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Age-Related Composition of BMI and Body Composition Based on Fujimmon's Growth Curve

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1. Abstract

The pubertal peak in body fat percentage was estimated and its relationship with menarche was previously investigated in regard to changes with age in BMI. However, there are no direct findings on age-related changes in body fat percentage and muscle percentage. In this study, wavelet interpolation model was applied to the values for muscle percentage, body fat percentage, and age-related change in BMI. Then, to compare the age-related change curves of muscle percentage and body fat volume with the described age-related curve of BMI, a cross correlation function was applied and the similarities and dissimilarities between BMI, muscle percentage, and body fat percentage were investigated. Moreover, their dependence on Fujimmon's growth curve was investigated. The results were judged from three growth patterns based on Fujimmon growth curves. Muscle and body fat percentages in boys did not depend on any growth patterns. Thus, it is thought that independent growth patterns were formed. Similarly, the muscle percentage in girls also formed an independent growth pattern, but body fat percentage is thought to depend on the general type growth pattern, similar to age-related changes in BMI. These results present the novel findings that body fat percentage in girls is closely related to BMI throughout the school years, and shows a general type growth pattern.

2. Introduction

Increases in muscle percentage basically depend on increases in body weight, but the trends in these increases differ between men and women. Body weight is expressed as the total of body fat mass, bone mass, and muscle mass. In males, muscle mass shows a rapid increase during puberty, but in females it is body fat mass that increases and the increase is not that rapid. We therefore thought that in place of the absolute indices of muscle percentage and body fat percentage as the proportion of the body accounted for by muscle mass and fat mass, the increases in muscle mass and body fat mass could be compared between boys and girls if was known how they change with age. The growth in height and weight are fundamentally classed in the general-type growth pattern in Scammon's growth curves [1]. Tanner [2, 3] and Takaishi et al. [4] gave detailed explanations of growth patterns for various physical attributes, and of course the growth in physical size is shown to be classified as the general type of Scammon growth curve.

However, Scammon's growth curves were proposed more than 90 years ago, and the theory was constructed in an age when computers did not exist. Today, when so much more is understood scientifically, it is natural that we should to try and verify the validity of a theory proposed more than 90 years ago. No report has yet clearly validated this theory. Given the above, in this study the theory proposed by Scammon was first re-examined to investigate the standardization of the human growth system, and a new growth curve model was constructed for the standard human growth pattern by Fujii [5]. That growth model pattern is proposed as the Fuijimmon growth curve. Fujimmon growth curve is constructed by a wavelet interpolation model, and sigmoid curve in which the growth of body size belongs to the general type can be described. In other words, attribute determination of growth patterns belonging to the neural, lymphoid, and general type based on the Fujimmon growth curve can be established.

Therefore, with regard to the age-related changes in BMI, as indicated by Fujii [6], Fujii et al. [7], and Fujii et al. [8], the age-related distance curve is shown as a sigmoidal curve, and a clear pubertal peak is detected when judging from the behavior of the velocity curve. Therefore, the curve of age-related changes in BMI in boys and girls depends on Fujimmon's general type growth pattern. Muscle and body fat percentages are not absolute changes in mass, and so there is some doubt as to whether they can be classified in Fujimmon's three growth curve patterns, but there is a need to investigate the patterns of age-related changes in muscle and body fat percentage.

The pubertal peak in body fat percentage was estimated and its relationship with menarche was previously investigated by Fujii and Demura [9], and Fujii and Tanaka [10] in regard to changes with age in BMI. However, there are no direct findings on age-related changes in body fat percentage and muscle percentage. In this study, referencing the age-related changes in BMI that are dependent on the general growth curve of Fujimmon [5], wavelet interpolation model was applied to the values for muscle percentage, body fat percentage, and age-related change in BMI. Then, to compare the age-related change curves of muscle percentage and body fat volume with the described age-related curve of BMI, a cross correlation function (Matsuura et al., [11] Yamada et al.,[12]) was applied and the similarities and dissimilarities between BMI, muscle percentage, and body fat percentage were investigated. In addition, to consider cases that depend on growth curves other than the general type, that is, the neural type, lymphoid type, or reproductive type, data belonging to these three patterns shown by Fujii et al. [7] are cited.

