Quanti🅇cation of body movement measurements in low-birthweight infants

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Quantification of body movement measurements in low-birthweight infants

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Abstract

Aim: This study was performed to quantify body movements for low-birthweight（LBW）infants, and to elucidate the relationship with body weight.

Materials and Methods: Thirty-five LBW infants were studied utilizing piezoelectric body movement sensors placed under incubator mats to record body movements over a 4 – 7-day period with 24-hour continuous measurements. The average number of body movements in a 1-day period was calculated for infants divided into four groups according to body weight: 900 – 1399 g, 1400 – 1699 g, 1700 – 1999 g, and 2000 – 2399 g. Correlation and regression analyses were performed for weight at the time of study and number of body movements in 1 day.

Results: The average values（± SD）for the number of body movements in 1 day were 525 ± 326 times for infants with a body weight of 900 – 1399 g（n = 6）, 772 ± 203 times for infants weighing 1400 – 1699 g(n = 12), 1002 ± 303 times for infants weighing 1700 – 1999 g(n = 12）, and 1096 ± 180 times for infants weighing 2000 – 2399 g（n = 5）at the time of the study. Infants with a higher body weight at the time of the study tended to show more body movements. The average body weight at the time of the study (± SD) was 1693.8 ± 308.9 g, and the average number of body movements in 24 hours was 854.4 ± 316.6, both showing a strong positive correlation with r = 0.588. Using y = 0.6031x – 167.12 from regression analysis of body weight at the time of the study and number of body movements, all infants were within the 95% confidence interval.

Conclusion: The body movements of LBW infants can be detected in a non-invasive manner by utilizing a highly sensitive body vibration measuring device with two piezoelectric elements, and a strong positive correlation was observed between the number of body movements in 1 day and the body weight at the time of the study.

KEY WORDS

Low-birth-weight infants, body movement measurement, quantification of body movements, dual piezoelectric sensor, non-invasive

INTRODUCTION

The aim of this research is to quantify body movements for low-birth-weight（LBW）infants that has a clear observational index and is unaffected by observer subjectivity, and elucidate the relationship with body weight.

The body movement of newborns is an important clinical finding in neonatal diagnostic studies, yet when an infant seems to be lacking energy for some reason, the vague phrase "not doing well" is used. One observation is that of a decrease in activity（lacking energy, lethargy, exhibiting less movement, etc.）[1]. However, such a finding results merely in a temporary record of the subjective observation. Due to there being no standardized observation method or observation record, it is difficult to use this as the basis for treatment or care. Furthermore, methods for objectively measuring and evaluating observations related to "not doing well" have not been

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sufficiently investigated.

Previous research regarding the body movement of newborns has been conducted, with one report classifying the activity of infants into 7 action patterns and investigating the proportion of each action pattern [2]. There are also reports which have quantified the activity of newborns utilizing actigraph measurements [3) 4)]. Actigraphy is a method of measuring a subject's activity level per unit of time which can produce measurements both non-invasively and continuously for long periods of time. In recent years, there have been neonatal apnea monitors such as "Neoguard®" [5) 6)]. However, such research focuses on premature infants and has not examined data from LBW infants, and it has problems with sensitivity as well as with recording data over longer periods of time.

On the other hand, there is a report on birth weight and development outcome. According to Uetani [7) 8)], the development outcome for LBW infants is worse than term infants, and such cases of development outcome have been reported to be particularly prevalent in very low-birth-weight (VLBW) and extremely low-birth-weight (ELBW) infants. In other words, body weight at the time of birth is related to future development and incidence of disorders. Furthermore, infant activity has garnered attention, and with a tendency for the incidence of disorders to be higher the lower the body weight, a thorough investigation of the relationship between body weight and body movement shows promise in turning everyday observational findings into a useful tool.

METHODS

1. Subjects

The study was conducted on 35 LBW infants born between November 2011 and October 2013 at "A" University Hospital and admitted to the neonatal intensive care unit.

The case subjects were LBW infants managed in an incubator immediately following birth, with a gestational age ranging from 28 weeks and 1 day to 37 weeks and 0 days, being born on average at 32 weeks and 3 days, with an average age at the time of study of 2–66 days and number of weeks at the time of study of 30 weeks and 0 days to 38 weeks and 2 days, with an average of 34 weeks and 3 days. The birth weights were 640–2470 g (average of 1686 g), and the body weights at the time of study were 956–2358 g (average of 1681 g). Infants with complications of severe asphyxia or chromosomal abnormalities were excluded.

