Counting fetal movements of small-for-gestational infants using a fetal movement acceleration measurement recorder

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Background: Our purpose was to clarify whether small-for-gestational (SGA) infants is associated with a decrease in fetal movements even in the absence of hypoxia. We used a fetal movement acceleration measurement recorder, which enabled counting gross fetal movements for hours at a time.

Methods: 1) Parameters of fetal movements for 13 women who delivered SGA infants were plotted over normal reference value curves made from 64 normal pregnant women in another study. 2) Linear regression analysis was conducted for the women with SGA infants and the normal pregnant women.

Results: Thirty-eight data recordings were available in the SGA group. 1) For ratio of movement positive 10-second epoch, 14 recordings (36.8%) were below 10% of the normal values. For average number of movements, 13 (34.2%) were below 10%. Regarding average number, average duration, and longest duration of non-movement period, 12 (31.6%), 13 (34.2%) and 15 records (39.4%) were above 90% of the normal values, respectively. 2) SGA was a factor that decreased the positive epoch ratio and the average movements number, and increased the average number and duration, and the longest duration of non-movement period.

Conclusion: SGA is associated with decreased movements even in the absence of hypoxia.

Keywords: FMAM recorder; Fetal movements; SGA; FGR; Neurodevelopment

Introduction

It is well-known that decreased fetal movements, as counted by the mother, have a significant association with small-for-gestational (SGA) infants. In a retrospective analysis of women with reduced fetal movement counts conducted by Heazell AE, et al. [1], 29.1% of such infants were SGA infants. In another study by Scala C, et al. [2], repeated episodes of decreased fetal movements at term were strongly associated with the birth of SGA infants. In a review of 24 studies by Frφen JF [3], decreased fetal movements, as counted by mothers in high-risk pregnancies, were associated with a high risk of fetal growth restriction (FGR). In a randomized controlled study by Saastad E, et al. [4], decreased fetal movements, as counted by mothers in low-risk pregnancies, identified more FGR before birth. However, the nature and extent of the association between decreased fetal movements and FGR is still unclear. One of the reasons is low sensitivity of maternal perception of fetal movements. Johnson TR, et al. [5] reported that the mother perceived only about 16% of fetal movements detected by Doppler.

On the other hand, ultrasonographic observations have been unable to clarify whether FGR is associated with decreased fetal movements. Mor-Yosef S, et al. [6] reported a significant decrease in fetal movements in FGR. Bekedam DJ, et al. [7] identified a lower incidence of gross movements in FGR than in normal fetuses; however, they also showed a large overlap in the incidence between the two. D'Elia A, et al. [8] reported that FGR showed no quantitative differences compared to normal-sized fetuses in terms of gross movements.

We think that one of the difficulties in studying fetal movements by ultrasongraphy is the length of observation. Fetuses have rest-activity cycles and do not move at a uniform pace; therefore, counting the number of fetal movements will lead to inaccuracies if the length of observation time is insufficient. In previous studies of FGR

[6-8], where fetal movements were counted during ultrasonography, the observation time was one hour; however, it may be that a one-hour observation is insufficient to detect subtle differences. In order to determine a normal reference range, Ten Hof, et al. [9] observed fetal movements for 120 minutes after 36 weeks, and Pillai M, et al. [10] made observations for 90 to 100 minutes. We also reported that a two-hour observation was sufficient in most cases during the earlier stages of pregnancy, but even a two-hour observation is sometimes insufficient, especially in the later stages [11].

We have developed a fetal movement acceleration measurement recorder (FMAM recorder, http://e-mother.co-site.jp) that has made it possible to count gross fetal movements during overnight sleep at home [12-14].

The purpose of the present study was to use the FMAM recorder during long-term observation to clarify whether SGA is associated with decreased fetal movements.

