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# Proposal of WIM-LMS Curves for Standardized Curves of Physical Growth in Young Children

**Kentaro Hayakawa[1*], Katsunori Fujii[2] and Nozomi Tanaka[3]**

[1]Faculty of Human Life Science, Nagoya University of Economics, Inuyama City, Aichi prefecture, Japan
[2]Aichi Institute of Technology, Department of Business Administration, Toyota City, Aichi prefecture, Japan
[3]School of Sport and Health Science, Tokai Gakuen University, Miyoshi City, Aichi prefecture, Japan

***Corresponding author:**
Kentaro Hayakawa,
Faculty of Human Life Science, Nagoya University of Economics, Inuyama City, Aichi prefecture, Japan,

**Received Date:** 08 Oct 2024
**Accepted Date:** 25 Oct 2024
**Published Date:** 30 Oct 2024

**Citation:**
Kentaro Hayakawa. Proposal of WIM-LMS Curves for Standardized Curves of Physical Growth in Young Children. Annals of Clinical and Medical Case Reports 2024.

## 1. Abstract

The standardized curves of physical development in infancy should reflect the reality of developmental phenomena. Especially curves using percentile values, it is important to verify developmental changes by analyzing growth rate curves. Therefore, a wavelet interpolation model that can derive speed was applied to the 50th percentile and mean values of height and weight as calculated using the LMS method to construct a WIM-LMS curve, while the behavior of infant physical developmental parameters and speed curves were analyzed. The results revealed that both the speed curves were most significantly increased in the first month of life, and FLPV was also detected. Furthermore, mid-growth spurt events were also observed, suggesting that the WIM-LMS curve reflects the reality of infant development and that the WIM-LMS curve can used as a standardized chart of infant physical growth in the future.

**Keywords :**
Infants, BMI, Physical growth, Wavelet Interpolation Model, LMS method

## 2. Introduction

The National Growth Survey on Preschool Children is conducted on a national scale by the Ministry of Health, Labor and Welfare's Child and Family Bureau as an administrative survey. This survey was first conducted in 1960 and was conducted every 10 years until 2010. However, the most recent survey, which was supposed to have been conducted in 2020, was postponed to 2023 due to the COVID-19 pandemic and the results have not yet been made public. Naturally, this kind of physical growth survey of young children is especially important. It clarifies the standards for young Japanese children and enables comparison with other countries and is a very meaningful survey that allows us to grasp the standard growth phenomena of Japanese infants and young children. Still, we must ask whether such nationwide data are being fully utilized. In other words, although individual evaluations at the present time are possible based on the measure of standard growth, such evaluations do not assess the growth process. Unless the rate of change in growth is analyzed, it is impossible to evaluate individual longitudinal growth. As pointed out by Tanner [1], annual growth rates derived from average data are affected by the phase difference effect with longitudinal data. This is an important problem when evaluating the rate of change in growth. To overcome this problem, longitudinal data are necessary and a method for analyzing the rate of change is essential.

Particular methods of analyzing the rate of change include the drawing method proposed by Takaishi et al. [2] and the classical growth research of Tanner [3], but in recent years the Wavelet Interpolation Model (WIM) proposed by Fujii [4] has also been found to be useful. Much is known about WIM, but in particular, research on early childhood physical growth [5][6] has used reports of physical growth surveys of young children from 1960 to 2000 by the Ministry of Health, Labor and Welfare's Child and Family Bureau to analyze the growth volume and velocity curves from birth to age 6 for height, weight, chest circumference, and head circumference. This knowledge has allowed for a detailed examination of the physical growth process in young children and further analysis of its historical changes, and has been of particular significance in enabling examinations of the relationship between the rapid increase in physical growth and the high economic growth of specific times. Physical growth in infancy is the period called the first growth period, and Kimura [7], Takaishi et al. [2], and Tanner [3] have explained that the first year after birth is the period in which the greatest increase in the human body is seen in human life. According to Scammon's [8] growth curve theory, the growth of each part of the body shows a pattern of normal or neurotypical growth, but this theory may be somewhat dated. However, if we refer to Fujii's [9] growth curve theory of recent years, the growth patterns in infancy are also seen to be normal and neurotypical. In consideration of such qualitative growth phenomena, Takaishi et al. [10] and Kato et al. [11] have reported the results of the Infant Physical Growth Survey conducted on a nationwide scale by the Ministry of Health, Labor and Welfare's Child and Family