2. Body Movement Measuring Device

The body movement measuring device is constructed from piezoelectric elements and acrylic boards as shown in Fig. 1. Piezoelectric elements transform mechanical force applied to the piezoelectric body into voltage. Under this piezoelectric effect, applying pressure (force) to the ceramic piezoelectric material results in a polarizing (surface charge) voltage corresponding to the pressure. In this study, we utilized the piezoelectric bodies attached to the diaphragms of unimorph piezoelectric speakers. In other words, utilizing unimorph piezoelectric speakers, we created vibration sensors. The vibration sensors were 2 piezoelectric speakers attached on either side of a metal pressure-transmitting material. Therefore, pressure (force) applied to the 2 piezoelectric bodies would be pressure with identical phase components. The signals from these 2 polarization potentials becomes the summed voltage signal via the operational amplifier, thereby producing a dual piezoelectric sensor with ultra high sensitivity. Fig. 1 shows the 30 x 3 mm dual piezoelectric sensors utilized in this study. Two acrylic boards (600 x 200 x 5 mm) were used to sandwich the aforementioned dual piezoelectric sensors, with 4 screws placed in the 4 corners to hold the sensors in the center of the boards. The dual piezoelectric sensor voltage signals were recorded and saved to a computer via a 16-bit A/D interface. In this study, the sampling period of the A/D interface was set to 50 msec, and 24-hour continuous measurements were conducted. The 24-hour measurement data periods spanning from 12:00 midnight to 11:55 p.m. were automatically written to files. These continuous measurements were carried out for a 4 to 7-day period and the data was saved.

In this study, dual piezoelectric sensors sandwiched between acrylic boards were placed under mats in the incubators to conduct measurements. Fig. 2 shows the dual piezoelectric sensor voltage when 0–100 g loads are added after applying a static load of 1 kg to the acrylic boards containing dual piezoelectric sensors. It also shows the dual piezoelectric sensor voltage when the load is reduced. It shows a detection sensitivity of 1 g.

3. Body Movement Data Detection and Analysis Methods

The body movement analysis used in this study was

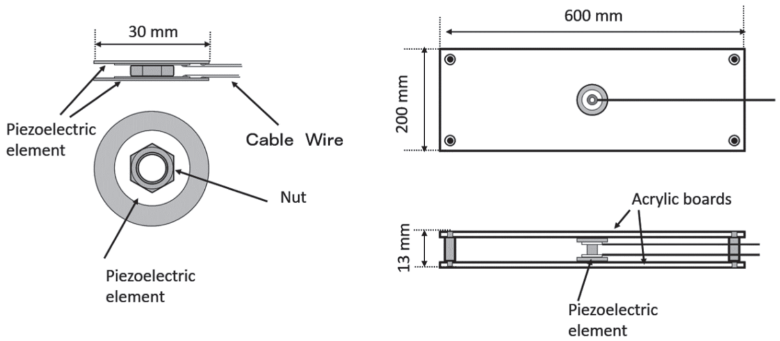

Fig.1 Body Movement Measuring Device
The device is constructed with dual piezoelectric sensors as on the left and 2 acrylic boards. The dual piezoelectric sensors are sandwiched between the 2 acrylic boards and held in place in a central location using screws at the 4 corners.

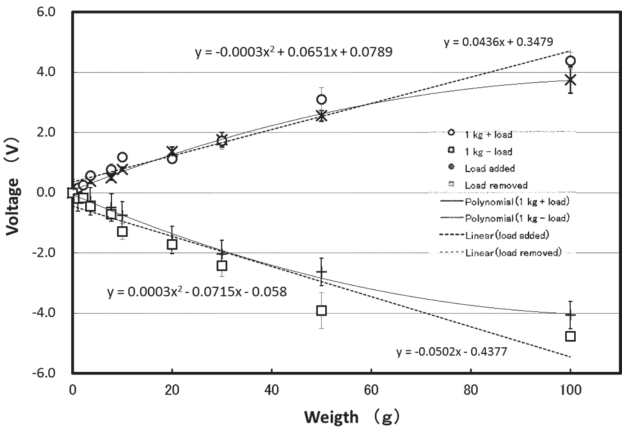

Fig.2 Detection characteristics of the body movement measuring device
The relationship of the piezoelectric element sensor voltage when a load of 0-100 g is applied to a static weight of 1 kg (top) and the piezoelectric element sensor voltage when the load is removed from the static weight of 1 kg (bottom).