Methods

FMAM recorder and fetal movement counting

The FMAM recorder (Figure 1) has been explained in detail elsewhere [11-14]. It weighs 290 grams and has two acceleration sensors: one is a fetal movement (FM) sensor that attaches to the mother's abdomen, and the other is a mother's movement (MM) sensor that attaches to her thigh. The sensitivity of the FM and MM sensors is 700mV/0.1G and 120mV/0.1G, respectively. The FM sensor detects oscillations of the mother's abdominal wall caused by gross fetal movements. However, the mother's body movements themselves also cause oscillations. The recorder is unsuitable when the mother moves frequently; therefore, it is used only during night time sleep. The mother does move occasionally during sleep, though. In principle, when the MM sensor detects no movement, and the FM sensor detects oscillations of her abdominal wall, gross fetal movements are judged to have occurred.

In this study, the FMAM recorder was used at the mother's home. In principle, the mothers were asked to record fetal movements once a week after 28 weeks. We accepted the record as valid only when data could be obtained for more than 4 hours per night.

The record was analyzed and fetal movements were counted using a software system (Version 1.04A, NoruPro Light Systems, Inc. Tokyo Japan), which was developed especially for the FMAM recorder [11, 14]. The brief principles of the system were as follows: (1) The low acceleration signals were filtered and changed to absolute integral values per 50 ms. (2) When the integral values were greater than twice the average amplitude during 3 s just before and after measurement, they were judged to be positive for acceleration. (3) Any period in which the MM sensor detected positive accelerations more than four times per minute was deleted from the data because this usually indicated that the mother was active or awake. (4) Characteristic regular accelerations at 15-20 beats/min detected by the FM sensor were the sign of fetal hiccups and not counted as fetal movements [15]. All the setting conditions of the software were same between the SGA group and the control group.

From the number counted, the following parameters were calculated: (a) The ratio of positive 10-second epochs. The recording was divided into intervals (epochs) of 10 seconds each, and an epoch with any fetal movements was judged to be positive. The ratio of positive epochs to all epochs during one night was calculated. (b) The average number of fetal movements per one hour for each night. (c) The average number, average duration, and longest duration of fetal non-movement periods. A period of no fetal movement was defined as when no fetal movements were observed for more than

5 minutes. Then, the average number per hour, the average duration, and the period with the longest duration were calculated for each night.

Examinations

This study was a prospective cohort study. After delivery, women who delivered SGA were classified as the SGA group. We defined SGA as those with a birth weight below 10th percentile on Japanese neonatal anthropometric charts for gestational age [16]. There were a total of 13 women who could record fetal movements for more than 4 hours per night and eventually delivered SGA at Teikyo University Hospital from 2008 to 2017. None of the mothers had medical complications or took hormonal or psychological medications. The reasons we selected the subjects from infant's birth weight and not from fetal estimated weight were that weight estimation with ultrasonography has 10% error and that selecting the subjects during pregnancy might cause some interventions and biases afterward. The characteristics of the mothers and babies are shown in Table 1 as the SGA group. There were eight cases of premature delivery.

In principle, all mothers who recorded fetal movements took the non-stress test to confirm reassuring fetal status every time they came to the hospital for routine checkups after 28 weeks of pregnancy. After hospitalized, they undertook the non-stress test at least once a day during pregnancy and continuous fetal heart rate monitoring during labour.

1)Distribution of fetal movement parameters for small-for-gestational infants (SGA) over a normal reference range

As mentioned in the Introduction, normal reference values for FMAM recorder's count of gross fetal movements were reported previously [11]. The values were based on data from 64 women who successfully recorded fetal movements for more than 4 hours per night and eventually delivered full-term singleton newborns without anomalies or neurological problems. Their characteristics are shown in Table 1 as the control group.

In order to better understand the results of the fetal movement counts for the SGA, the fetal movement parameters of SGA were plotted over the normal reference value curves [11].

2) Comparison of fetal movements between the SGA and the control group.

Linear regression analysis was conducted with two explanatory variables (SGA/control and gestational weeks) and with the fetal movement parameters as response variables. The statistical analysis used was JMP PRO 12 (SAS Institute Inc., Tokyo, Japan), and P values < 0.05 were considered to be significant.

The Ethics Committee of our hospital approved the study, and all participants provided written informed consent.

Results

Thirty-eight data recordings were available from the 13 women in the SGA group. The mean times (standard deviation) of recordings per woman were 2.92 (2.27), and the total recording time was 275 hours. The mean recording time for one night was 434.7 minutes (67.72).