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Bureau. Looking more closely, the first Infant Physical Growth Survey was conducted in 1960, and Funakawa et al. [12] reported the results of the survey conducted at that time. Funakawa et al. [12] reported that, based on nationwide growth monitoring surveys conducted in 1940 and 1950, the height, weight, chest circumference, and head circumference in 1960 were higher than the same measures in the results of Kuriyama et al. [13] in 1950. Takaishi et al. [10] also reported that, while the results for 1960 and 1970 showed a marked increase in physical growth, the results for 1980 showed only a slight increase, and that in 1990 there was a slight downward trend in weight, chest circumference, and head circumference. These reports from the physical growth surveys of infants and young children from 1960 to 2000 are extremely important in creating standard values for physical growth in early childhood. Kamioka and Takaishi [14] applied the percentile method to the results of the 1980 Infant Physical Growth Survey to create a standard value for head circumference and created a freehand standard growth curve graph. In recent years, Kato [11] created a standardized curve by applying the smoothing method of Tango [15] to the percentile values and average values of the results of the 2000 Infant Physical Growth Survey. Although such efforts to create standardized curves are considered essential, strict verification of the growth process is needed to grasp and evaluate individual growth phenomena. However, there is no knowledge from analysis of individual growth processes from longitudinal early childhood data. In other words, the actual phenomenon of early childhood physical growth, which is the basis of the evaluation chart, is not clear. As mentioned earlier, analyzing only actual growth curves is meaningless in understanding the actual state of physical growth. Unless one analyzes the growth rate curve, the changes in growth cannot be verified. In short, the actual state of the growth phenomenon cannot be seen.

Recently, Kato and Yokoyama [16] and Kato et al. [17] have constructed standardized charts for physical growth in early childhood using the LMS method proposed by Cole [18]. It is certainly more objective than constructing an evaluation chart freehand, but the effectiveness of the smoothing method using least squares approximation (spline smoothing) used to draw the curve is questionable. In other words, there is a clear drawback to analysis using the smoothing method in that the actual state of the growth phenomenon is not reflected in the evaluation chart. Of course, without reflecting the actual state of the growth phenomenon, it is impossible to grasp and evaluate the growth process. In short, the smoothing method can guarantee statistical objectivity, but it cannot show the relationship with the growth phenomenon. The smoothing method is the averaging (standardization) of a group of data, which naturally includes phase differences and does not reflect individual growth phenomena. Therefore, to construct an evaluation chart that reflects individual growth phenomena, a method that can analyze individual longitudinal growth data would be effective. Methods of analyzing longitudinal growth data have been debated for a long time. Fujii [19] and Fujii [20] have explained the details of the process, so little space will be devoted to it here. In short, the growth curves using the LMS method proposed by Cole [18] are dependent on a complex logistic function system originating from Tanner [1] and are a fitting system function as a method of analyzing growth curves. Since these curves do not pass through the observed data points, they have the disadvantage of not reflecting strict growth values and rate curves. It is impossible to precisely identify the important pubertal peak. Therefore, it is evident that if the growth curve does not pass through each age point of the median derived by the LMS method, the growth value curve will be very approximate. Fujii4) has tried to elucidate the growth phenomenon from growth value curves by applying WIM to the average values, but it has not been confirmed whether the growth value curve using the median value of the LMS method reflects the actual state of the growth phenomenon. There fore, in this study, we constructed a WIM-LMS curve derived by applying the WIM to the median value using the LMS method applied by Kato and Yokoyama [16] and Kato et al. [17], analyzed the behavior of the early childhood physical growth current values and velocity curves, and also applied the WIM to the time series of average values to verify whether the WIM-LMS curve is valid as an early childhood physical growth standardization curve.

## 3. Methods

### 3.1. Data used

We used the average height and weight of boys and girls taken from the infant and child physical growth survey records published by the Ministry of Health, Labor and Welfare in 2010 [21] and the median values calculated using the LMS method from the same survey records.