3. Methods

3.1. Subjects and Materials

The subjects were first to sixth grade students in one elementary school and first to third year students in one junior high school in Aichi Prefecture. They included 331 elementary school boys, 329 elementary school girls, 392 junior high school boys, and 327 junior high school girls. A breakdown is shown in the table below. The survey and measurements were explained to the subjects in advance and their informed consent was obtained. The subjects did not include any children with acute or chronic disease (Table 1).

3.2. Analysis

Elementary School								Junior high school			
	1	2	3	4	5	6	Total	1	2	3	Total
Boys	50	64	50	65	44	58	331	139	120	133	392
Girls	66	47	48	63	51	54	329	118	100	109	327

1) Measurement of physique and body composition (body fat percentage, muscle percentage)

Height was measured using a Tanita digital stadiometer. Body weight was measured during body composition measurements using a Tanita DC-320 dual frequency body composition analyzer. For body composition, soft lean mass (SLM) and fat mass were measured using the same Tanita DC-320 used in body weight measurements. Muscle percentage was calculated as muscle mass (kg) ÷ body weight (kg) × 100. SLM was calculated with the addition of protein mass, and fat mass was calculated by subtracting SLM and mineral mass from body weight. SLM, bone mass, and fat mass were all taken as values relative to height in order to eliminate the effects of height.

3.2.1. Wavelet interpolation model: The wavelet interpolation model (WIM) is a method to examine growth distance values at adolescent peak and menarchal age. A growth curve is produced by data-data interpolation with a wavelet function and by deriving the growth velocity curve obtained by differentiating the described distance curve to approximately describe the true growth curve from given growth data. The effectiveness of the WIM lies in its extremely high approximation accuracy in sensitively reading local events. Details on theoretical background and the basis for this effectiveness are omitted here as they have already been set forth in prior studies by Fujii [6, 13, 14, 15].

3.2.2. Cross correlation function: A cross correlation function is used to show the similarity between two waveforms, and the cross correlation function may be evaluated by convolving one function as shown below. In addition, the degree of time lag can be examined when there are similar regions (Matsuura et al [11], Yamada et al. [12]). In this study, a cross correlation function was assumed from the velocity curve values found from differentiation using the WIM for growth distance values of change of BMI, muscle muss and fat percentage with age. If the calculated values for the two velocity curves are given as x'(t) and y'(t), then the median value-subtracted transformation x(t) and y(t), is given as x(t)=x'(t)-μ and y(t)=y'(t)-μ. Using the transformations x(t) and y(t), the cross covariance is defined as follows, with τ as the time lag assigned to the other data-set and n as the sample size.

$$C_{xy}(\tau) = \overline{x(t)y(t+\tau)} = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x(t)y(t+\tau)dt$$

The cross correlation is the cross covariance Cxy(τ) normalized by the standard deviation of the values for the two velocity curves x'(t) and y'(t), and is given as follows:

$$R_{xy}(\tau) = \frac{C_{xy}(\tau)}{C_x(0)C_y(0)N-j} = \frac{\overline{x(t)y(t+\tau)}}{\sqrt{\overline{x^2}}\sqrt{\overline{y^2}}}$$

Analysis was conducted using the cross correlation function Rxy(τ) calculated as outlined above.

3.2.3. Fujimmon growth curve: Fujii [5] re-examined Scammon's growth curves and considered the general type and genital type, which show the same phenomenon of rapid increase during puberty, to be the same pattern. He then proposed the Fujimmon growth curves. Figure 1 shows Fujimmon growth curves classified as neural, lymphoid, and general curves. Figure 2 shows compared with the traditional Scammon growth curves, the growth in the neural type growth reaches a value near the adult value in early childhood. In the lymphoid type, it may be more valid to consider a growth peak up to about 130%, not to 200%, in puberty. The general type is not all that different from the general type in Scammon's growth curves, but the sigmoid shape is not formed to the extent that it is in Scammon's general growth type. This may be the difference between curves drawn freehand and by mathematical functions.

Figure 3 shows the morphological/visceral type and genital type curves classified within the general growth type. The genital type remains classified in the general type and is recognized as a growth type that is split off from the general type. At first glance they appear to be quite different, but they have a very high degree of similarity in that a pubertal peak appears. These morphological/visceral and genital type curves also resemble a logistic curve. In other words, these two curves also have changes that resemble a logistic curve, like the changes in the curve depending on the coefficient of the denominator in a logistic equation. In the framework of a logistic curve, therefore, both the morphological/visceral curve and the genital curve are thought to be the same general type curve.