1)

Figure 2 shows the distribution of the ratio of positive 10-second epochs (a) and the average number of fetal movements (b) for the SGA infants over the normal reference value curves. Regarding the ratio of positive epochs, 14 recordings (36.8%) were below the 10th percentile of the normal values. As for the average number of movements, 13 recordings (34.2%) were below the 10th percentile.

Figure 3 shows fetal non-movement periods, including the average number per hour (a), the average duration (b), and the longest duration (c).

As for the average number per hour, 12 recordings (31.6%) of the SGA group were above the 90th percentile of the normal value curves. For the average duration, 13 recordings (34.2%) were above the 90th percentile. For the longest duration, 15 recordings (39.4%) were above the 90th percentile.

Overall, it seemed that fetal movements decreased and fetal non-movement periods increased in the SGA group.

2)

Table 2 shows the results of the linear regression analysis. As was expected, gestational week was a factor that decreased the fetal movement parameters and increased the fetal non-movement period parameters. SGA was a factor that decreased the ratio of positive epochs ($p=0.0002$) and also decreased the average number of fetal movements ($p<0.0001$). Similarly, SGA was a factor that increased the average number ($p<0.0001$), the average duration ($p=0.0012$), and the longest duration ($p<0.0001$) of the fetal non-movement periods.

Discussion

We performed this study to clarify whether SGA is associated with a decrease in fetal movements. First, fetal movements seemed to decrease and fetal non-movement periods seemed to increase in the SGA group in plotting the data over the normal reference value curves. Second, we used a linear regression model. We reported that gross fetal movements decreased as pregnancy progressed [11]. In general, smaller fetuses are forced to be born earlier, since they tend to approach fetal non-reassuring status. Actually, there were eight cases of premature delivery in the SGA group in this study. Between the SGA and the control groups, there was inevitably a bias regarding gestational weeks which affect fetal movement counting; therefore, fetal movements between the two could not be simply compared. That was why we used the model. The linear regression model demonstrated that SGA was the factor that decreased fetal movements and increased fetal non-movement periods.

Fetal hypoxia occurs more frequently in FGR than in normal growth fetuses. Fetal movements decrease when FGR is due to hypoxia. Ribbert LS, et al. [17] reported that nine out of 11 acidaemic growth retarded fetuses showed a decrease in fetal generalized movements. They suggested that a reduction in body movements might precede a reduction in breathing movements. They also reported in their study of 19 FGR that general movements fell below the normal range with progressive deterioration of fetal condition. Baschat AA [18] reported that biophysical profile scores declined 24 hours after blood flow deterioration occurred in severe growth restriction. In a study by Bekedam, et al. [19], maternal hyperoxygenation was applied to women with FGR fetuses with abnormal Doppler blood velocity waveforms of the umbilical artery, and there was a significant increase in fetal breathing and body movements after the hyperoxygenation.

However, most FGR is not due to hypoxia, and it is not clear whether fetal movements decrease in a majority of FGR fetuses with no hypoxia. D'Elia A, et al. [8] commented that quantitative alterations of fetal movements in FGR could be observed only in fetal hypoxia. In a study by Pardi G, et al. [20], none of 21 FGR fetuses with normal heart rates showed hypoxia by umbilical-vein blood measurements. All the SGA infants in our study showed normal heart rate patterns during pregnancy, indicating that they did not suffer from hypoxia. Umbilical blood examinations and Apgar scores for the newborns also suggested that they were not hypoxic during pregnancy. Our study demonstrated that SGA is associated with decreased movements even when fetuses are not hypoxic.

The etiologies of FGR are various; however, majority of them is placental functional deficiency. It is well known that placental weight of FGR is smaller, which was shown also in the Table 1 of this study. FGR increases blood flow to the brain and decreases the flow toward the peripheral body. This redistribution of blood flow occurs before the fetus becomes hypoxic and is considered an adaptation of the fetus to an insufficient environment. Similarly, we thought it would be reasonable if the fetus decreased body movements in order to adapt to placental functional deficiency before becoming hypoxic.

The Table 1 also showed that umbilical cord length of FGR was shorter. We recently reported that gross fetal movements might be a promoting factor to elongate the cord length [21]. Though it is unclear whether decreased fetal movements is related to shorter cord in SGA, we thought it interesting that FGR has shorter umbilical cord. Those need further studies.