### 3.2. Analysis method

WIM uses a wavelet function (the basis function is Meyer's mother wavelet) to interpolate data and draw a current value curve to approximate the true growth curve from given growth data. The drawn current value curve is then differentiated to derive a growth velocity curve, and the current values at the pubertal peak and age of menarche are examined. WIM is characterized by its sensitivity to local phenomena and extremely high approximation accuracy. Details of its theoretical background and the basis for its effectiveness have been described in the author's earlier research [4] [5] [20] [21]. The procedure for analyzing growth data using WIM is as follows:

- The age axis (t) for early childhood represents the ages at which measurements were taken every six months from 0.25 to 6.25 years of age: 0.25, 0.75, 1.25, 1.75, 2.25, 2.75, 3.25, 3.75, 4.25, 4.75, 5.25, 5.75, and 6.25 years, and the vertical axis (y) represents the current growth values of height and weight at each measurement age {ti: i = 0.25, 0.75, 1.25 … , 6.25}.
- With the above settings, when 13 time series data {(ti, yi) :i = 025, 0.75, 1.25 ... , 6.25} are given, the growth curve y = F(t) and the approximation curve of the first derivative f(t) of F are derived from an algorithm that calculates the wavelet coefficients aj and k.

### 3.3. Analysis procedure

First, we apply the WIM to the median height and weight of boys and girls in 0.5-year increments from 0.25 to 6.25 years old to construct WIM-LMS

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curves. Similarly, we apply the WIM to the average height and weight of boys and girls to construct average curves, and then provide an overview of the two curves. Next, the largest peak velocity (LPV) age is calculated from the velocity curve obtained by differentiating the WIM-LMS curve from 0.25 to 6.25 years of age. Similarly, the LPV age and LPV are calculated from the velocity curve obtained by differentiating the average curve, and the appearance of each is analyzed. The first local peak velocity (FLPV) and FLPV age are calculated from the velocity curve, and the occurrence status of FLPV age and FLPV are analyzed.

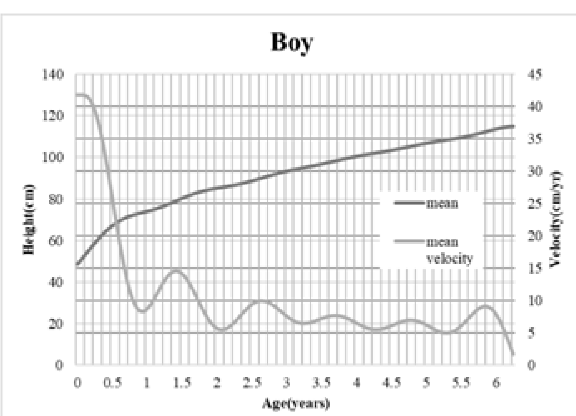
**4. Results**

Figure 1 shows the WIN-LMS curve and velocity curve calculated from the median height of boys. Figure 2 shows the average value curve and velocity curve calculated by applying WIM to the average height of boys. Figure 3 shows the WIN-LMS curve and velocity curve for height of girls, and Fig. 4 shows the average value curve and its velocity curve. Figure 5 shows the WIN-LMS curve and velocity curve for weight of boys, and Fig. 6 shows the average value curve and its velocity curve. Figure 7 and Fig. 8 show the WIN-LMS curve and velocity curve for weight of girls, and the average value curve and its velocity curve.

