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Quantitative Studies on Fetal Actocardiogram

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Aim To quantitatively analyze actocardiography as a method to differentiate between active and resting fetal states.

Methods We established five new quantitative parameters for actocardiogram; they include duration, occupancy, and frequency of movement bursts, and fetal heart rate acceleration to movement ratio (A/B ratio) in duration and number. These parameters were analyzed and compared in 14 normal late pregnancies and in non-hypoxic sinus bradycardia due to fetal cardiac sick sinus syndrome (n = 1), hypoxic non-reactive non-stress test (n = 3), hypoxic fetal distress (n = 1), and that ensuing in death (n = 1).

Results Fetal hypoxic disorders differed from non-hypoxic states in the significant reductions of burst frequency (normal pregnancy mean was 0.65 ± 0.22 cpm and fetal distress 0.24 cpm), occupancy (32.67% and 10.00%, respectively), and the ratio of durations of acceleration to movement burst (1.03 and 0, respectively).

Conclusion Our study of quantitative actocardiogram parameters in normal pregnancy and various hypoxic fetal disorders demonstrated new characteristics of fetal movement and its relation to fetal heart rate. The results are promising for further analysis of fetal behavior and abnormalities.

Fetal movements have been studied by several methods, including maternal perception, electromagnetic detection, mechanical fetal actogram, and external tocometry, all of which are inadequate for scientific study. In behavioral examination, fetal gross movements and eye movement are studied by real time B-mode with a cardiotocograph (1). Four-dimensional ultrasound is useful for updates in fetal status (2). The fetal heart rate is monitored with a non-invasive ultrasonic Doppler monitor for fetal heartbeat and autocorrelation (3). To reduce the detection of false-positive non-reactive cases, we have created an actocardiogram that detects fetal movements by an ultrasonic Doppler method and records fetal heart rate tracings (4). Since fetal heart rate acceleration was shown to be related to fetal movements by actocardiogram, non-reactive fetal heart rate decreased by 60 to 70% (5,6) due to the reduction in false positive cases and the possibility to diagnose a true non-reactive state.

A pathological fetal sinusoidal heart rate is ominous and frequently associated with fetal death (7). Whereas a physiological fetal sinusoidal heart rate record is similar to a pathological one, its outcome is favorable. A physiological fetal sinusoidal heart rate is differentiated from a pathological one by fetal periodic respiration or sucking motion recorded by actocardiogram (7,8). Fetal movements are not detected by actocardiogram in the presence of a pathological fetal sinusoidal heart rate. Whereas these results indicate the usefulness of actocardiogram, quantitative analysis is required to enhance its application.

Methods

Actocardiogram

Ultrasonic Doppler actocardiogram continuously records fetal heart rate and movement spikes on the lower channel of the cardiotocograph chart. A single ultrasound transducer re-

cords both phenomena. Any movement in the body produces Doppler signals of various frequencies when ultrasound is reflected from subjects. The Doppler frequency is higher than 100 Hz when reflected from the wall and valves of fetal heart when ultrasound is 2 MHz. It is lower than 1 Hz in maternal motion and respiration, and fetal movement signal is observed by oscilloscope when the maternal signals are eliminated by inserting a high-pass filter with a cut-off of 8 Hz (-3 dB/octave, oct). Fetal movement signals are 20 to 50 Hz by fast Fourier transform analysis and a band pass filter of 20-80 Hz (-18 dB/oct) is inserted to obtain fetal movement signals in the prototype model made by the author (4). The Doppler signals higher than 400 Hz are converted into fetal heart rate, and 20-80 Hz signals are changed into spikes recorded by the cardiotocograph recorder (4). Chart speed is usually 3 cm per minute (3), a speed convenient for the analysis of slow and rapid fetal heart rate changes.

