Confirmation of Delayed Menarche Based on Regression Evaluation of Age at Menarche for Age at MPV of Height in Female Ball Game Players

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Abstract

A general delay in menarche in female athletes has been confirmed based on comparisons of mean ages between athletes and non-athletes; however, it has not been possible to judge such delays individually. If delayed menarche could be evaluated for an individual, the athlete could be advised as to necessary precautions. In this study, the age at maximum peak velocity (MPV) of height, adopted as an index of physical maturation, was identified by the wavelet interpolation method (WIM). The relationship between the age at menarche and age at MPV of height in female athletes and non-athletes was then examined. For the athlete group, health examination records of 90 female ball game players in the first year of university in the Tokai area, all of whom had participated in national level competitions, were reviewed for the period from the first grade of elementary school until the final year of high school (from 1985 to 1996). A similar examination was conducted for the control group, among whom a final group of 78 female non-athletes were selected. The age at menarche was determined by questionnaires, and the longitudinal data for height and weight were obtained from the health examination records. Based on a comparison of the difference between the age at MPV of height and age at menarche in ball game players and the control group, a tendency was seen for the difference between the two ages to narrow as the age at MPV of height rose. A corrected regression evaluation of age at menarche against age at MPV of height was derived in the control group, and the evaluation system was applied to ball game players. The delay in menarche in ball game players could be individually evaluated.

Key word: delay in menarche, maximum peak velocity (MPV), ball game players, wavelet, regression analysis

Introduction

The age at menarche is generally well-known as an index of female physical maturation. Because this age is controlled by inheritance factors, it is considered to be an index of a steady physical maturation. Menarche occurs during puberty as a result

of changes in the endometrium, ovarian follicles, and secretions from the ovaries and pituitary gland, which is located inferior to the cerebrum, caused by stimulation from the hypothalamus. However, age at menarche, the conventional index of a steady physical maturation, has been reduced in significance with the appearance over the past few decades of theories as to what

The trend line 1 applied conveniently with the above corrected regression evaluation is derived from the following equation.

Trend line 1: $y=0.589x+6.61$

The calculation method of trend line 1 is as follows.

First, substitute 9.80 years of age at MPV of height as the mean in early maturation for the regression equation ($y=0.682x+4.55$). The estimated age at menarche, $y=0.682 \times 9.80 + 4.55 = 11.2336$, is calculated. Next, substituting 12.05 years of age at MPV of height as the mean in late maturation for the regression equation ($y=0.682x+4.55$), the estimated age at menarche, $y=0.682 \times 12.05 + 4.55 = 12.7681$, is calculated. 1.5 SD ($1.5 \times 0.76 = 1.14$, $1.5 \times 0.62 = 0.93$) of difference between age at MPV of height and age at menarche in both maturation bands is added to the above-mentioned estimated age at menarche in the early and late maturation bands. The trend line 1 that

passes through the two points (y_1, y_2) in the early and late maturation bands with the added 1.5 SD is determined.

In other words,

$y_1 = 11.2336 + 1.14 = a \times 9.80 + b \dots (1)$ $y_2 = 12.7681 + 0.93 = a \times 12.05 + b \dots (2)$

From equations (1) and (2), $a=0.589$, $b=6.61$, trend line 1 $y=0.589x+6.61$ is derived.

Received Sep. 1, 2003/Accepted Oct. 20, 2004

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triggers the onset of menarche. Frisch and Revelle (1) proposed a critical weight hypothesis for the onset of menarche. This was soon afterward reinvestigated by Johnston et al. (2) and later discussed, but refuted by Johnston et al. (3) and Trussel (4). A critical fat hypothesis has also been proposed, in which body fat is adopted instead of weight.

Attention has also been focused on a series of reports by Malina (5, 6) and Malina et al. (7–9) on delayed menarche from sports training. These reports suggest that girls who undergo regular daily training before and after menarche come to lose the balance in the ratio of body weight to fat, and that the excessive physical and mental stress from regular training in female athletes tends to cause delayed menarche. Mesaki et al. (10) compared the age at menarche between a group that began training before menarche and a group that began training after menarche. They reported later menarche in the group that had begun training before menarche, suggesting that the delayed menarche was caused by the athletic training. The essential problem with regard to delayed menarche in athletes, however, is that the delay itself has not been objectively proven, even though a hypothesis for delayed menarche has been constructed by Malina and Bouchard (11). Essentially, there are no objective criteria by which to judge a delay in menarche.