**Fig1:** Growth distance and velocity curves from 0 to 6 years

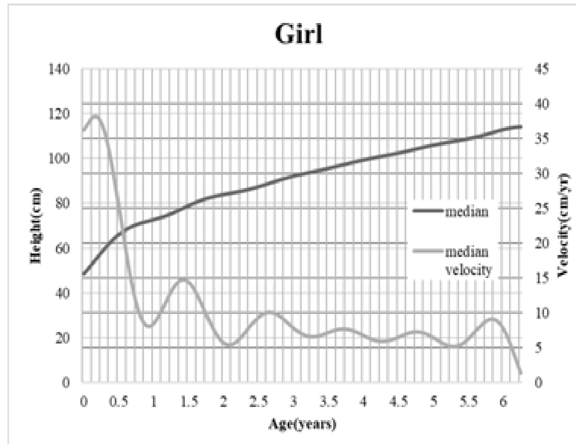

in height of boys by WIN-LMS curves

Fig2: Growth distance and velocity curves from 0 to 6 years



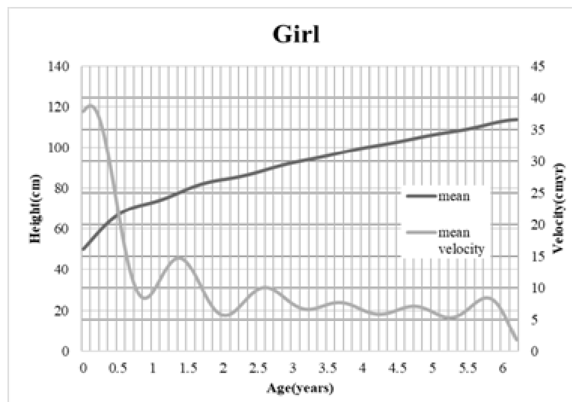

in height of boys by mean curves

**Fig3:** Growth distance and velocity curves from 0 to 6 years in



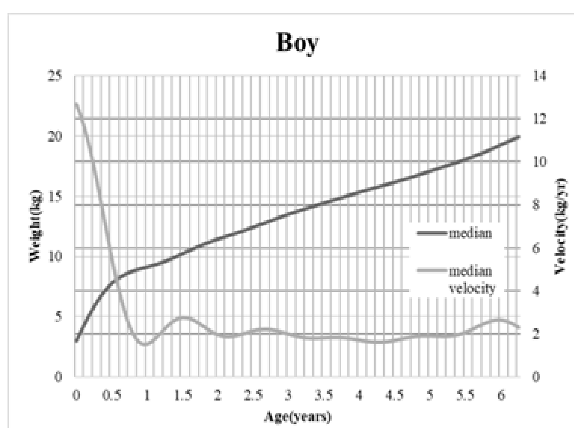

height of girls by WIN-LMS curves

**Fig4:** Growth distance and velocity curves from 0 to 6 years in




height of girls by mean curves

**Fig.5:** Growth distance and velocity curves from 0 to 6 years of




age in boy weight by WIN-LMS curves

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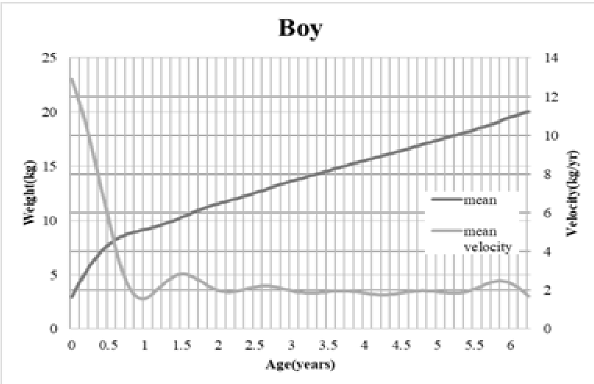
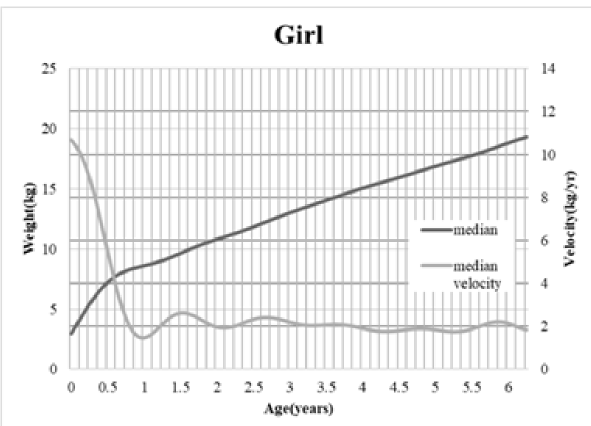
**Fig.6:** Growth distance and velocity curves from 0 to 6 years of



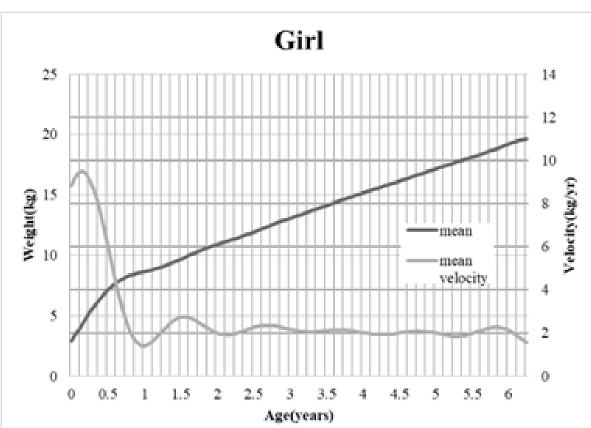

age in boy weight by mean curves

Fig.7 Growth distance and velocity curves from 0 to 6 years of




age in girl's weight by WIN-LMS curve

**Fig.8:** Growth distance and velocity curves from 0 to 6 years of




age in girl's weight by mean curve

Both height and weight show a significant rapid increase from 0 to 1 year of age for both boys and girls. After that, it is clear to the naked eye that they increase at the same rate. Furthermore, boys always have higher rates until age 6. This is clearly shown in the velocity curves. For both boys and girls, there is a sudden drop from 0 to 1 year of age. A slight increase in velocity is shown around age 1.40, but it is then shown to remain steady until age 6.

