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用胎动加速测量记录仪在家进行胎动计数:初步报告

Fetal movement counting at home with a fetal movement acceleration measurement recorder: A preliminary report

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***Objective*: Fetal Movement Acceleration Measurement (FMAM) recorder was developed to facilitate gross fetal movement counting. The aim was to assess its reliability. *Methods*: Using the recorder, six pregnant women recorded fetal movements by themselves when they slept at their home weekly from 30 weeks to term. The recorder has 2 acceleration sensors; 1 for fetal movement (FM sensor) and another for maternal movement (MM sensor). Before sleeping, each subject attached the FM sensor to her abdomen, and the MM sensor to her thigh. All the recorded data were divided into 10-sec epochs, and presence of fetal movements was judged for all epochs (total epoch). The epoch was judged as positive for movement (positive epoch) when the FM sensor detected abdominal wall oscillations and the MM sensor did not detect maternal movements. The percentage of positive epoch number to total epoch and the maximum consecutive negative epoch number was calculated. *Results*: The mean percentage was approximately 20–25% at 30–34 weeks and 10–15% at 35–38 weeks. The negative epoch number linearly increased after approximately 33–34 weeks of gestation. *Conclusions*: The FMAM recorder was reliable for long-duration recording of gross fetal movements at home.**

FMAM记录仪可在家中长期记录胎儿大体运动。

Keywords: Capacitive acceleration sensor, fetal movement acceleration measurement recorder, fetal death, fetal monitoring, fetal movement counting, fetal well-being, gross fetal movement, home monitoring

关键词:电容式加速度传感器，胎儿运动加速度测量记录仪，胎儿死亡，胎儿监测，胎儿运动计数，胎儿幸福，胎儿总运动，家庭监测

Introduction

Fetal movements are an important biological index to estimate fetal well-being. They are one of the variables of fetal biophysical profile scoring used world-wide [1]. The scoring system has substantially contributed to the field of perinatal medicine; however, it allows qualitative and not quantitative analysis of fetal movements. Furthermore, the scoring system can be used only for a short time in medical facilities and not at home because it involves the use of ultrasonography. Thus, there have been no practical and objective methods for long-duration fetal movement counting.

Nishihara et al. [2] employed a newly developed capacitive acceleration sensor and recorded oscillations of the maternal abdominal wall caused by fetal movements. They demonstrated that oscillations detected by the sensor were strongly correlated with maternal subjective perceptions of fetal movements. By using the newly developed sensor, we have developed a fetal movement acceleration recorder (FMAM recorder, http://e-mother.co-site.jp). The recorder is designed to monitor fetal movements when the mother is sleeping at home. In the previous study [3], we simultaneously observed oscillations of the maternal abdomen by the recorder and gross fetal movements by ultrasonography and demonstrated a high level of consistency between the two instruments. In particular, readings of the 2 instruments were almost perfectly correlated after 30 weeks of gestation. However, these results were examined during a 30-minute interval when the mothers were asked to keep quiet on a bed at a laboratory. It is still unclear how reliable the recorder is when mothers use it at home by themselves.

The purpose of the study was to assess the reliability of the FMAM recorder at home. For this, we collected fetal movement data obtained by the mothers by using the recorder at home and analyzed whether their results were reasonable.

本研究的目的是评估家用FMAM记录仪的可靠性。为此，我们利用家中的胎动记录仪收集母亲的胎动数据，分析其结果是否合理。

Methods

FMAM recorder

The FMAM recorder is shown in Figure 1. It contains 2 acceleration sensors and 4 batteries and weighs 290 g. Both the sensors are similar in structures but have different sensitivities. One sensor is a fetal movement sensor (FM sensor) and the other is a maternal movement sensor (MM sensor). When the FM sensor attached to the maternal abdomen detects abdominal wall oscillations and the MM sensor attached to the thigh of the mother does not detect any maternal movements, fetal movements are judged to have occurred. Both the sensor is disk-shaped, 20 g in weight, and 2.8 cm in diameter. The sensor has 2 electrodes with capacitive acceleration, of which 1 is a movable diaphragm, and the other is a fixed backplate. The diaphragm has a slight weight which works as a pendulum; this increases its sensitivity to detect oscillation. A change in acceleration appears as the amount of change of delta C in electrostatic capacity C between the diaphragm and the backplate arising from the displacement of the diaphragm. The sensitivity of the FM and MM sensors was set at 700 mV/0.1 G and 120 mV/0.1G, respectively. The sensors are completely non-invasive.