It would thus seem virtually impossible to prove delayed menarche. However, Fujii (12) proposed age at peak height velocity in adolescence as the criterion of physical maturation against which to verify delayed menarche. The reasoning is that since, in any event, training would not influence age at peak height velocity in adolescence (13), the difference between this age and age at menarche may be used to derive the delay in menarche. As a trial for this, Fujii (12) used the wavelet interpolation method to derive the age of the peak height velocity in adolescence, as a criterion for the physical maturation indicated by Tanner (14) and Tanner et al. (15). A delayed menarche in female athletes is suggested based on these results.

However, these results are based on averages for multiple groups of athletes, and one cannot say that delayed menarche will necessarily occur in all athletes. It is also suggested that there are differences in the extent of the delay according to the type of sport and intensity of training. Thus, it would seem that great individual variation exists in the tolerance to physical and mental stress from training, not just for athletes but for non-athletes as well.

The status of female athletes who show delayed menarche may be understood as a problem of school health, for which delayed menarche needs to be judged in individuals. The age at maximum peak velocity (MPV) of height in female athletes and non-athletes was identified by using the wavelet interpolation method proposed by Fujii (16, 17), Fujii and Yamamoto (18), and Fujii and Matsuura (19, 20).

This technique is effective in a way that other mathematical fitting functions are not. Other mathematical functions, for example, the kernel estimation of Gasser et al. (21) and logistic functions {general logistic functions of Marubini et al. (22), double logistic functions of Bock et al. (23) and triple logistic functions of Bock and Thissen (24) or the Preece and Baines model (25)} are fundamentally data smoothing methods like the spline smoothing method of Largo et al. (26). In other words,

the growth curve does not pass through observed data points when using these methods; rather, they are structured so that the curve passes a place near each data point, as in the technique using the least squares method. The greatest drawback of these methods, as pointed out by Simonoff (27) is the lack of local adaptability, and local peaks cannot be specified because the areas of the maximum and minimum points are flattened. Protrusions like the peak height velocity (PHV) are leveled, and as a result this kind of mathematical fitting function is not suitable for application to determine peaks during puberty.

Using the wavelet interpolation method, it becomes possible to judge the delay in menarche based on the difference between age at MPV of height and age at menarche. However, the possibility has been suggested that this difference changes with the differences in physical maturation, as shown in the previous study (12). Thus, with the criterion in which this difference is assumed to be constant, girls with different physical maturation will have different results. Therefore, there is a need to objectively understand the changes in this difference.

In the present study, the relation between physique at menarcheal age and the final height was first examined, and the change in the difference between age at MPV of height and age at menarche was examined from a regression analysis of age at menarche against the age at MPV of height. Next, by designing a regression evaluation for the age at menarche against the age at MPV of height, the validity of the evaluation was examined with consideration of the change in difference between age at MPV of height and age at menarche. This evaluation was then applied to female ball game players to clarify individual status in terms of delayed menarche and examine delayed menarche in this group.

Methods

Data

One hundred and fifty first-year female university students in the Tokai region of Japan, all of whom had participated in national sport competitions at the high school level (ball game players group), were chosen as subjects. Consent was obtained for the inspection of health examination records, the use of measurement data on height and weight, and participation in a questionnaire survey. Longitudinal height and weight records of the subjects for the period from the first grade of elementary school to the final year of senior high school (1985 to 1996) were used. The age at menarche was confirmed according to the method of Malina et al. (9) and Mesaki et al. (10), which is used internationally. After consent from each subject had been obtained, we confirmed ages down to units of months in an interview (calculated to the first decimal place in each age). Height and weight were limited to those measured in April, and data in which the age at menarche could not be confirmed to the month were not used. Finally, 90 subjects for which data were complete were used for the analysis.