A detailed overview of the velocity curves shows that for both height and weight of boys and girls, there is a rapid decrease in velocity from birth to one year of age, followed by the largest peak in velocity immediately after birth. After a period of velocity decline (the concave point), there is a slight spurt of velocity again, and again a localized peak in velocity is shown. Thereafter, there is a plateau until age six. It is well known that the first year after birth is the period of most rapid growth in a person's life, and the largest peak in velocity at one time after birth proves this fact. Table 1.2 shows the statistics of LPV and LPV age, and FLPV and FLPV age for height and weight. The LPV age for height differed between boys, with a mean of 0.05 years and a median of 0.1 years, but the mean and median FLPV ages were both 1.4 years. For girls, the LPV age was 0.15 years and the FLPV age was 1.4 years. For weight, the LPV age for boys was 0.05 years and the FLPV age was 1.5 years. The LPV age differed between girls, with a mean of 0.15 years and a median of 0.05 years, but the FLPV ages were both 1.55 years.

**Table1:** Statistics of largest peak velocity and first local peakvelocity in boy's height and weight

| | Height | | | | Weight | | | |
|---|---|---|---|---|---|---|---|---|
| | LPV | | FLPV | | LPV | | FLPV | |
| | age | Velocity (cm/yr) | age | Velo-city (cm/yr) | age | Velo-city (kg/yr) | age | Velocity (kg/yr) |
| Mean | 0.05 | 41.8 | 1.4 | 14.6 | 0.05 | 12.3 | 1.5 | 2.8 |
| Median | 0.1 | 40.9 | 1.4 | 14.2 | 0.05 | 12.2 | 1.5 | 2.8 |

**Table2:** Statistics of largest peak velocity and first local peak velocity in girl's height and weight

| | Height | | | | Weight | | | |
|---|---|---|---|---|---|---|---|---|
| | LPV | | FLPV | | LPV | | FLPV | |
| | age | Velo-city (cm/yr) | age | Velo-city (cm/yr) | age | Velo-city (kg/yr) | age | Velocity (kg/yr) |
| Mean | 0.15 | 38.7 | 1.4 | 14.7 | 0.15 | 9.5 | 1.55 | 2.8 |
| Median | 0.15 | 38.2 | 1.4 | 14.8 | 0.05 | 10.5 | 1.55 | 2.6 |

**5. Discussion**

Surveys of physical growth in infants and young children are conducted on a national scale as an administrative survey by the Ministry of Health, Labor and Welfare's Bureau of Equal Employment Opportunities

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and Children and Families. Immediately after the start of this national project, the results of surveys of infant and young child physical growth by Funakawaet al.[12], Takaishi et al.[10], and Kuriyama et al. [15] were reported, but they only compared the results of current values with past data. As mentioned in the introduction, it is difficult to understand the phenomenon of growth unless the rate of change in growth, and the velocity curve, can be derived. In other words, is there any point in constructing an evaluation chart without elucidating the actual state of growth? The WIM was applied to both the median and mean data calculated by the LMS method for height and weight, and the changes in the velocity of height and weight according to the growth velocity curve were clarified. It was shown that the rapid increase in height and weight during the first year after birth, which had been pointed out in the past, was actually most noticeable in the first month after birth, after which the rate of growth rapidly decreased. After that, the FLPV findings shown in the velocity curves can be said to be estimated from the monthly growth amount, and then the FLPV phenomenon shown in the velocity curves is detected. The first detected LPV was the largest peak of growth velocity in the lifetime of both boys and girls, and the FLPV shown afterwards was the first detected local peak as a local maximum velocity. Such findings were detected not only in the current value curves used to date, but also in the WIM-LMS curves, and both curves are considered to show the actual state of height and weight growth in early childhood.