Fetal movement counting by using FMAM recorder at home

Six pregnant women volunteered to participate in the study and underwent a total of 61 experiments. Table I shows the characteristics of pregnant women participating in this study. None of these mothers had any complications, and all their newborns were delivered at term without anomalies or neurological problems.

六名孕妇自愿参加了这项研究，共进行了61项实验。表一显示了参与本研究的孕妇的特征。这些母亲都没有任何并发症，所有的新生儿都在足月分娩时没有异常或神经问题。

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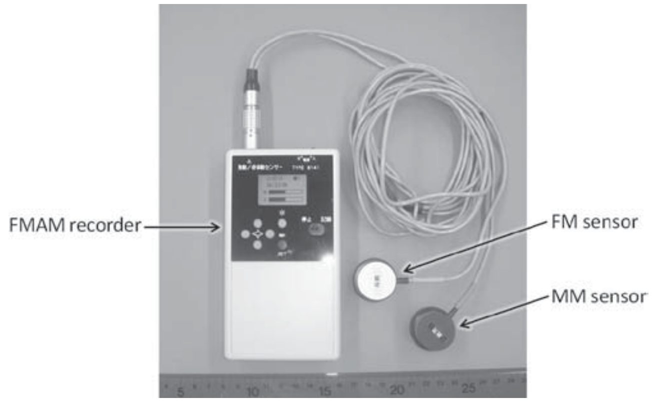

Figure 1. Fetal movement acceleration measurement (FMAM) recorder. It contains 2 capacitive acceleration sensors.

表一:纳入研究的孕妇的特征

Table I. Characteristics of the pregnant women included in the study.

Case	Mother Age	Para	BMI	Delivery day	New born weight (g)	Sex	UA pH
1	36	0	17.53	39w4d	2740	Male	7.285
2	32	0	21.77	40w6d	2776	Female	7.124
3	30	2	19.48	39w4d	3438	Female	7.297
4	35	0	21.48	39w5d	3266	Female	7.368
5	26	0	19.43	38w1d	2896	Male	7.300
6	34	0	22.89	40w6d	3182	Male	7.269

BMI = Body mass index; UA = Uterine artery.

Each pregnant woman was instructed on how to use FMAM recorder and was allowed to take the device home to record fetal movements by herself; the instruction took approximately 10 min. The batteries of the device can be charged at home, and a record is available during 40 h after 1 charging cycle. Fetal movements were recorded during the night while the mother was sleeping. Each mother was asked to record fetal movements weekly from 30 weeks to term. Just before sleeping, each mother attached the FM sensor to her abdomen and the MM sensor to her thigh by using adhesive tape. Next, they turned on the recorder and fell asleep. The next morning, they would wake up and turned off the FMAM recorder. The data were recorded in a SD card. Each time the mothers visited the hospital for a routine check-up, they would remove the card from the recorder and give it to the researchers. The data from the card were transferred to a computer, and the card was given back to the mother for the next recording period.

Data analyses

All the data transferred to the computer were divided into 10-sec epochs; thus, 360 epochs per h. At first, epoch readings for periods when the MM sensor detected maternal leg movements were deleted from data analysis. Next, all the remaining epochs (total epoch) were reviewed to determine whether gross fetal movements occurred. An epoch was judged to be positive for fetal movements (positive epoch) when an oscillation was detected by the FM sensor and it was larger than that caused by the maternal heartbeat and it was not caused by maternal breathing. Abdominal oscillations caused by maternal heart beat and breathing could be identified by their specific regular pattern. Other epochs were judged to be negative for fetal movements (negative epoch). We are now developing a computer program to analyze the oscillation signals, but it is not yet completed. Therefore, the data of this study was analyzed manually.

Thereafter, the number of positive epochs was counted, and its percentage in relation to the total epoch number in 1 night was calculated. Furthermore, the maximum consecutive negative epoch number during 1 night was counted, which indicated the longest interval of fetal quiescence during the night. If the resulting number was 10, it meant that the longest interval of fetal quiescence was approximately 100 sec.

This study was approved by the ethical committee at Teikyo University. All the participating mothers gave their written informed consent for the study.