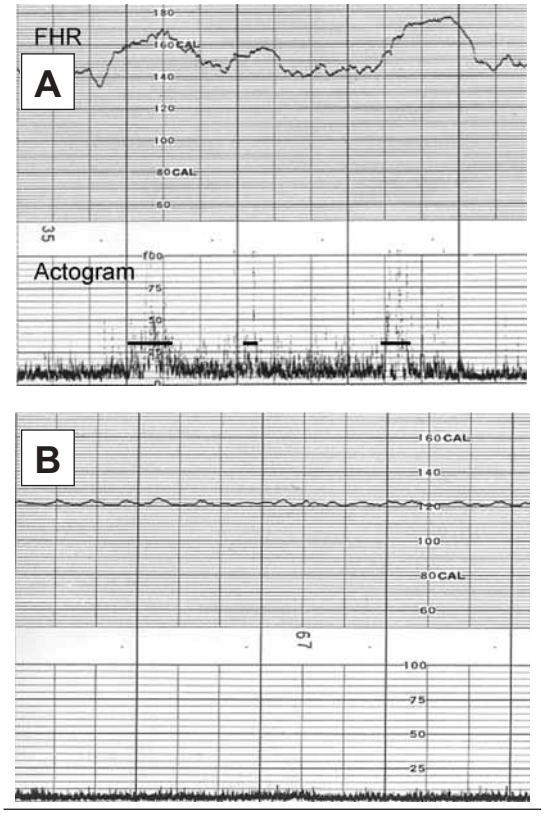

Figure 1. Actocardiogram in normal late pregnancy. **A.** Active fetal state. Fetal heart rate (FHR) accelerations are associated with fetal movement bursts. Transverse bars in actocardiogram show durations of movement bursts. **B.** Resting fetal state. Non-reactive non-stress test is excluded because fetal movement is not detected. Low fetal heart rate baseline, small 3-6 cpm oscillations and irregular variability are characteristic of resting fetal state, which changes into active state within 40 minutes.

The fetal probe is placed on the maternal abdomen, where the fetal heart is most clearly detected and is also suitable for recording movements. The actocardiogram models used in this study were MT320 and 325 (Toitu, Tokyo, Japan). The clusters of movement spikes are called movement bursts in this report (Fig. 1). Since many machines record dots for fetal movements, movement durations were measured and compared between spike and dot records. Quantitative character is different in precise measurements, although the trends are equal in both records, the author analyzed original spike records in this report.

Five Quantitative Actocardiogram Parameters

Although some successful results are obtained by visual studies of actocardiogram, quantitative parameters are needed for further analyses. Duration of fetal movement bursts, their number and interval, and those of fetal heart rate accelerations were measured and studied in a preliminary analysis. Durations were measured, but the height of the movement bursts was not determined, because the spike amplifier gain was not standardized. Bursts and accelerations were manually measured according to the time scale on the chart or with a ruler.

The correlation between the durations of movement bursts and the fetal heart rate accelerations in the late stage of normal pregnancy, and the correlation between the wavelength of the physiological sinusoidal heart rate and the duration of movement bursts were significant. On the basis of these results, we decided to use values related to movement bursts and accelerations obtained in active fetal states in quantitative studies. The 5 parameters were as follows:

1) Mean movement burst duration (seconds).

2) Movement burst occupancy (occupancy, %): the sum of all burst durations (s) is divided by the whole record duration (s).

3) Movement burst frequency (frequency): the number of bursts is divided by the full record duration (minutes). The unit is cycles per minute (cpm).

4) Fetal heart rate acceleration/movement burst duration ratio (A/B duration ratio): the sum of fetal heart rate acceleration widths (s) is divided by the sum of burst duration (s). The result is 0 if both acceleration and burst duration are 0.

5) Fetal heart rate acceleration/burst number ratio (A/B number ratio): the count of fetal heart rate acceleration is divided by that of movement bursts. The result is 0 if both counts are 0. There is no unit in 4 and 5.

Manually-measured duration of every movement burst and the width of fetal heart rate accelerations were entered into Excel (Microsoft Office) on a VAIO PC (Sony, Tokyo, Japan) to calculate their count, sum, average, and standard deviation (SD). Linear regression equation and correlation coefficient (r) were obtained with our BASIC program in Sharp PC-1255 (Tokyo, Japan). Group pairs were compared by *t* test, proportion test, and Fisher exact test with DA Stat software (Shinko, Tokyo, Japan).

Cases Studied by Quantitative Analysis

Five quantitative actocardiogram parameters were studied in active states of 14 normal pregnancy cases after 28 weeks of gestation. Fetuses of 28 weeks or less were excluded because of the possible physiological decrease in baseline variability in the young fetus. One case of non-hypoxic fetal sinus bradycardia due to fetal cardiac sick sinus syndrome (9), three actocardiographic non-reactive fetal heart rate which shows no fetal heart rate acceleration to movement bursts (Fig. 2), one fetal distress (non-reassuring status), and a severe fetal distress followed by fetal death which showed no baseline variability, no acceleration, and late deceleration were compared with normal pregnancies.