The sports played by the 90 female athletes were as follows (numbers of individuals are in parentheses): basketball (15), volleyball (21), softball (7), tennis (16), soft-ball tennis (25), and table tennis (6). All were prizewinners in prefectural level competitions, and had been selected for national competi-

tions. All had trained about three to four hours a day, six days a week from the beginning of junior high to the end of senior high school (ages 12 to 17). According to the questionnaires and interview responses, their previous history of training had in most cases started from the fifth grade of elementary school (age 10).

For the control group of non-athletes, we chose 131 first-year female university students in the Tokai region that had undergone almost no athletic training before and after the age of menarche. Longitudinal height and weight records were obtained for the years from the first grade of elementary to the third year of senior high school (1985 to 1996), following a procedure similar to that for the ball game players. The age at menarche also was confirmed according to a procedure similar to that for the ball game players. Moreover, the data for 78 subjects for whom complete data were available were examined closely using a similar standard to the ball game players, and those data were used for the analysis. The content of the questionnaire survey was shown in a previous study (12), and shall be omitted here.

Analytical techniques

To approximate the true growth curve from the supplied growth data with the wavelet interpolation method (WIM), the interval between data and data are interpolated from the wavelet function and a growth distance curve is drawn. This distance curve is differentiated to arrive at the growth velocity curve, and the growth distance value of the age at menarche and the puberty peak is examined. The WIM can sensitively read local phenomena, and has an extremely high level of approximation accuracy. The theoretical background and grounds for its efficacy have been described in previous studies (16–20).

The procedures were applied to the growth distance values for height and weight from 6 to 17 years of age in the ball game players and control groups. First, WIM was applied to the age distance value for height. Then, the age distance curves for height in both groups were differentiated, and the age at MPV of height (MPV of height during puberty) was specified from the velocity curve through this process. In addition, this process was conducted for each individual, height and weight at menarche were calculated, and the difference between age at MPV of height and age at menarche was calculated for each person.

Procedure of analysis

1. Regression analysis of age at menarche for age at MPV of height in ball game players and control groups

The difference between age at menarche and age at MPV of height is the difference demonstrating the essential delay in menarche; however, this difference becomes gradually smaller as the age at MPV of height increases. A regression analysis for age at menarche against age at MPV of height was carried out in order to construct an evaluation system based on this change. The actual changes with the increase in age at MPV of height were therefore examined in the ball game players and control groups.

2. Construction of regression evaluation system for age at menarche against age at MPV of height

Standard error is derived from the regression plane based on the results of regression analysis for age at menarche against age at MPV of height in the control group. However, since it is predicted that the difference between the age at MPV of height and age at menarche changes with the age at MPV of height, standard deviation may differ in the early and late maturation bands. Next, the confidence interval and regression of age at menarche for age at MPV of height are derived. In this case, the confidence interval is not treated as a straight line though it has the meaning of a band. Accordingly, a corrected regression evaluation by which the trend lines refer to standard deviation in early and late maturation bands are graphically drawn, and constructed as a standard.

Results

Relationship between age at menarche and age at MPV of height

Normality of age at menarche in ball game players and control groups

Normality regarding the age at menarche was examined in the ball game players and control groups. The normal distribution function for the theoretical frequency calculation is shown as follows.

$$\begin{array}{l} \text{<Age at menarche in the ball game players group>} \quad \text{<Age at menarche in the control group>} \\ f(x) = \frac{0.5 \times 90}{\sqrt{2\pi} \times 1.21} e^{-\frac{(x_i - 12.82)^2}{2(1.21)^2}} \quad f(x) = \frac{0.5 \times 78}{\sqrt{2\pi} \times 0.90} e^{-\frac{(x_i - 12.11)^2}{2(0.90)^2}} \end{array}$$

The chi-square (χ^2) values obtained from the above-mentioned normal distribution function are 23.88 for the ball game players group and 7.77 for the control group, demonstrating normality in both groups.

Physique at menarche in ball game players and control groups

Table 1 shows the statistical values for age at menarche, and the difference between age at menarche and age at MPV of height in all ball game players, players of each ball game, and the control group. As shown in Table 1, there was a significant difference ($p < 0.01$) between the ball game players and control group in difference of age at MPV of height and age at menarche.