Results

All the mothers in the study were able to record the fetal movements every time. The mean (SD) recording time and total epoch number for one night was 6.2 (1.3) h and 2147.2 (442.9), respectively. No negative side effects were noted, except for mild contact dermatitis caused by the adhesive tape. Figure 2 is an example of the resulting record showing fetal and maternal movements during 1 night at a study participant's home. The upper part of the figure shows the general view of maternal and fetal movement during maternal sleep from 1:30 to 6:30 AM. The lower part focuses a 5-min epoch at 2:40 AM. We can see 1 signal of fetal movement and no maternal movement in a circle.

Figure 3 shows the percentage of positive epoch number to total epoch number related to gestational weeks. The mean percentage was approximately 20–25% at 30–34 weeks, and it decreased to approximately 10–15% at 35–38 weeks. Figure 4 shows the maximum consecutive negative epoch number during the entire night. It increased after approximately 33–34 weeks of gestation.

Discussion

The purpose of the study was to assess the reliability of the FMAM recorder at home. The only way to accurate assessment is to simultaneously observe the oscillations of the maternal abdomen by the recorder and fetal movements by ultrasonography when the mother is sleeping the night. However, this cannot be done because of practical difficulties and ethical issues.

As the next option, we collected preliminary data on fetal movements recorded by the mothers themselves and analyzed whether the data were reasonable. We asked the mothers to record fetal movements at home with a FMAM recorder. Its use was simple and easy. All the mothers successfully recorded fetal movements every time by using the provided FMAM recorder. The FMAM recorder was handy, safe, and available at home.

To date, various fetal movements in mothers have been studied through ultrasonography, and several quantitative assessments of fetal gross movements have been reported. Patrick et al. [4] studied 10 fetuses at 34–35 weeks and reported that the mean percentage time during which gross movement existed was 8.2%. In another report, Patrick et al. [5] described mean percentage gross movement times of 9.3%, 9.8%, and 11.2% at 30–31, 34–35 and 38–39 weeks, respectively. The same group [6] studied 28 fetuses at 38–40 weeks of gestation, and showed a mean percentage gross movement time of 12.2% for fetuses delivered within 3 days and 11.6% for fetuses delivered >7 days after the study. Similarly, Ten Hof et al. [7] studied 29 fetuses between 24 and 36 weeks and found that the median percentage time during which fetal body movements existed was 17% at 24 weeks and 7% at near term. Furthermore, in a study on 15 fetuses by D'Ellia et al. [8], the median incidences of body movements at every 60-min interval were 50, 43, and 34

每位孕妇都被指导如何使用FMAM记录仪，并被允许带回家自己记录胎儿运动;该设备的电池可以在家里充电，在一次充电循环后的40小时内可以获得记录。在母亲夜间睡觉时记录胎儿的运动。每位母亲被要求从30周到足月每周记录胎儿运动。在睡觉前，每个母亲用胶带将FM传感器固定在腹部，将MM传感器固定在大腿上。接着，他们打开录音机睡着了。第二天早上，他们醒来后会关掉FMAM录音机。数据记录在SD卡上。每次母亲去医院做例行检查时，他们都会把卡片从记录仪上拿下来交给研究人员。卡片上的数据被转移到电脑上，卡片被交还给母亲以进行下一个记录阶段。

数据分析：

所有传输到计算机的数据都被划分为10秒的时间段;因此，每小时360个纪元。首先，当MM传感器检测到母亲的腿部运动时的纪元读数从数据分析中删除。接下来，所有剩余的纪元(全纪元)被回顾，以确定是否有大的胎儿运动发生。当FM传感器检测到一个振荡时，判定胎儿运动为正期(正期)，且该振荡大于母体心跳引起的振荡，而不是由母体呼吸引起的。由母亲的心跳和呼吸引起的腹部振动可以通过其特定的规则模式来识别。其他时期被判定为胎儿运动阴性(阴性时期)。我们现在正在开发一个计算机程序来分析振荡信号，但它还没有完成。因此，本研究的数据采用人工分析。

然后计算正历元数，并计算其占1晚总历元数的百分比。并计算了1夜内最大的连续负历元数，表明夜间胎儿沉默时间间隔最长。如果结果为10，则意味着胎儿沉默的最长间隔约为100秒。该研究得到了Teikyo大学伦理委员会的批准。所有参与研究的母亲都对这项研究给予了书面知情同意。