In addition, when the behavior of the velocity curves obtained by differentiating the WIM-LMS curve and the growth instantaneous value curve is examined in detail, a local peak velocity is shown around 5.5 to 6 years of age for both boys and girls, but this event may be regarded as a mid-growth spurt. According to Fujii[22], a mid-growth spurt is an event that appears before the MPV age (peak age of puberty) in physical growth, and is also said to be a secondary spurt event to the appearance of the maximum growth velocity in adolescence. It is a phenomenon that indicates an increase in growth velocity. Although there has been no clear investigation into the actual situation, it appears from around 5 to 7 years of age, especially in height growth, and is said to appear slightly earlier in girls than in boys. The name mid-growth spurt was coined by Tanner [23] ,and refers to a spurt event in which a slight increase in growth velocity is seen during the process of a continuous decrease in growth velocity from birth to the age at which the rapid pubertal increase begins (pubertal spurt age) in cross-sectional height growth data. Prior to Tanner [23], there had been other classic studies on the mid-growth spurt phenomenon, such as those by Backman [24], Count [25], Meredith [26], Boynton [27], and Meredith and Boynton [28], but no clear explanations have been given. In the end, Tanner and Cameron [29] speculated that the mid-growth spurt occurs at around 5.5 to 7.5 years of age in terms of height growth, and that the rise in blood levels of the adrenal cortical hormone androgens at around 7 years of age in both boys and girls is related to the appearance of the mid-growth spurt. However, they said that they had no evidence to support this.

This is probably because these spurts cannot be detected from the current value curves during the growth process alone. In recent years, Berkey et al. [30] applied spline smoothing, and Gasser et al. [31] applied kernel functions to the analysis. Malina and Bouchard [32] also reported on the application of spline smoothing. However, both are data smoothing methods called nonparametric regression. With them, it is difficult to detect localized events. Fujii [23] applied WIM to show that multiple mid-growth spurts appear in height growth before the MPV age and are a precursor of MPV. In this study, the appearance of local peak velocity from 5.5 to 6 years of age is an event that averages out the process of the appearance of multiple spurts. Therefore, it can be said that this study is the first to find that a mid-growth spurt can be detected in the physical growth process from 0 to 6 years of age from the behavior of the WIM-LMS velocity curve. Based on the above, it can be confirmed that the WIM-LMS curve drawn by WIM using the median values calculated by the LMS method reflects the actual state of growth in infants and young children, and therefore it is possible to propose the WIM-LMS curve as a standardized curve for physical growth in early childhood.

**6. Research limitations and future challenges**

The limitation of this study is that it uses the physical growth survey records issued by the Ministry of Health, Labor and Welfare. This is because there are no large-scale longitudinal data on physical growth in early childhood. Because this cross-sectional data was used, there are limitations to how much can be interpreted. In the future, it will be necessary to collect and analyze longitudinal data, as it may be possible to see the details of longitudinal changes in physical growth using an evaluation chart that uses the WIM-LMS curve

**7. Conclusion**

In this study, we analyzed the behavior of the WIM-LMS curve and velocity curve derived by applying the WIM to the median value of the LMS method for physical growth in early childhood, and also applied the WIM to the time series of the average value. The validity of the WIN-LMS curve as an early childhood physical growth standardization curve was verified by comparing it with the growth volume curve and velocity curve. As a result, the change in the velocity of height and weight according to the growth velocity curve in 2010 was clarified. Both curves showed that the rapid increase in the first year after birth, which has been pointed out in the past, is actually most noticeable in the first month after birth, and then there is a rapid decrease in the growth rate. Next, the FLPV phenomenon shown in the velocity curve was detected. The first detected LPV is the largest peak of growth velocity in the lifetime of both boys and girls, and the FLPV is the first detected local peak as a local maximum velocity. Such findings are events detected in both curves and are thought to show the actual state of height and weight growth in early childhood. Finally, a detailed examination of the behavior of the velocity curves revealed that for both boys and girls, a local peak velocity was seen at around 5.5 to 6 years of age. This was interpreted as a mid-growth spurt. The identification of this phenomenon is significant, and therefore the WIM-LMS curve drawn by applying the WIM using the median value calculated by the LMS method reflects the actual state of early childhood growth. For the future, the WIM-LMS curve can be proposed as a standardized curve for early childhood physical growth.

**8. Acknowledgements**

This research was supported by JSPS KAKENHI Grant Number JP23K0224

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