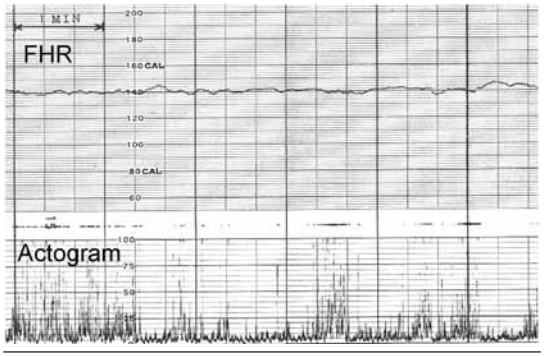

Figure 2. Non-reactive non-stress test shows many fetal movement bursts whereas no acceleration in fetal heart rate (FHR) is recorded. The case had severe decelerations 2 days later; Caesarean section was carried out and the neonate was weak.

Results

Normal Pregnancy after 28 Weeks

The mean ± SD and coefficient of variation (CV) of 5 parameters were studied in active states of 14 cases of normal late pregnancy (Table 1, Fig. 3). Mean burst duration was 29.69 s; occupancy was 32.67%; and frequency was 0.65 cpm, meaning that the fetus moves on average about 30 out of 92 s. The values agree with occupancy. The coefficient of variation was as large as 30.77% to 34.59% in burst duration, frequency, and A/B duration ratio, whereas it was as small as 14.57% in occupancy and 11.46% in A/B number ratio.

Comparison of Hypoxic and Non-Hypoxic Cases

Burst frequency and A/B duration ratio were also measured in cases of non-hypoxic

Table 1. Quantitative actocardiographic values of normal pregnancies after 28 weeks of gestation (n=14)

Parameter	Mean±standard deviation	Coefficient of variation (%)	Range
Burst duration (s)	29.69±10.27	34.59	18.90-51.8
Occupancy (%)	32.67±4.76	14.57	12.90-58.8
Frequency (cpm)	0.65±0.22	33.85	0.23-0.99
Fetal heart rate acceleration/movement:			
burst duration ratio	1.43±0.44	30.77	0.90-2.55
burst number ratio	0.96±0.11	11.46	0.86-1.00

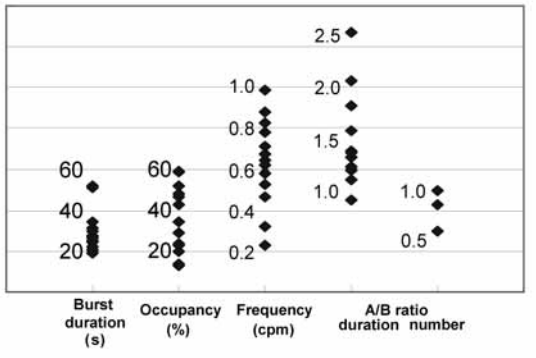

Figure 3. Mean values of 5 actocardiogram parameters in normal pregnancy after 28 weeks of gestation. Mean± standard deviation values are: 29.69±10.27 seconds for burst duration, 32.67±14.76% for occupancy, 0.65±0.22 cpm for frequency, 1.43±0.44 for fetal heart rate (FHR) acceleration/movement burst duration ratio, and 0.96±0.11 for FHR acceleration/movement burst number ratio.

Table 2. Burst frequency, occupancy, and fetal heart rate acceleration/movement burst duration ratio (A/B duration ratio; mean±standard deviation) in normal and abnormal pregnancies, non-hypoxic fetal bradycardia due to fetal sick sinus syndrome, genuine non-reactive non-stress test, fetal distress, and fetal distress before fetal death

Cases	Burst duration (s)	Occupancy (%)	Frequency (cpm)	Fetal heart rate acceleration/movement burst duration ratio	Fetal heart rate acceleration/movement burst number ratio
Normal pregnancy (n=14)	29.69±10.27	32.67±4.76	0.65±0.22	1.44±0.44	0.96±0.11
Non-hypoxic fetal bradycardia due to fetal sick sinus syndrome (n=1)	22.70	24.00	0.45	1.03	1.00
Genuine non-reactive non-stress test (n=3)	21.30±2.00	64.63±9.51	1.37±0.69	0	0
Fetal distress (n=1)	29.30	10.00	0.24	0	0
Fetal distress before fetal death (n=1)	0	0	0	0	0