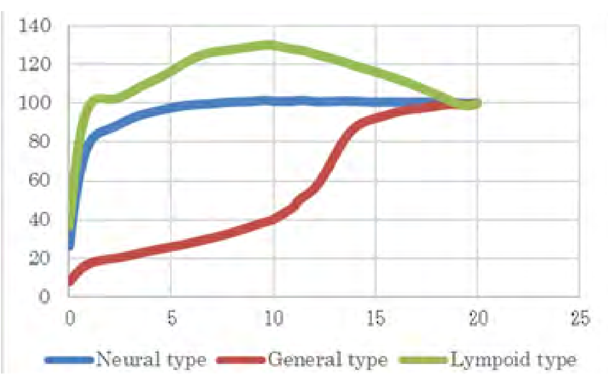

Figure 1: Fujimmon growth curve described by wavelet interpolation model

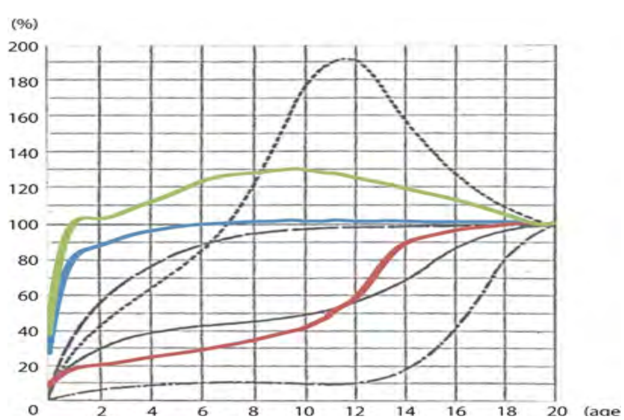

Figure 2: Comparison between Fujimmon and Scammon growth curve

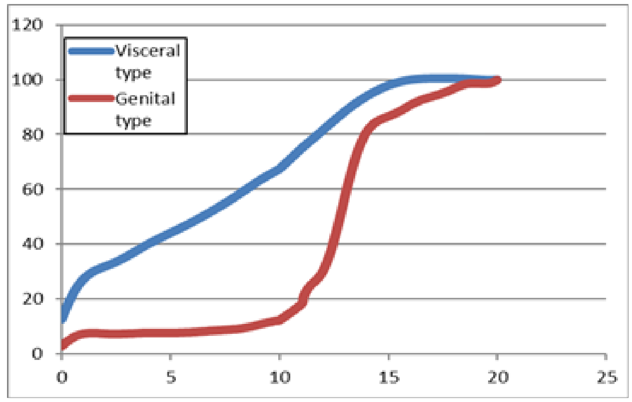

Figure 3: Visceral and genital type curve involved in general type of Fujimmon growth curve

4. Result

4.1. Age-related Changes in Muscle Percentage, Fat Percentage, and BMI in Boys and Girls

The changes with age in muscle percentage in boys are shown in Figure 4. There is a rapid decrease from the first to third grades of elementary school, after which the trend is flat for a time. Another increase is then shown from about the sixth grade of elementary school, and the distance value reaches a peak in the first or second year of junior high school. Looking at the behavior of the velocity curve, there is judged to be a purbertal peak. The age-related changes in muscle percentage in girls are shown in Figure 5. There is a steady decrease from the first grade of elementary school. Looking at the behavior of the velocity curve, concave points are detected in three places, the greatest of which is judge to be at around 13.5 years of age.

Next, the age-related changes in body fat percentage of boys and girls are shown in Figure 6 and 7. In boys the age-related changes in body fat percentage are the direct opposite of those in muscle percentage. From the first to third grades of elementary school body fat percentage increases rapidly, then shows a flat trend until the sixth grade. From about the second year of junior high school it rapidly decreases, then again shows an upward trend. Looking at the behavior of the velocity curve, a velocity peak is shown at around eight years old and a purbertal peak is shown at around 13.5 years old. In girls, body fat percentage exhibits a steady increase that is the opposite of muscle percentage. Looking at the behavior of the velocity curve, peaks appear in three locations but the peak that appears at around 13.5 years may be judged to be the pubertal peak. The age-related changes in BMI in boys and girls are shown in Figure 8 and 9. The distance curves exhibit a steady increase in both. Looking at the behavior of the velocity curve, peaks are detected in three locations in both boys and girls. The peak that appears at around 13.5 years may be judged to be the pubertal peak in both sexes.