结果：

所有参与研究的母亲每次都能记录下胎儿的运动。平均记录时间为6.2 (1.3)h，总历元数为2147.2 (442.9)h。除因胶布引起的轻度接触性皮炎外，无不良反应。图2是研究参与者家中一个晚上胎儿和母亲运动的结果记录的一个例子。图的上半部分为凌晨1:30 - 6:30产妇睡眠时产妇和胎儿运动的总图。较低的部分集中在凌晨2点40分的5分钟纪元。我们可以在一个圆圈里看到一个胎儿运动的信号和一个母亲没有运动的信号。图3显示了与孕周相关的正历期数占总历期数的百分比。在30-34周时，平均比例约为20-25%，在35-38周时下降至约10-15%。图4显示了整晚连续最大的负历元数。大约在妊娠33-34周后增加。

讨论：

本研究的目的是评估家用FMAM记录仪的可靠性。只有在母亲夜间睡觉时，用记录仪同时观察母亲腹部的摆动和超声检查胎儿的运动，才能准确判断。然而，由于实际困难和伦理问题，这是无法做到的。下一步，我们收集母亲自己记录的胎动的初步数据，并分析数据是否合理。我们要求母亲们在家里用FMAM记录仪记录胎儿的运动。它的使用简单易行。所有母亲均使用所提供的FMAM记录仪成功记录了每次胎动。FMAM记录仪方便、安全，在家就能买到。

迄今为止，已经通过超声检查研究了母亲的各种胎儿运动，并报道了几种胎儿总运动的定量评估。Patrick et al.[4]研究了34-35周的10个胎儿，报道了存在大移动的平均百分比时间为8.2%。在另一份报告中，Patrick等人[5]描述了30 - 31,34 - 35和38-39周的平均总运动时间百分比分别为9.3%、9.8%和11.2%。[6]同一组研究了28个妊娠38-40周的胎儿，显示3天内分娩的胎儿的平均总运动时间百分比为12.2%，在研究7天后分娩>的胎儿的平均总运动时间百分比为11.6%。类似地，Ten Hof等人[7]研究了29个24 - 36周的胎儿，发现24周胎儿存在身体运动的中位数百分比时间为17%，近期为7%。此外，在D 'Ellia等人[8]对15个胎儿的研究中，每60分钟间隔的身体运动的中位数发生率为50、43和34(图1)。胎动加速测量(FMAM)记录仪。它包含2个电容式加速度传感器。表一:纳入研究的孕妇的特征。如何,母亲年龄对位BMI交货日新出生体重(g)性UA pH值17.53 1 36 0 39 w4d 2740男性7.285 2 32 0 21.77 40 w6d 2776女性7.124 3 30 2 19.48 39 w4d 3438女性7.297 21.48 4 35 0 39 w5d 3266女性w1d 5 26 0 19.43 7.368 2896男性7.300 6 34 0 22.89 40 w6d 3182男性7.269体重指数=身体质量指数;UA =子宫动脉。胎儿移动计数记录2631©2012 Informa UK, Ltd.分别为28、34和38周，中位持续时间分别为9.4、7.15和7.2秒。通过将这些数字相乘，他们分别获得了470、307和245秒的持续时间，他们在60分钟间隔内的百分比分别约为13%、8.5%和7%。这些研究显示，近期存在大胎动的平均和中位比率持续在10%左右。另一方面，怀孕早期妇女的平均总运动时间百分比因报告而异;然而，这些值与term的值相同或大约是term的两倍大。

在我们的研究中，我们统计了正纪元数，并计算了它们与总纪元数的比值;然而，由此得出的数字与胎儿大体运动的持续时间并不完全相等。即使一个短的运动引起腹壁震荡，一个10秒的纪元也被认为是正的。当一个胎儿运动跨越两个时期时，两个10秒时期的计算方法是相似的。在D 'Ellia等人[8]的研究中，近期粗胎动的中位持续时间约为7秒。考虑到这些因素，历期数为正的比率应大于胎儿总运动存在的时间比率，但不应超过最大时间的两倍。在我们的研究中，这个数字在妊娠期大约在10% - 20%之间，这与之前的研究一致。对于妊娠早期，我们的结果显示正历期数比率约为足月数的两倍，这与以前的一些报道一致。