conducted with Origin 8.1 (Light Stone Corp.) data analysis and graphing software. Dual piezoelectric sensor voltage data included subtle vibration components caused by breathing and heartbeat components in addition to the limb movements that accompany body activity. Therefore, we performed 5-point data smoothing to remove the subtle components. The removed dual piezoelectric sensor voltage data were the breathing component and the saturated voltage component due to body movement. Body movement was determined by the height of the saturated voltage peak value and the waveform shape in the peak detection setting.

The number of body movements was determined from peak detection in the dual piezoelectric sensor voltage data, and the number of peaks was calculated as the number of body movements per minute. Furthermore, the number of times per minute was detected as the number of body movements in a 5-minute period. The number of body movements in a 5-minute period were taken to be zero when there was absolutely no body movement, with the maximum number of times determined, ranging up to 20. The period of calculation from 12：00 midnight to 11:55 p.m was taken as the 24-hour period of 1 day. The number of body movements that were continuously measured in a 4 to 7-day period were used to determine the average value of the number of body movements at the same point in time of each day, and this was taken as the number of body movements in 1 day.

The analysis of body movements was divided into the following 4 groups based on body weight at the time of study and using the 75 percentile of the normal distribution as a reference: 900–1399 g, 1400–1699 g, 1700–1999 g, and 2000–2399 g. The average number of body movements in 1 day was calculated for each group, and correlation and regression analyses were performed on the body weight at the time of study and the number of body movements in 1 day.

The number of body movements per 5-minute interval and the cumulative number of body movements were also graphed, and the 4 groups (see above classification) were compared by body weight. The statistical software used in this statistical analysis was SPSS ver. 21.0 Japan for Windows.

4. Ethics Approval

This research was approved by the Kanazawa University Medical Ethics Committee (approval number 237). General information on this research and an overview of the study were explained to the parents of the children in this study, and consent was obtained both verbally and in writing. Recorded data was saved to a USB drive with security features, strictly stored in a locked shelf, and every effort was made to preserve anonymity, to prevent leaks of information, and to protect confidentiality.

RESULTS

The detection characteristics of the body movement measuring device are shown in Fig. 2. A 1 kg weight was placed on the acrylic board as a static load, and the dual piezoelectric sensor voltage output values are shown when 1 g, 2 g, 3 g, 10 g, and 20 g weights were added in order. The relation between dual piezoelectric sensor voltage and adding a weight (0–100 g) when a static load of 1 kg has been applied is given by the equation y = -0.0003x2 + 0.0651x + 0.0789. The relation when a weight is removed is given by y = 0.0003x2 - 0.0715x - 0.058. Moreover, the relationship between dual piezoelectric sensor voltage and weight (0–100 g), both when adding and removing weight, was shown to have slightly higher sensitivity in dual piezoelectric sensor voltage when compared to the static 1 kg load.

The average number of body movements in LBW infants was calculated from the number of body movements in a 1-day interval for each day of the 4 to 7-day continuous measurement period. The results are shown in Table 1. From Table 1, for a body weight of 900–1399 g (n=6) at the time of study, the average number of body movements and standard deviation (SD) were 525 ± 326; for a body weight of 1400–1699 g (n=12) at the time of study, the average number of body movements and SD were 772 ± 203; for a body weight of 1700–1999 g (n=12) at the time of study, the average number of body movements and SD were 1002 ± 303; for a body weight of 2000–2399 g (n=5) at the time of study, the average number of body movements and SD were 1096 ± 180. There was a trend showing that the higher the body weight at the time of study, the greater the number of body movements.

The relationship between body weight at the time of study and number of body movements is shown in Fig. 3. The average body weight at the time of study (±SD) was 1693.8±308.9 g, with an average number of body movements in a 24-hour period of 854.4±316.6, both showing a strong positive correlation with r = 0.588 with a significance level of α = 0.01. From a regression analysis of body weight at the time of study and the number of body movements, the subjects were all within the 95% confidence interval, and due to there being no recognized developmental disorders at the point of 3 months after birth, the calculated regression equation for body weight at the time of study and number of body movements, y = 0.6031x - 167.12, was taken as the "standard value."

