement signal was parallel to that of fetal movement, and it appeared at the same time as fetal movement in real-time B-mode. Fetal brain damage was diagnosed by the loss of variability after the loss of acceleration evoked by fetal movements. Fetal behavior was diagnosed tracing fetal movements. Physiologic benign sinusoidal FHR was separated from pathologic one by the synchronization to cyclic fetal movements. Acceleration duration/ movement burst ratio (A/B ratio) was >1 when Apgar score was >7. Conclusion: As results obtained by my hand-made prototype was useful, TOITU Ltd (Tokyo) was asked to provide commercial model by the author. Researchers reported that all fetal motions were recorded by new device, which was called as actocardiogram (ACG).

Keywords: Cardiotocogram, actocardiogram, FHR, fetal movement, uterine contraction, hypoxia, fetal brain damage, sinusoidal FHR
1. Introduction

Fetal movement percepted by mother, as fetal kicking, was a nonmedical sign of fetal well-being in mothers subjective decision, the FHR acceleration recorded on CTG nonstress test was favorable fetal sign, whereas no acceleration was ominous fetal sign, which was called “non-reactive”, and amniotic fluid volume were important signs in antepartum biophysical tests.

Fetal movement was detected on the surface of maternal abdomen with mechanical method [1] or electronic techniques, while they were insufficient to detect all of fetal movement, requiring directly to detect the movement at fetal surface in scientific study.

2. Methods and Materials

Ultrasonic Doppler method has been utilized to detect blood flow or extremity movement [2] of the fetus fortunately, there was ultrasonic autocorrelation FHR meter in a cardiotocograph (CTG) which detected Doppler fetal heart beat signal. It was TOITU TN-400 CTG., Maeda remodeled it changing to an actocardiograph, which was able to detect fetal movements at fetal chest surface, where fetal heart beat was detected to trace FHR curve in the CTG.. However, the Doppler signal reflected from fetal chest was a mixture of various Doppler signals. The largest artifact was maternal motion, including body movements, respiration, laugh, speech, etc. while fortunately all of them was 2 Hz or less Doppler frequency. They were excluded passing through a high-pass filter before observation of fetal movement Doppler signals on oscillographi c screen. Another foreign Doppler signal was fetal heart beat, which was sent to autocorrelation FHR meter, passing through 100Hz high-pass filter. The aim was fetal chest movement Doppler signal, which contained all fetal movement conducted every part of fetal body and extremities, of which frequency measured by real time frequency meter was 20-50 Hz when the ultrasound was 2MHz. The movement Doppler signal was obtained with a band-pass filter of 20-80 Hz, -18 dB/Oct, and its negative half was cut off and obtained low frequency spikes to trace them by the CTG recorder.

As fetal heart beat Doppler signal was 100Hz or more when ultrasound was 2 MHz, fetal heart beat Doppler signal was detected passing through 100 Hz high-pass filter, then processed by an autocorrelation heart rate meter and simultaneously recorded with fetal movement. In the uterine contraction channel in prototype hand-made acto (motion)-cardio (heart rate) graph [3]. Uterine contraction was added in commercial model, and formed an Acto-cardio-toco (contraction) graph. Therefore two type FHR analyzers including Actocardiograph (ACG) and Cardiotocograph (UCG) was possible in single device in commercial models provided by TOITU (Tokyo), to whom Maeda asked to provide commercial model (Figure 1), because Maeda set no patent in order to distribute actocardiograph in the world.
3. Results

The record on actocardiogram

The actocardiograph was able to record fetal movement in 14 gestational weeks. As the fetal motion was whole body, before the period, the motion was analyzed using real-time B-mode device before 14 weeks. Fetal researchers reported that almost all of fetal movements were detected by the new Doppler actocardiogram [4-6].

The FHR acceleration, which was the sign of fetal well-being, was 15 bpm or more and 15 sec or longer after 30 gestational weeks, while it was 10 bpm and 10 sec before 30 weeks, thus, the actocardiogram was utilized for common fetal monitoring in pregnancy and also in intrapartum monitoring.

Common relation of fetal movement burst (grouped motion) associated with FHR acceleration is observed in normal fetal brain function, while the acceleration was lost in early stage of fetal hypoxia, or the duration of acceleration is shorter than that of fetal movement burst in case of lower Apgar score than 7, namely, A/B ratio, which was the ratio of the duration of acceleration (A) to that of fetal movement burst (B), was shorter than 1 in case of low Apgar score [7]. The loss of acceleration is usually followed by severe fetal asphyxia, loss of variability in fetal brain damage causing cerebral palsy [8].
Fetal behavior

Active fetal state is recognized, by frequent fetal movement bursts associated with FHR accelerations (Figure 2). Resting fetal state is characterized by the loss of fetal movement bursts and the loss of associated FHR acceleration, preserving baseline variability.

Figure 2: Two actocardiograms in active state. Triangular FHR accelerations appear against fetal movement bursts. FHR delayed for 7 sec to movement.