我们知道，胎儿行为状态是在妊娠后期形成的，胎儿静息状态随着妊娠进展[9]而延长。Pillai等人的[10]报道了胎儿运动静止时间最长的间隔，在大约30周后随着妊娠年龄的增加而线性增加。我们的研究结果表明，夜间最大连续负历元数也线性增加，如图2所示。这是研究参与者家中胎儿和母亲运动记录的一个例子。图的上半部分显示了从凌晨1:30到6:30整个晚上母亲和胎儿运动的总体视图。下面的部分集中在凌晨2点40分的5分钟时期。我们可以在一个圆圈里看到一个胎儿运动的信号和一个母亲没有运动的信号。图3。与孕周相关的正历期数占总历期数的百分比。图4。与妊娠周相关的1晚最大连续负历元数。2632 E. Ryo & H. Kamata:妊娠进展的母体-胎儿和新生儿医学杂志，这与Pillai等人获得的结果非常相似。综上所述，本研究中使用家庭FMAM记录仪统计的胎儿总运动数与既往报道相比较为合理。通常情况下，新数据的可靠性难以确认，因为没有其他方法可以提供这种确认，只能通过一种新的方法获得。在之前[3]实验室的研究中，我们分别使用fam记录仪和超声，同时观察了母亲的腹部振动和胎儿的大体运动。事实证明，在怀孕20-29周时，两人的协议是实质性的，在30-39周时，协议几乎是完美的，而且在怀孕后期的协议比怀孕早期的协议要高。这可能是因为胎儿运动的强度随着胎儿的发育而增加。在本研究中，孕妇在妊娠30周后在自己家中记录胎儿运动，其数量与之前的研究相比是合理的。作为初步研究，我们认为FMAM记录仪可以在妊娠30周后准确地进行大体胎动计数。然而，孕妇肥胖和羊水过多等因素可能会降低记录仪的可靠性。这方面的数据很少。记录器的可靠性应在以后获得更多数据后再进行评估。综上所述，当母亲长时间处于睡眠状态时，FMAM记录器可以可靠地计数妊娠30周后的大体胎动。