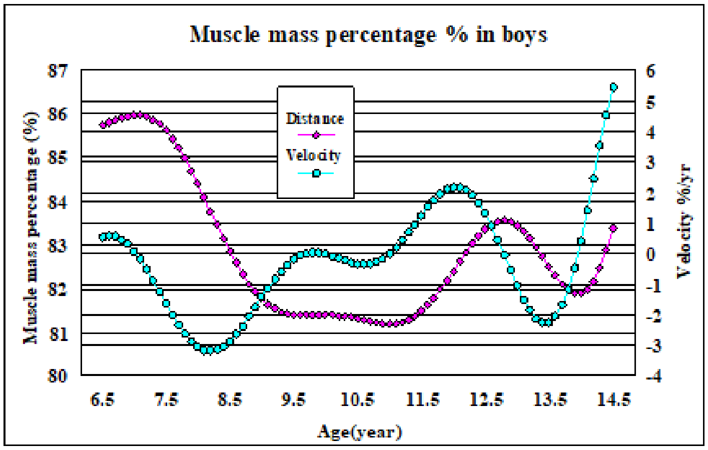

Figure 4: Change of muscle percentage with age in boys by wavelet interpolation method

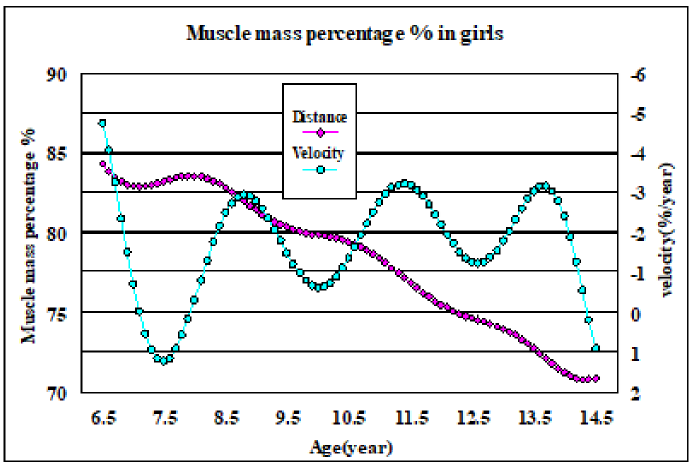

Figure 5: Change of muscle percentage with age in girls by wavelet interpolation method

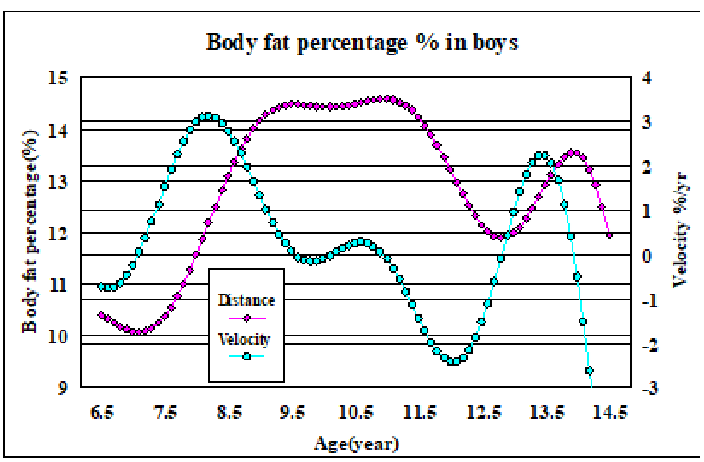

Figure 6: Change of fat percentage with age in boys by wavelet interpolation method

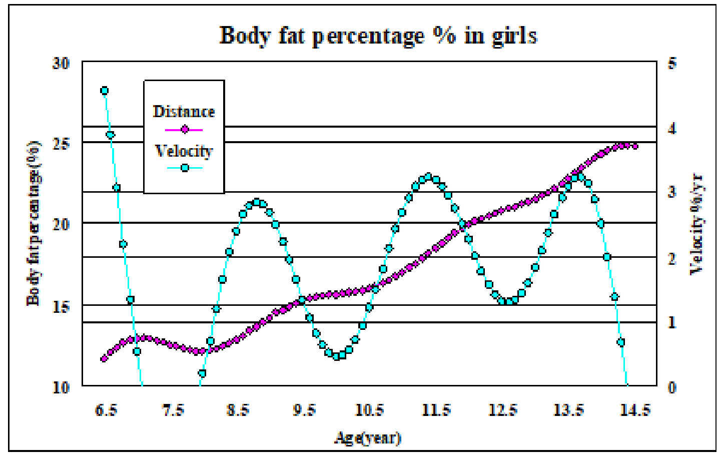

Figure 7: Change of fat percentage with age in girls by wavelet interpolation method