In a comparison by weight at the time of study, of the distribution of number of body movements in a 5-minute interval and the cumulative number of body movements

Table 1 Number of body movements in 1 day by weight at time of study

Weight at time of study(g)	n	Number of body movements(N/day)
900-1399	6	525 ± 326
1400-1699	12	772 ± 203
1700-1999	12	1002 ± 303
2000-2399	5	1096 ± 180

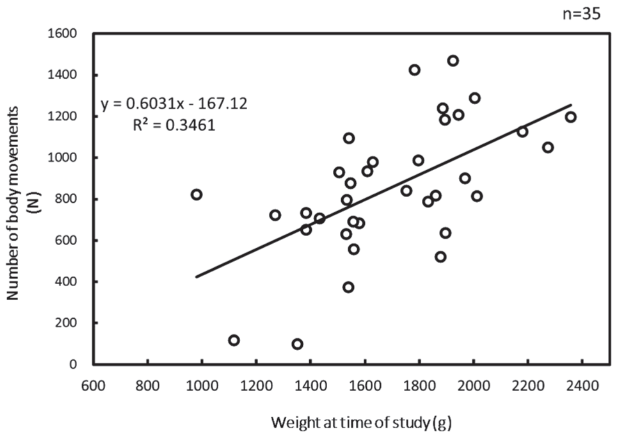

Fig.3 Relationship between weight at time of study and number of body movements in 1 day

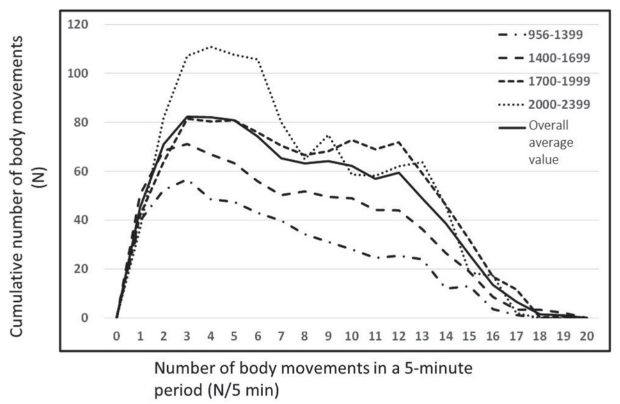

Fig.4 Number of body movements in a 5-minute period by weight class and cumulative number of body movements

in 1 day, the results of the 4 groups sorted by weight at the time of study are shown in Fig. 4. For the group with a body weight of 900–1399 g at the time of study and the group with a body weight of 1400–1699 g at the time of study, the number of body movements in a 5-minute interval peaked at 3 (beats/5 min) and then showed a gradually declining pattern; however, for the groups with body weights of 1700–1999 g and 2000–2399 g at the time of study, after the number of body movements in a 5-minute interval peaked at 3 (beats/5 min) and then gradually declined in a manner similar to the previous 2 groups, the number of body movements in a 5-minute interval again increased at 12–13 (beats/5 min) and then showed a declining pattern thereafter. The number of body movements in a 5-minute interval decreased dramatically at 15 (beats/5 min) and above, with 20 (beats/5 min) being virtually non-existent.

The results of individual comparisons of cumulative

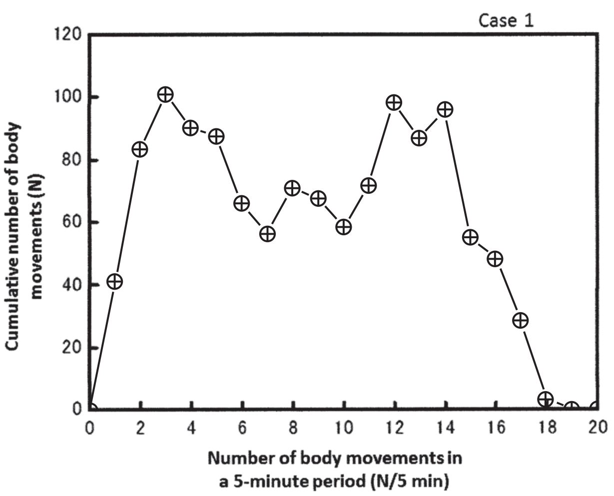

Fig.5 The relationship between cumulative number of body movements and number of body movements in a 5-minute period for an infant weighing 1700-1999 g and aged 10 days or less at the time of study.
The infant in case 1 had complications of CMV infection and thrombocytopenia. Number of weeks at time of study: 34 weeks and 5 days.