Mean values and the results of significance tests for height, weight, BMI at menarcheal age and final height are shown for the ball game players and control group in Table 2. There was a significant difference ($p < 0.01$) in each item, and final height in the ball game players group was greater than in the control group. Height, weight and BMI at menarche were also larger in the ball game players group than in the control group. The correlation between height at menarcheal age and final height was $r = 0.813$ in the control group and $r = 0.701$ in the ball game players group, both significant at $p < 0.01$.

Table 1 Mean and standard deviation of age at menarche, age at MPV of height, and difference between age at MPV of height and age at menarche

		Age at menarche	Age at MPV of height	Difference between age at MPV of height and age at menarche
Control	mean	12.11	11.02	1.08
N=78	SD	0.90	0.96	0.74
Ball game players	mean	12.82	11.13	1.70
N=90	SD	1.21	1.02	1.22
Basketball	mean	12.67	10.95	1.72
N=15	SD	0.98	0.92	1.15
Volleyball	mean	12.60	10.99	1.61
N=21	SD	1.14	1.08	0.89
Softball	mean	12.90	11.12	1.78
N=7	SD	0.70	1.24	1.06
Tennis	mean	12.85	11.61	1.25
N=16	SD	1.10	0.92	1.11
Soft tennis	mean	13.22	11.01	2.21
N=25	SD	1.27	0.91	1.36
Table tennis	mean	12.17	11.18	0.99
N=6	SD	1.74	1.28	1.22

Table 2 Mean and standard deviation in height, weight and BMI at menarcheal age, and final height

		Ball game players		t-test
		Control group	group	
N		78	90	
Height at menarcheal age	mean	151.80	155.82	**
	SD	6.36	6.89	
Weight at menarcheal age	mean	42.62	46.70	**
	SD	6.59	6.48	
BMI at menarcheal age	mean	18.43	19.18	*
	SD	2.39	1.97	
Final height	mean	158.61	161.12	**
	SD	5.48	5.55	

*p<0.05, **p<0.01.

Regression analysis for the age at menarche against the age at MPV of height

Figure 1 shows the regression equation for the age at menarche against the age at MPV of height in the control group. The correlation coefficient between the two ages was $r=0.747$, which was significant ($p<0.01$). The regression equation ($y=0.682x+4.55$) shown in Fig. 1 gives a construct in which the difference between age at menarche and age at MPV of height becomes gradually smaller as the age at MPV of height increases.

This is confirmed by forming early and late maturation groups from actual data. For convenience, it is assumed that the early maturation band (age at MPV of height<10.54 years= $11.02-SD/2=10.54$) and late maturation band (age at MPV of height>11.50 years= $11.02+SD/2=11.50$) are more than and less than $SD/2$, respectively, judging from statistics (mean=11.02, $SD=0.96$) for age at MPV of height. Therefore, the difference in statistics between age at MPV of height and age at menarche in the early and late maturation bands was a mean value of 1.37

Fig. 1 Regression equation of age at menarche for age at MPV of height in the control group. **Fig. 2** Regression equation of age at menarche for age at MPV of height in the ball game players group.

($SD=0.76$) in the early maturation band and 0.79 ($SD=0.62$) in the late maturation band. In other words, mean and standard deviation were shown to differ in the early and late maturation bands.

Figure 2 shows the regression equation for the age at menarche against the age at MPV of height in the ball game players group. The correlation coefficient between the two ages was $r=0.446$, which was significant ($p<0.01$).

Regression evaluation of delayed menarche in ball game players and control groups

In the case of five-step regression evaluation, five straight lines are constructed in the regression evaluation chart. However, because statistics for the difference between the age at MPV of height and age at menarche differ between the early and late maturation bands, the inclination of each straight line is assumed to differ. Thus, a construction is considered in which the interval between each straight lines is wide in the early maturation band and narrow in the late maturation band.