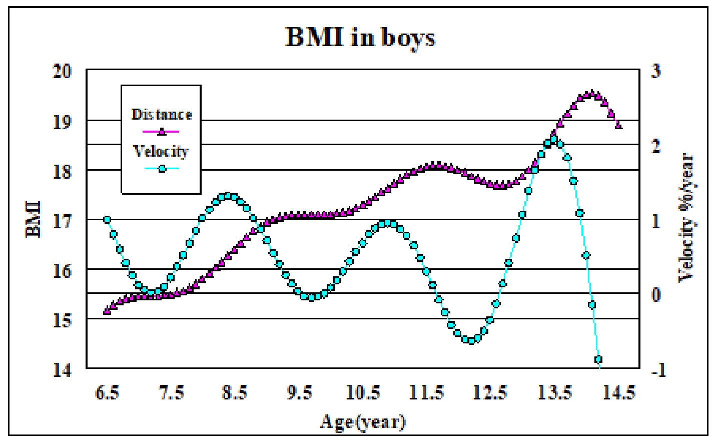

Figure 8: Change of BMI with age in boys by wavelet interpolation method

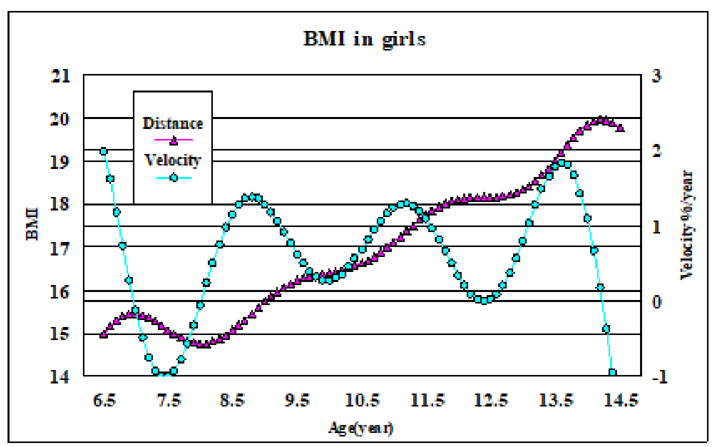

Figure 9: Change of BMI with age in girls by wavelet interpolation method

4.2. Similarities and dissimilarities between the curves of age-related changes in muscle percentage, body fat percentage, and BMI

When the age-related changes in muscle percentage, body fat percentage, and BMI in boys and girls are judged with use of the simple age-related changes in BMI as the reference, very clear trends are seen in girls. The changes in the age-related distance curves for BMI and body fat percentage are nearly the same. To examine the similarity in these two traits, a cross-correlation function was applied to the change curves of the age-related distance values for BMI and body fat percentage. As shown in Figure 10, r = 0.99 and the curves almost completes overlap. Next, a cross-correlation function was applied to the velocity curves for these two traits, and a very high similarity was seen with r = 0.92 (Figure 11). However, when a cross-correlation function was applied to the change curves for the age-related distance values in BMI and muscle percentage, a completely opposite relation was seen with r = −0.99 (Figure 12). Similarly, when a cross-correlation function was applied to the velocity curves, a very high inverse correlation was seen with r = −0.94, showing a considerable disparity (Figure 13).

Among boys, very different from girls, the changes in the age-related distance curves for BMI and body fat percentage differ. The results of application of cross-correlation functions and an analysis of similarities between the two traits showed r = 0.54 in the age-related distance curve, and the degree of similarity was low (Figure 14). The relatively high degree of similarity in the velocity curve (r = 0.84) (Figure 15) was thought to be due to the fact that fluctuations were shown in the behavior of the velocity curve. Obvious similarity was judged to be low in the age-related distance curves. Cross-correlation functions were applied to the age-related distance curves for BMI and muscle percentage, and considerable disparity was shown with r = −0.66. An analysis done using the same method for the velocity curves found a high disparity with r = −0.83 (Figure 16 and17).