Looking at the distributions of fetal movement parameters of SGA plotted over the normal reference curves in Figure 2, the decrease of fetal movements in SGA seems slight. There seems to be substantial variability in fetal movements in SGA. Also, several studies have reported that there is a great deal of variability among normal fetuses (Bekedam, et al. [7], Vries, et al. [22], Ten Hof, et al. [9]). In a review by Bos AF, et al. [23], the authors commented that this large variability in fetal movements makes quantitative assessment an insensitive indicator of compromising conditions. The slight decrease of fetal movements in SGA and large individual differences in both SGA and normal fetuses make it difficult to detect differences between the two groups. Short-term observations could not detect these differences.

We originally thought that hypoxia would cause a large decrease in fetal movements that could be detected even during short-term observation; however, the decrease in fetal movements as an adaptation in order to avoid hypoxia is slight and cannot be detected by short-term observation. Detection requires long-term observation.

The fetal non-movement periods increased in SGA. A period of no fetal movements means not only fetal stillness but the continuation of stillness, and this could be related to fetal rest-activity cycles. There have been several studies demonstrating that the emergence of fetal behavior states is delayed in FGR. Arduini, et al. [24] reported that healthy fetuses showed a significant trend in the change of behavioral states; however, FGR fetuses showed a random sequence in the order of changes. The same researchers [25] also reported that FGR fetuses showed an increase in periods of no coincidence between behavioral state variables when compared to normal fetuses. The increase of periods of no fetal movements in FGR might have an association with the delay of behavior state establishment, which needs further studies.

The advantage of the FMAM recorder is that it can count fetal movements over a long time period; however, there is a concern about its accuracy. We discussed the accuracy of the FMAM recorder in our previous studies [11-13]. It is ethically and methodologically difficult to confirm the accuracy of the FMAM recorder during home use while mothers sleep naturally. However, in a previous study [12], after 28 weeks of gestation, gross fetal movements were counted simultaneously by the FMAM recorder and ultrasonography with the mothers being kept quiet for 60 minutes in a hospital, and the agreement between the FMAM recorder and ultrasonography was almost perfect. Moreover, when the fetal movement counts obtained by the FMAM recorder used at home were compared with those of several ultrasonographic studies [9, 26-27], the numbers from the FMAM recorder were found to be very similar to those from the ultrasonographic results. However, clinical prospective cohort studies are still needed to confirm whether the FMAM recorder is accurate and useful.

This study is one of the needed prospective studies. This study showed that SGA was associated with a decrease in fetal movements. The results were positive and seemed reasonable. We think this study suggests the accuracy of the FMAM recorder.

In conclusion, counting fetal movements over a longer time period using the FMAM recorder has demonstrated that SGA is associated with decreased fetal movements even in the absence of hypoxia.

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Declaration of interest of statement

The authors report no conflict of interest.

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Figure captions

Figure 1. FMAM recorder with two acceleration sensors.

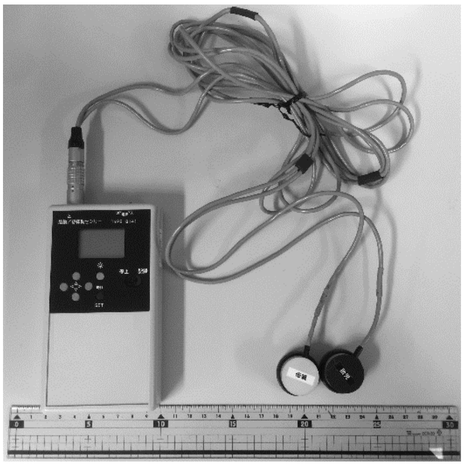

Figure 2. Distribution of fetal movement parameters in SGA over normal reference value curves: (a) ratio of positive epochs, (b) average number per hour. Normal curves are taken from reference [11]. Each dot shows one night's record.