Accordingly, utilizing the standard deviation calculated expediently in the difference between the age at MPV of height and age at menarche in the early and late maturation bands, straight lines other than a standard line were conveniently made, graphically illustrating the line showing the confidence interval (Fig. 3). For reference, this line becomes trend line 1 (TL1)–trend line 4 (TL4) when it approaches a straight line.

The standard for evaluating delayed menarche may be as follows. When trend line 1 (TL1) is exceeded, there is a possi-

Fig. 3 Corrected regression evaluation of age at menarche for age at MPV of height in the control group. TL1–TL4 are trend lines, RL is regression line.

Fig. 4 Corrected regression evaluation of age at menarche for age at MPV of height in the ball game players group. TL1–TL4 are trend lines, RL is regression line. The above corrected regression evaluation chart is one in which corrected regression evaluation of age at menarche for age at MPV of height in the control group is applied to the ball game players group.

bility of delay. The interval between trend line 1 (TL1) and 2 (TL2) indicates the possibility of some delay, and the regression line (RL) is the standard regression equation of age at menarche for age at MPV of height in the control group. The interval between trend line 2 (TL2) and 3 (TL3) indicates the possibility of normality, and the interval between trend line 3 (TL3) and 4 (TL4) indicates the possibility of somewhat early menarche. Below trend line 4 (TL 4) is judged to be early menarche.

Fig. 4 shows a case in which the corrected regression evaluation constructed on the basis of the control group was applied to the ball game players group. Twenty-six females (28.9%) in the ball game players group and 6 females (7.7%) in the control group exceeded trend line 1, and there was a significant difference between both groups.

Discussion

Even if a delay in menarche among female athletes were proven, there would still be individual differences in the extent of the delay. Moreover, because a girl's height at menarche highly ($r=0.813$) correlated to her final height, it does not mean that physique at menarche can specify the period of onset of

menarche and does not serve as a criterion for determining delayed menarche.

Malina (13) reported that regular sports training does not affect height, timing of PHV, or rate of growth in stature. Subsequently, Fujii (12) derived the physical indicator of age at MPV of height as a criterion showing the delay in menarche, and established the difference with age at menarche as a standard against which to judge delayed menarche.

We compared the age at menarche and age at MPV of height in the present study with those reported in previous studies. Kikuchi et al. (28) stated that age at menarche was about 12.5 years until about 1960. In other more recent studies, Ohi et al. (29) reported that mean age at menarche was 12.10 years old (SD=0.90), Maesaka et al. (30) that it was 12.20 years old (SD=1.10), and Noda et al. (31) that it was 12.16 years old (SD=1.05). Judging from these studies, the age at menarche of 12.11 years old (SD=0.90) in the control group in the present study may be regarded as the average for Japanese girls in general. Age at MPV of height, was reported to be 11.45 years old (SD=0.94) by Takaishi et al. (32), 10.88 years old (SD= 1.33) by Kanefuji and Shohoji (33) and 11.10 years old (SD= 0.92) by Ashizawa et al. (34). Ages at PHV in these studies did not differ greatly with age at MPV of height, 11.02 years old (SD=0.96) in the control group in the present study. Accordingly, though there is a difference in the calculation method, age at maximum peak velocity during adolescence in the present study may be regarded as the average of Japanese girls in general, similarly to age at menarche.

A delay in menarche in ball game players was suggested in the present study (Table 1). However, the results of the present study indicated that this difference changes with the difference in age at MPV of height. Thus, one cannot readily say that a delay in menarche in an individual can be determined without considering the physical maturation in the mean value evaluation method using the difference between age at MPV of height and age at menarche as the standard.

Therefore, to construct a method of assessment that takes physical maturation into consideration, one needs to understand how the difference between age at MPV of height and age at menarche changes with the increase in age at MPV of height. We therefore applied a regression analysis of age at menarche to the age at MPV of height in the control group and investigated the change in the difference between age at MPV of height and age at menarche with the increase in age at MPV of height.