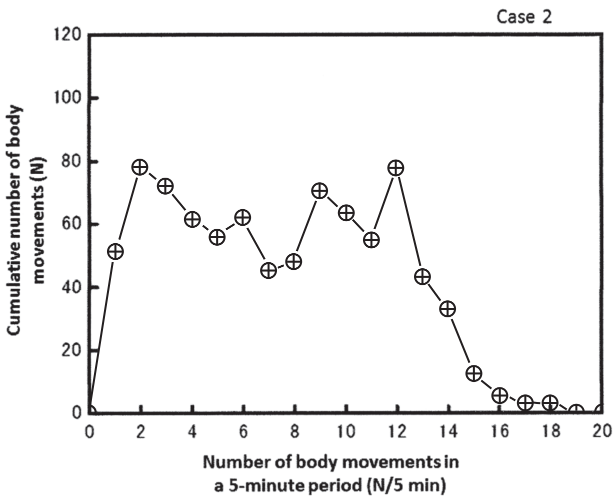

Fig.6 The relationship between cumulative number of body movements and number of body movements in a 5-minute period for an infant weighing 1700-1999 g and aged 10 days or less at the time of study.
The infant in case 2 was an MCDA twin with a complication of disruption of umbilical cord blood flow. Number of weeks at time of study: 36 weeks and 5 days.

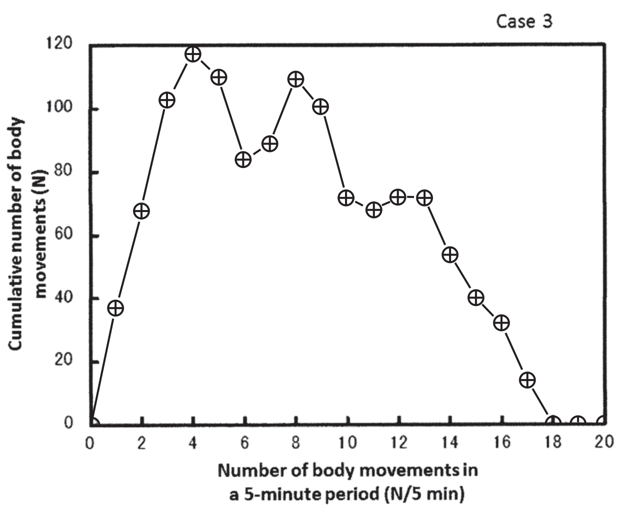

Fig.7 The relationship between cumulative number of body movements and number of body movements in a 5-minute period for an infant weighing 1700-1999 g and aged 10 days or less at the time of study.
The infant in case 3 had no complications. Number of weeks at time of study: 34 weeks and 3 days.

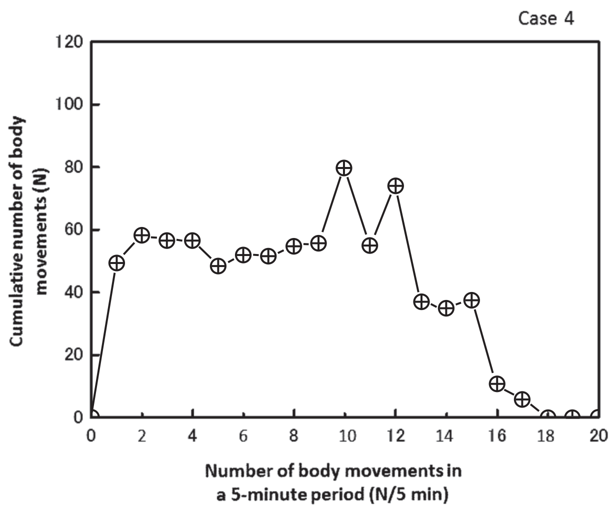

Fig.8 The relationship between cumulative number of body movements and number of body movements in a 5-minute period for an infant weighing 1700-1999 g and aged 10 days or less at the time of study.
The infant in case 4 had no complications. Number of weeks at time of study: 34 weeks and 3 days.

number of body movements in 1 day and number of body movements in 5-minute intervals of infants within 10 days of age and with a body weight of 1700–1999 g at the time of study are shown in Figs. 5–8. Figs. 5–8 show that there are various patterns even within weight groups and that there are large differences between individuals.