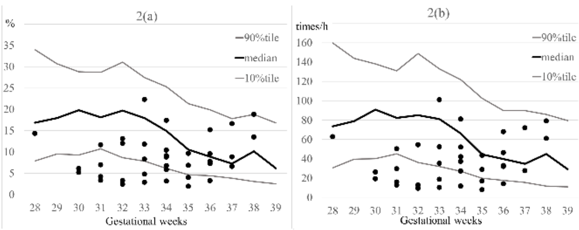

Figure 3. Distribution of fetal non-movement period parameters in SGA over normal reference value curves: (a) average number per hour, (b) mean duration, (c) longest duration through one night. Normal curves are taken from reference [11]. Each dot shows one night's record.

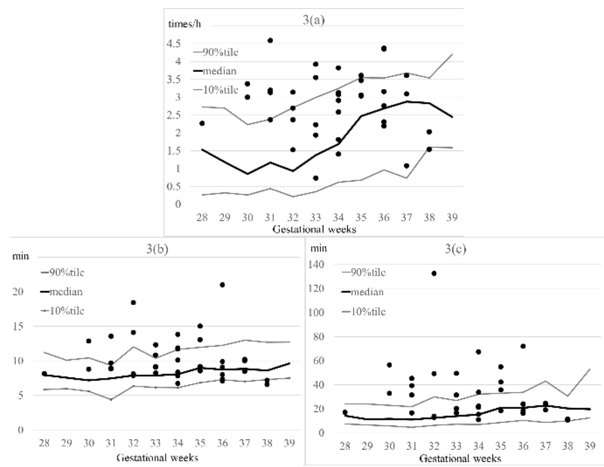

Table1: The characteristics of the SGA group and control group

Characteristics of the mothers	SGA group (n=13)	Control group (n=64)	P-value
Age	33.4 (5.13)	32.7 (4.63)	0.08
Nulliparaous/ Multiparous	10/3	42/22	*
Vaginal delivery/ Cesarean delivery	5/8	45/19	*
Height (cm)	156.4 (4.49)	157.5 (5.14)	*
Body weight (kg)	52.2 (7.40)	52.1 (7.60)	0.84
Body mass index	21.4 (2.85)	21.0 (2.64)	0.10
Complications			
Gestational diabetes mellitus	0	3	
Hypertensive disorder of pregnancy	3	3	
Premature separation of normally implanted placenta	1	0	
Characteristics of the newborns			
Delivery weeks and days	36w5d (11d)	39w1d (8d)	*
Male/Female	5/8	30/34	0.05
Body weight (g)	1910.0 (245.98)	2979.3 (358.51)	*
1min Apgar score less 7/more 8	3/10	2/62	*
5min Apgar score less 7/more 8	0/13	0/64	
Umbilical artery pH	7.3 (0.06)	7.3 (0.07)	*
Placenta weight (g)	405.0 (51.53)	573.9 (101.43)	*
Umbilical length (cm)	44.6 (6.64)	54.6 (11.96)	*

The comparisons between the two groups were done
by Student-t test and chi-square test.
Data are expressed as mean (SD: standard deviation) and number.
*:P-value was below 0.05

Table2：The results of linear regression analysis with the parameters of fetal movements

Explanatory variables : gestational weeks				
Response variables	Regression coefficient	Standard deviation	95% Confidence interval	P-value
The positive epoch ratio (%)	-1.0	0.13	-1.24~-0.74	*
The average number of fetal movements (times/h)	-4.3	0.60	-5.51~-3.18	*
The parameters of non-fetal movement period				
The average number (times/h)	0.1	0.02	0.11~0.18	*
The average duration (min)	0.2	0.05	0.13~0.31	*
The longest duration (min)	1.0	0.21	0.59~1.41	*

Explanatory variables : SGA and control				
Response variables	Regression coefficient	Standard deviation	95% Confidence interval	P-value
The positive epoch ratio (%)	-2.4	0.63	-3.66~-1.15	0.0002
The average number of fetal movement (times/h)	-14.1	2.96	-19.91~-8.27	*
The parameters of non-fetal movement period				
The average number (times/h)	0.4	0.09	0.26~0.61	*
The average duration (min)	0.8	0.24	0.31~1.24	0.0012
The longest duration (min)	6.2	1.03	4.20~8.24	*

*:P-value was below 0.0001