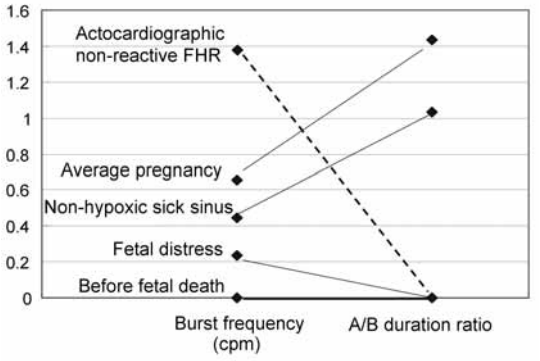

Figure 4. Non-hypoxic and hypoxic cases are compared for burst frequency and fetal heart rate (FHR) acceleration/movement burst duration ratio. Non-reactive non-stress test of possible hypoxia shows high burst frequency, whereas FHR acceleration/movement burst duration ratio is zero. Average normal pregnancy and non-hypoxic bradycardia of cardiac sick sinus syndrome show medium burst frequency and high FHR acceleration/movement burst duration ratio. Fetal distress and fetal distress with fatal outcome have low burst frequency and FHR acceleration/movement burst duration ratio. Mild hypoxia may show movement bursts without FHR acceleration, whereas severe hypoxia shows reduction of both burst and acceleration, ie hypoxic fetuses are characterized by the highly diminished FHR acceleration/movement burst duartion ratio in the actocardiogram.

bradycardia due to cardiac sick sinus and abnormally hypoxic cases including actocardiographic non-reactive cases, a case of fetal distress and a case of fetal distress with fatal outcome (Table 2 and Fig. 4). Movement burst frequency and A/B duration ratio of non-hypoxic sick sinus (9) were within normal limits of normal pregnancy, whereas non-reactive fetal heart rate due to possible moderate hypoxia showed abnormally high burst frequency and no fetal heart rate acceleration. Hypoxic fetal distress showed less movement burst than normal or no acceleration, whereas in severe hypoxia followed by fetal death neither fetal movement nor acceleration could be detected.

Discussion

The aim of this study was more accurate recognition of fetal condition by the quantitative analysis of actocardiogram, because we already reported the validity of quantitative studies on fetal heart rate (10). Quantitative parameters of fetal condition in this report were composed of various variations of movement bursts and fetal heart rate accelerations.

Five quantitative parameters were studied in normal late pregnancy. Fetal heart rate acceleration/movement burst number ratio had a mean of almost 1 and a small CV because fetal heart rate acceleration appears in almost all fetal movements in normal pregnancy. The mean of the fetal heart rate acceleration/movement burst duration ratio, however, was about 50% greater than 1 and the CV was large. The results indicate longer duration of fetal heart rate acceleration than of movement burst in normal late pregnancy, suggesting that the normal fetal brain is sensitive to fetal motion. Therefore, fetal heart rate acceleration/movement burst duration ratio may be a sensitive index for fetal brain function.

The variability of the fetal heart rate baseline has been taken as an index of fetal well-being, and its reduction is an ominous sign in fetal monitoring if it is caused by hypoxia (11). Anesthesia and sedatives also reduce variability. In the immature young fetus, fetal heart rate variability is low. In these cases, reduction in fetal heart rate variability or its disappearance is explained by incomplete or lost fetal brain function. The variability is caused by an auto-induced excited state in the fetal brain, whereas brain reaction to fetal movement causes fetal heart rate acceleration (12). As the reaction may be weak in the young fetus, the acceleration is low in height and short in duration, indicating immature fetal brain function. Therefore, fetal heart rate acceleration/movement

burst duration ratio is a good index for fetal brain function.

Two parameters, fetal movement burst frequency and the ratio of durations of acceleration and movement burst (A/B duration ratio), were compared in normal and abnormal pregnancies. This simple examination of two quantitative parameters in the comparison of non-hypoxic and hypoxic conditions clarified the different fetal states in the two conditions. Future experiments will analyze five actocardiogram parameters to further define fetal behavior.

In conclusion, actocardiogram is a good record of fetal movement and fetal heart rate. It is useful in accurate fetal diagnosis to exclude various false positive and negative cardiotocograph interpretations. It was also used to automatically recognize fetal behavioral states with fetal active, resting, and intermediate phases (12). These have allowed correct diagnosis of fetal hypoxic disorders.

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