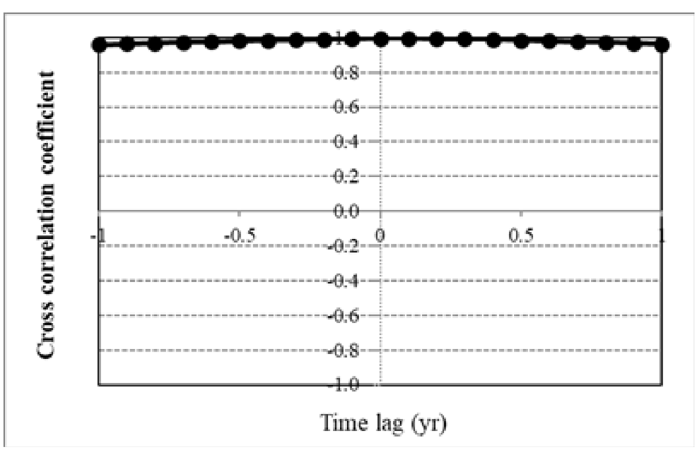

Figure 10: Cross correlation coefficients between change distance curve of BMI and fat percentage with age in girls

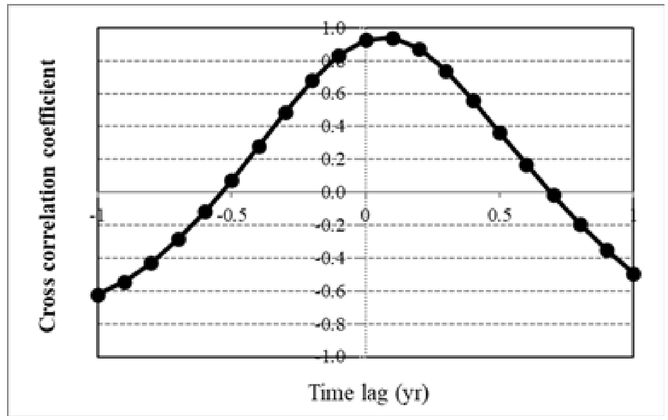

Figure 11: Cross correlation coefficients between change velocity curve of BMI and fat percentage with age in girls

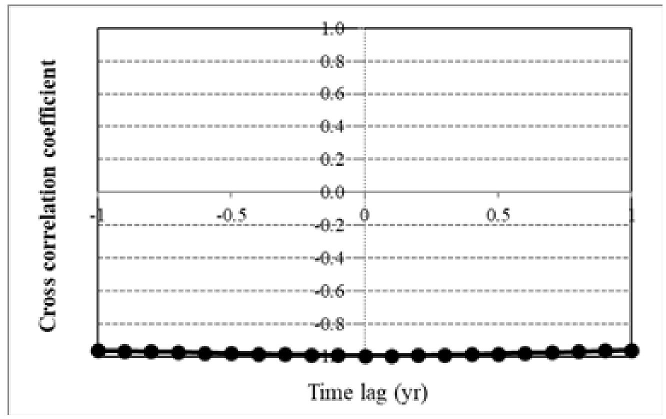

Figure 12: Cross correlation coefficients between change distance curve of BMI and muscle percentage with age in girls

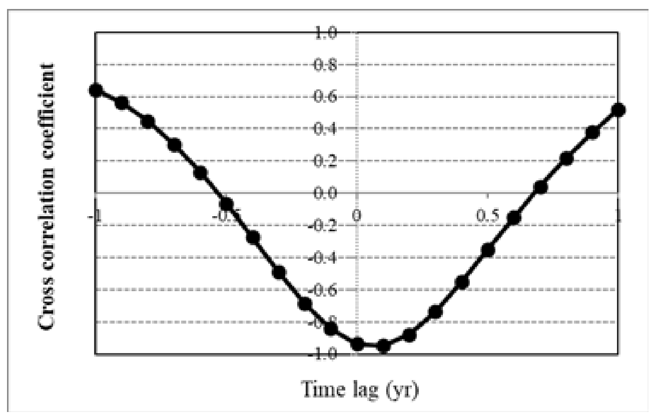

Figure 13: Cross correlation coefficients between change velocity curve of BMI and muscle percentage with age in girls