As a result, a regression line was found in which the difference between age at menarche and age at MPV of height becomes gradually smaller as the age at MPV of height increases. In general regression analysis, the standard error is used to construct an evaluation range parallel to the reference line for evaluation. However, as pointed out in the results, the statistical values for the difference in the early and late maturation bands differ, and are judged to be as follows: higher in the age band (early maturation band) in which age at MPV of height is low, and lower in the age band (late maturation band) in which age at MPV of height is high. Accordingly, it is necessary to construct a regression with consideration of the above problem.

In general, three types of groups (mean $\pm$ 1 SD) are used

when forming groups based on distribution. In the present study for age at MPV of height, the 78 people in the control group were classified into early maturers (13 people, 16.7%), normal maturers (57 people, 73.1%), and late maturers (10 people, 10.3%). There were fairly low numbers of early and late maturers, so that confidence in the statistics based on the number of subjects is judged to be low. However, with a 5-group classification (± 0.5 SD, ± 1.5 SD), they were classified into early maturers (7 people, 9.0%), somewhat early maturers (15 people, 19.2%), normal maturers (30 people, 38.5%), somewhat late maturers (20 people, 25.6%) and late maturers (6 people, 7.7%). Therefore, using statistics from both groups, including the somewhat early maturers, somewhat late maturers, early maturers (22 people) and late maturers (26 people) in the 5-group classification, is judged to be appropriate in conveniently constructing a trend line. Accordingly, while utilizing the standard deviation of the interval between age at MPV of height and age at menarche in early and late maturation bands, trend lines other than the standard line showing the confidence interval were constructed for expedience.

In other words, ± 1.5 SD and ± 0.5 SD were applied in standard deviation for difference for the expedient creation of trend lines 1, 2, 4, 5 (refer to the Fig. 3 notes for details). The actual delayed menarche phenomenon only occurs when age at MPV of height is between the ages of 8.5 and 13.5 years, so the setting of the age axis may be applied in a range between 8.5 years and 13.5 years. Moreover, because the correlation ($r=0.446$) between age at MPV of height and age at menarche in the ball game players group was significantly similarly to the control group, it is necessary to construct an evaluation standard that takes into consideration the effect of age at MPV of height.

As a result of applying the corrected regression evaluation constructed on the basis of the control group to the ball game players group, there was found to be a significantly greater number of girls who exceeded trend line 1 in the ball game players group (6 vs 26). Therefore, ball game players may have a high possibility of being judged as having delayed menarche. By comparison, normality was shown for the age at menarche in the control group, so 5 girls were classified by probability (6.7%) of $+1.5$ SD that would indicate delayed menarche. In fact there were 6 girls with delayed menarche in the group, but

it is thought that they corresponded with the expected value (five examples).

These trend lines are a standard which shows the possibility of delayed menarche. However, in the present study, it is suggested that the delayed menarche in the ball game players group is greater than in the control group, and the trend line is considered to be effective for evaluation of delayed menarche. A comparison of the difference between age at menarche and age at MPV of height in a previous study (12) suggested that menarche is delayed in athletes, and the evaluation method used in the present study further confirms this delayed menarche. This method takes into consideration the age at MPV of height of individuals, and provides new findings by making it possible to grasp the interrelationships between individual maturation characteristics and delayed menarche for the purpose of judging delayed menarche.

However, it will be necessary to examine the accuracy of age at menarche in the future since it is derived by the recall method. Moreover, though this corrected regression evaluation chart shows directionality with a correct individual judgment of delayed menarche, it will be necessary to examine strict judgments of delayed menarche. In the present study, we showed the fact of delayed menarche and proposed that it may be evaluated. In the future it will also be necessary to improve the effectiveness of the evaluation of the delayed menarche judgment based on more data.

Using previous methods it is very difficult to make a clear judgment of delayed menarche. The evaluation of delayed menarche in the present study adopts a new method to evaluate delayed menarche with consideration of age at MPV of height in order to judge delayed menarche in individuals. Clarification of the extent of delayed menarche in a group of ball game players using this method would seem to be a new finding derived from the novel method of evaluating delayed menarche proposed in this study.

Acknowledgments

This study was supported in part by the Ministry of Education, Science, Sports and Culture and by a Grant-in-Aid for Scientific Research (C) (2) No.11680060 from 1999 to 2000.

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