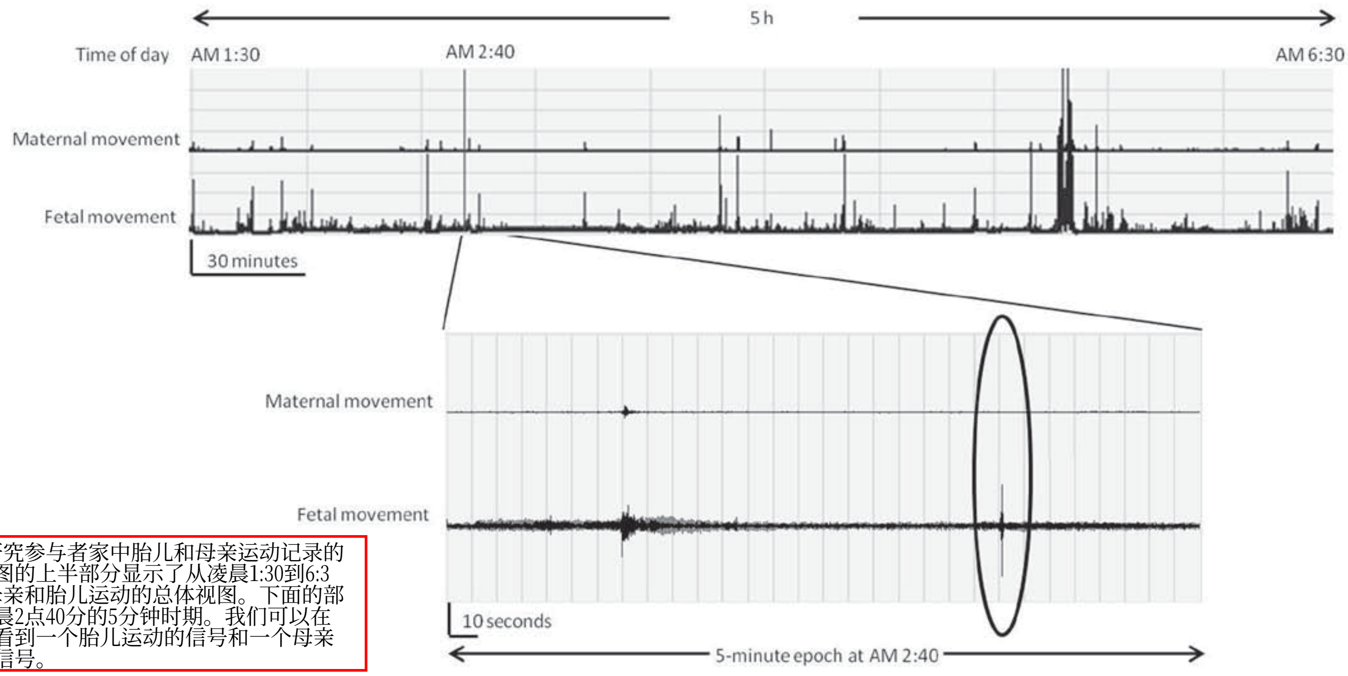

图2。这是研究参与者家中胎儿和母亲运动记录的一个例子。图的上半部分显示了从凌晨1:30到6:30整个晚上母亲和胎儿运动的总体视图。下面的部分集中在凌晨2点40分的5分钟时期。我们可以在一个圆圈里看到一个胎儿运动的信号和一个母亲没有运动的信号。

Figure 2. An example of the record showing fetal and maternal movements at a study participant's home. The upper part of the figure shows a general view of maternal and fetal movements during the entire night from 1:30 to 6:30 AM. The lower part focuses a 5-minute epoch at 2:40 AM. We can see 1 signal of fetal movement and no maternal movement in a circle.

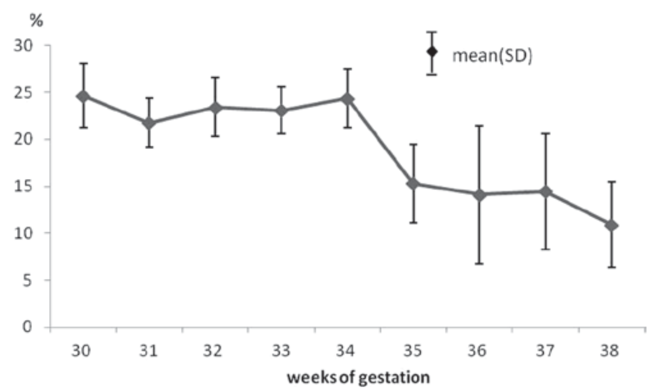

Figure 3. The percentage of positive epoch number to total epoch number associated with gestational weeks.

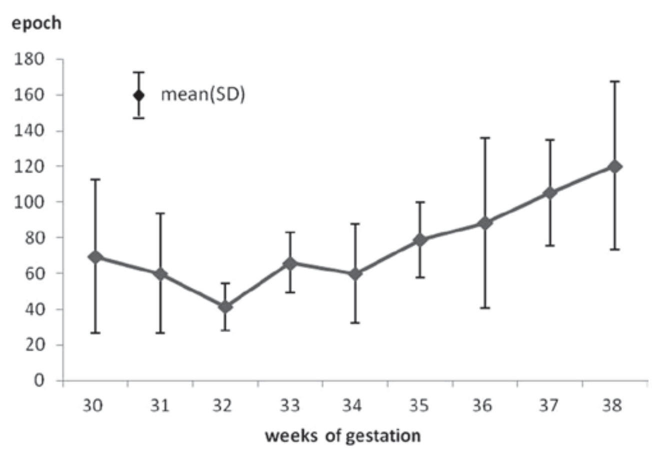

Figure 4. Maximum consecutive negative epoch number during 1 night associated with gestational weeks.

at 28, 34, and 38 weeks, respectively, and their median duration times were 9.4, 7.15, and 7.2 sec, respectively. By multiplying these figures, they obtained duration times of 470, 307, and 245 sec, respectively, and their percentages at 60-min intervals were approximately 13%, 8.5%, and 7%, respectively. These studies showed the mean and median rate of time during which gross fetal movements existed at near term was constantly around 10%. On the other hand, the mean percentage gross movement times for women at earlier stages of pregnancy were different depending on the reports; however, the values were same as those at term or approximately twice larger than those at term.