Intermediate state is reduced fetal movement and accelerations, between active and resting states. Highly active state shows long fetal movement bursts at most persisted 5 min, and associated long acceleration, that is almost transient tachycardia.

Fetal behavior is also numerically determined by the fetal movement burst length, occupation value of movement burst and acceleration, and their frequency [9].

Fetal hiccupsing movements

Fetal hiccupsing is a particular fetal motion, which was recorded as sharp spikes with mainly 2 sec intervals (Figure 3), and repeated more than 10 min, while they do not accompany FHR acceleration, which was the sign of fetal well-being, because fetal hiccupsing is a local diaphragmatic convulsive contraction, but it is not controlled by fetal brain. The hiccupsing is repeated from usual fetal movement controlled by fetal brain. Hiccupsing is continuously regular and the interval is mostly 2 sec, and the acceleration is lost, despite of continuous fetal movements, and the interval is mostly 2 sec, and the loss of acceleration despite of continuous fetal movements.
Environmental hypoxia

Fetal bradycardia and low PaO₂ are environmental change, but they do not mean fetal damage. Heart rate linearly lowered in the PaO₂ lower than 50 mmHg. Human fetal UAPO₂ is 50 or less mmHg.

Fetal brain damage

The sign of fetal hypoxic brain suppression is the loss of acceleration against fetal movement burst (Figure 4), and the sign of severe brain damage is the loss of FHR variability (Figure 5, 6) followed by cerebral palsy, where the hypoxia index (Sum of bradycardia duration (min)divided by nadir bradycardia (bpm) x 100) was 25-26. Caesarean delivery should be performed before the severe brain damage to prevent cerebral palsy [8].

Figure 3: Enlarged actogram of fetal hiccupping for 10 times, where its sharp spike intervals were regularly 2 sec.

Figure 4: Acceleration is lost against fetal movements (Non-reactive FHR), where baseline variability is preserved in the case.
Figure 5: The loss of variability shows severe fetal brain damage in the anencephalic fetus

Figure 6: Cases of the loss of variability. A: Late decelerations, B: Anencephalic fetus
Benign physiologic sinusoidal FHR

CTG was unable to diagnose physiologic sinusoidal FHR. As the correlation coefficient was the largest when fetal movement signal delayed for 7 sec, in the cross correlation between FHR and fetal movement, FHR changed 7 sec after the cyclic changes of fetal movement. Since the envelope was sine wave-like in the actocardiogram, the FHR was sine wave-like and diagnosed as benign physiologic sinusoidal one because the sinusoidal FHR was the same as the periodic change of fetal movements [10]. As the pathologic sinusoidal was caused by severe fetal anemia, there was no cyclic fetal movement (Figure 7).

![Figure 7: Pathologic (left) and physiologic (right) sinusoidal FHR](image)

Actocardiographic A/B ratio

As the duration of clear FHR acceleration was longer than that of provoked fetal movement burst, the ratio of the sum of the duration of FHR acceleration (A) to the sum of duration of fetal movement burst (B) was defined as A/B ratio (Figure 7). Since the regression equation of A/B ratio (X) and 1 min Apgar score (Y) is: \( Y = 8.0 X - 1.7 \), a neonate is normal, if the fetal A/B ratio is larger than 1. The long term outcome after birth was also related to fetal A/B ratio particularly a plegia infant was found in the low A/B ratio group [11].
Figure 8: Calculation of A/B ratio in an ACG recorded in active fetal state

Discussion

**FHR changes are related to fetal brain function**

FHR acceleration develops in fetal mid-brain Terao stated that the acceleration is related to fetal midbrain in anencephalic infant study [9], where triangular FHR acceleration is provoked by the integral function, which was confirmed by electronic and physiologic simulations. Also, fetal brain detects minor fetal movement to develop FHR variability. Thus, relatively complex process to develop acceleration is primarily disappears in hypoxic brain damage, and then the simple variability disappears in more severe brain damage followed by the cerebral palsy develops after fetal brain damage [8]. Therefore it is recommended to perform caesarean delivery before the loss of variability, after the detection of the loss of acceleration or severe FHR changes. Objectively it is recommended to calculate hypoxia index (HI), which is the sum of bradycardia durations (min) divided by the nadir bradycardia (bpm) multiplied with 100, in cases of repeated decelerations including severe late and variable decelerations and continuous bradycardia, where the HI was 25 and 26 in the loss of variability, while it was 20-24 before the loss of variability. Therefore, it is recommended to indicate caesarean delivery in the stage where the HI is 20-23, to prevent cerebral palsy [8]. It will be a new recommendation in fetal monitoring, to prevent fetal brain damage followed by cerebral palsy.

**Conclusion**

The invention of actocardiogram was listed in the details. It was useful to diagnose normal and abnormal fetuses, particularly fetal brain damage was discussed with new indices. Although physiologic sinusoidal heart rate was unable to diagnose with CTG, it is easily separated from patholoic sinusoidal one. Fetal hiccupping movement was recorded and discussed.
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