DISCUSSION

1. The Utility of the Body Movement Measuring Device

According to this study, it was possible to detect the body movements of LBW infants with high precision by utilizing the body movement measuring device. The method using acrylic boards and dual piezoelectric sensors for the body movement measuring device has been reported in previous research as a monitor for respiratory and heart rate during sleep [9) 10)]. There are also reports of conducting 24-hour sleep evaluations in bedbound elderly subjects based on body motion measurements [11)]. These reports show that heart rate and respiratory rate can be determined from an analysis of dual piezoelectric sensor vibrations. Similarly, the body movement measurements in this study have been reported by developing a device to measure vibrations of various parts of a living organism during sleep [9)]. On the other hand, there are reports which have measured the pulse wave propagation of pulsatile arterial blood vessels in the limbs by directly applying dual piezoelectric sensors to the body's surface [12)]. This report has observed that the detection sensitivity and response time of dual piezoelectric sensors are useful in the detection of vibrations of living organisms.

Detection characteristics are shown in Fig. 2 for the body movement measuring device depicted in Fig. 1. For detection characterization, a 1 kg weight was applied as a static load. Considering that LBW infants are defined as having a birth weight of less than 2500 g, this corresponded to the weight of an ELBW infant. Adding 0–100 g weights to the static load corresponded to body movements of the head and trunk by an ELBW infant at rest. In this case, the fluctuation in weight corresponded to a few hundred grams, and the dual piezoelectric sensor voltage value would be the saturation voltage. In contrast, if the body movement was caused by a portion of a limb, it would correspond to a weight fluctuation of only a few grams. Considering that movements of various parts of the limbs result in only slight body movement, the dual piezoelectric sensor voltage value would be less than the saturation voltage. Therefore, for body movement detection, the saturation voltage peak value as well as slightly lower peak values were classified as "positive body movement."

Furthermore, body movements were identified from peak detection by including the waveform period. From the above, even though monitored subjects in prior studies have all been adults, based upon its detection sensitivity and detection capabilities, this body movement measuring device is also thought to be useful in LBW infants. Furthermore, although actigraphy has been utilized to measure body movements in recent years, these measurements necessitate the application of sensors to the arms and legs, and for LBW infants with immature skin, such measurements may be considered invasive. In regard to Neoguard, since this system is intended for body weights over 1500 g, its use would be very limited for LBW infants. The body movement measuring device utilized in this study is thought to be useful in that it is able to take measurements even from LBW infants under 1500 g and without the need for sensors which come into direct contact with the body.

2. The Relationship Between Body Weight at the Time of Study and Number of Body Movements

In this study, the relationship between body weight at the time of study and number of body movements shows strong positive correlations in body weight and number of body movements as in Fig. 3, with the number of body movements being greater the higher the body weight. The relation of these two can be determined by the linear regression equation $y = 0.6031x - 167.12$, and the closer one is to the value of this regression formula, the more reasonable one can assume the number of body movements to be. In this study, all subjects were without problems in development at 3 months of age, but during collection of future data, there is the potential that outlying values in infants may be recognized as a sign of some sort of abnormality. In addition, prior research has shown that developmental disorders are more prevalent the smaller the birth weight [7) 8)], and by increasing the sample size for body movement measurement, it has been suggested that it may be possible to predict developmental disorders.

3. Distribution of Cumulative Number of Body Movements in 1 Day and Number of Body Movements in 5-Minute Intervals by Weight

In a comparison of the distribution of number of body movements in 5-minute intervals and cumulative number of body movements in 1 day grouped by body weight at the time of study, as a result of classifying the 4 groups by body weight at the time of study, the body weight at the time of study corresponds to a range of VLBW infants with a birth weight of less than 1500 g and LBW infants in the strictest sense with a birth weight of less than 2500 g. In the distribution of number of body movements for the group with a body weight of 900–1399 g at the time of study, the cumulative number of body movements in 1 day were few, and the number of body movements in a 5-minute interval showed a peak at 3 (beats/5 min). This shows that this group of VLBW infants had few body movements; alternatively, it could also be said that they spent the majority of their time in a resting state. In the distribution of number of body movements of LBW infants in the strictest sense, i.e., the group with a body weight of 2000-2399 g at the time of study, the number of body movements in a 5-minute interval was shown to peak at 3 (beats/5 min). In addition, another peak in the number of body movements in a 5-minute interval was observed from around 12 to 13 (beats/5 min). Considering possible contributors to the occurrence of body movements, crying and suckling actions could be thought of as contributing factors. Because oral suckling becomes more advanced the higher the body weight, there is expected to be a high likelihood that crying and suckling actions are involved in the number of body movements around 12 to 13 (beats/5 min). Moreover, there was shown to be a peak value in the number of body movements at 3 (beats/5 min) based on the relationship between the cumulative number of body movements in 1 day and the distribution of number of body movements in a 5-minute interval in each of the 4 groups based on body weight at the time of study. This peak of 3 (beats/5 min) in the number of body movements in a 5-minute interval is thought to be a physiological characteristic of LBW infants which could come from a physiological phenomenon of subtle motions arising from different parts of the body in a period of 5 minutes when at rest or when alert.