In our study, the number of positive epochs was counted, and their ratio to the total epoch number of epochs was calculated; however, the resulting figure was not precisely equal the duration of gross fetal movements. Even when a short movement caused abdominal wall oscillation, one 10-sec epoch was counted as positive. When a fetal movement crossed over 2 epochs, two 10-sec epochs were counted similarly. In the study by D'Ellia et al. [8], the median duration of gross fetal movements was approximately 7 sec at near term. With these considerations in mind, the rate of the positive epoch number should be larger than the rate of time during which gross fetal movements exist but should not exceed twice the largest. In our study, this figure was around between 10% and 20% at term of pregnancy, which is consistent with the previous studies.

Regarding earlier stages of pregnancy, our results showed that the positive epoch number rate was approximately twice larger than that at term, which was consistent with some previous reports.

It is known that the states of fetal behavior become established during late pregnancy, and that the fetal resting state is prolonged as pregnancy progresses [9]. Pillai et al. [10] reported the longest interval of quiescence of fetal movements, which increased linearly with advancing gestational age after approximately 30 weeks. The results of our study showed that the maximum consecutive negative epoch number during the night also increased linearly as pregnancy progressed, which was very similar to the results obtained by Pillai et al.

In summary, the number of gross fetal movements counted by FMAM recorder at home in our study appeared reasonable compared with the previous reports.

In general, it is difficult to confirm the reliability of new data, which can be obtained only by a novel method because no alternative methods can provide such confirmation. In the previous study done at a laboratory [3], we simultaneously observed maternal abdomen oscillations and gross fetal movements by using FMAM recorder and ultrasonography, respectively. The agreement between the two proved to be substantial at 20–29 weeks and almost perfect at 30–39 weeks, and it was higher at a latter stage of pregnancy than that at an earlier one. These are probably because the strength of fetal movement increases with fetal developments. In this study, fetal movements were recorded by pregnant women in their own homes after 30 weeks of gestation, and their numbers were shown to be reasonable compared to the previous studies. As a preliminary study, we think that the FMAM recorder can be relied upon for accurate gross fetal movement counting after 30 weeks of pregnancy. However, some factors such as maternal obesity and polyhydroamnios might decrease the reliability of the recorder. There are few data about that. The reliability of the recorder should be re-evaluated after more dater is later obtained.

In conclusion, the FMAM recorder is reliable for counting gross fetal movement after 30 weeks of pregnancy when the mother is asleep for long duration of time.

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***Declaration of Interest*:** The authors declare no conflict of interest.

References

1. Manning FA, Platt LD, Sipos L. Antepartum fetal evaluation: development of a fetal biophysical profile. Am J Obstet Gynecol 1980; 136:787–795.
2. Nishihara K, Horiuchi S, Eto H, Honda M. A long-term monitoring of fetal movement at home using a newly developed sensor: an introduction of maternal micro-arousals evoked by fetal movement during maternal sleep. Early Hum Dev 2008;84:595–603.
3. Ryo E, Nishihara K, Matsumoto S, Kamata H. A new method for long-term home monitoring of fetal movement by pregnant women themselves. Med Eng Phys 2012;34:566–572.
4. Patrick J, Fetherston W, Vick H, Voegelin R. Human fetal breathing movements and gross fetal body movements at weeks 34 to 35 of gestation. Am J Obstet Gynecol 1978;130:693–699.
5. Patrick J, Campbell K, Carmichael L, Natale R, Richardson B. Patterns of gross fetal body movements over 24-hour observation intervals during the last 10 weeks of pregnancy. Am J Obstet Gynecol 1982;142:363–371.
6. Carmichael L, Campbell K, Patrick J. Fetal breathing, gross fetal body movements, and maternal and fetal heart rates before spontaneous labor at term. Am J Obstet Gynecol 1984;148:675–679.
7. Ten Hof J, Nijhuis IJ, Mulder EJ, Nijhuis JG, Narayan H, Taylor DJ, Westers P, Visser GH. Longitudinal study of fetal body movements: nomograms, intrafetal consistency, and relationship with episodes of heart rate patterns a and B. Pediatr Res 2002;52:568–575.
8. D'Elia A, Pighetti M, Moccia G, Santangelo N. Spontaneous motor activity in normal fetuses. Early Hum Dev 2001;65:139–147.
9. Nijhuis JG, Prechtl HF, Martin CB Jr, Bots RS. Are there behavioural states in the human fetus? Early Hum Dev 1982;6:177–195.
10. Pillai M, James DK, Parker M. The development of ultradian rhythms in the human fetus. Am J Obstet Gynecol 1992;167:172–177.