In a comparison of the patterns in the number of body movements within the same weight group, Case 3 and Case 4 demonstrated completely different patterns even though neither case was noted to have complications or other changes in status throughout the course. Case 1 exhibited a cytomegalovirus infection with thrombocytopenia and elevated CRP, etc., and received treatment with antibiotics during the period of investigation. Case 2 was an MCDA twin (monochorionic-diamniotic twin) delivered via emergency cesarean section due to a disruption in umbilical cord blood flow. Although no remarkable changes in status were noted during the period of investigation, the graphs of Case 1 and Case 2 both showed peaks in 2 locations, forming an "M" shape. It has been suggested that this may be important data indicating an abnormality. In the future, additional collection of data may lead to the determination of "normal patterns" and "abnormal patterns." In prior studies on term infants, subjects underwent continuous behavioral observation from 2 to 5 weeks of age, and it was reported that when the pattern of the condition was not consistent, developmental disorders were later recognized [13]. In addition, in a study on the sleep of newborns on the first day of life utilizing the Home Monitoring System (HMS), many measurements had a relation to later development [14], and premature infants with developmental disorders are thought to display changes in the sleep status from a period in time when the developmental disorders have not yet emerged. Both of these were reports of the early postnatal period, and by conducting studies of body movement beginning in the early postnatal period, it has been suggested that the influence on development may be predicted in a more expeditious fashion.

4. Limitations and Challenges for the Future

Because the subjects of this research were limited to one facility and due to an inadequacy in the number of subjects, the results of this research cannot be generalized. In addition, there is also the possibility that the body movements in this study included not only spontaneous body movements but also artificial body movements due to treatment from medical staff, nurses, etc. Furthermore, the development of preterm infants cannot be adequately evaluated in 3 months, and so further, long-term investigations on the relationship between body movements and development would be needed in the future.

CONCLUSION

The body movements of LBW infants can be detected in a non-invasive fashion by utilizing a highly sensitive body vibration measuring device with 2 piezoelectric elements, and a strong positive correlation was observed between the number of body movements in 1 day and the body weight at the time of study.

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低出生体重児の体動計測と定量化

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要　　旨

目的：本研究の目的は、低出生体重児の体動を定量化し体重との関係を明らかにすることである。

対象および方法：35 名の低出生体重児を対象に圧電素子を用いた体動計を保育器内のマット下に設置し、24 時間の連続測定を 4 ないし 7 日間体動計測を行った。体動の分析は、調査時体重を 900 − 1399g、1400 − 1699g、1700 − 1999g、2000 − 2399g の 4 群に分類し、それぞれの 1 日あたりの体動の平均値を算出した。調査時体重と 1 日の体動数の相関関係と回帰分析を行った。

結果：1 日あたりの体動数の平均値（± SD）は、調査時体重 900 − 1399g（n=6）では 525 ± 326 回、1400 − 1699g（n=12）では 772 ± 203 回、1700 − 1999g（n=12）では 1002 ± 303 回、2000 − 2399g（n=5）では 1096 ± 180 回であり、調査時体重が大きいほど体動数が増加する傾向を示した。調査時体重の平均値（± SD）は 1693.8 ± 308.9g、24 時間体動数の平均値（± SD）は 854.4 ± 316.6 であり、両者は r=0.588 で強い正の相関を認めた。調査時体重と体動数の回帰分析より y = 0.6031x - 167.12 で求められ、対象全員が 95% 信頼誤差内にあった。

結論：圧電素子を 2 個用いた高感度の体振動計を用いることで、非侵襲的に低出生体重児の体動の検出ができ、調査時体重と 1 日の体動数には強い正の相関を認めた。