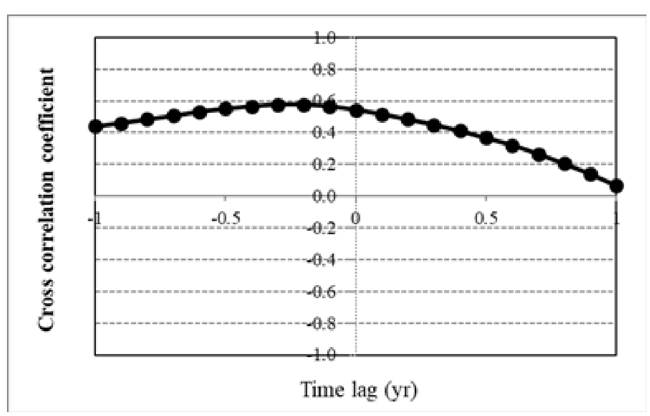

Figure 14: Cross correlation coefficients between change distance curve of BMI and fat percentage with age in boys

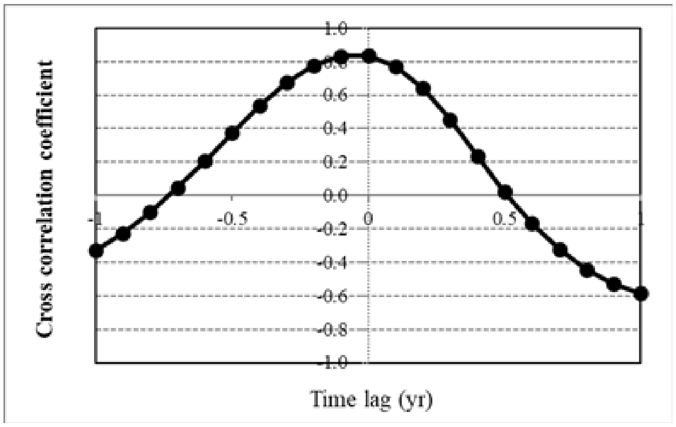

Figure 15: Cross correlation coefficients between change velocity curve of BMI and fat percentage with age in boys

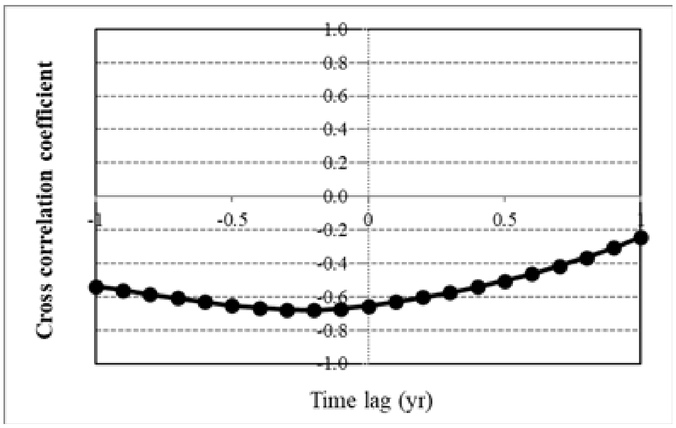

Figure 16: Cross correlation coefficients between change distance curve of BMI and muscle percentage with age in boys

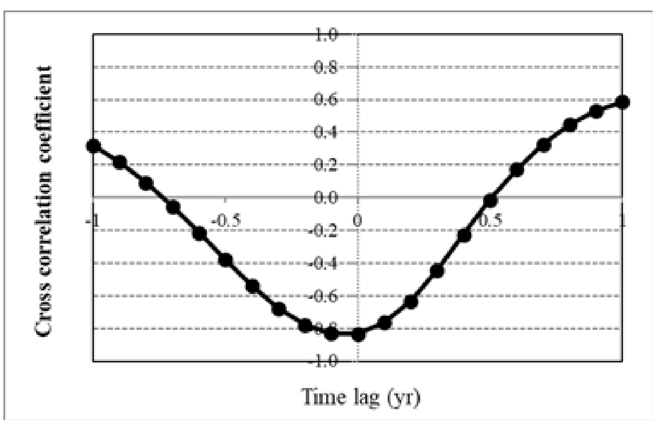

Figure 17: Cross correlation coefficients between change velocity curve of BMI and muscle percentage with age in boys.

4.3. Dependence of curves showing age-related change in muscle percentage, body fat percentage, and BMI on Fujimmon's growth curves

In both boys and girls the curve of age-related change in BMI showed a sigmoid shape, and a pubertal peak appeared in the velocity curve. Therefore, judging the age-related change curve for BMI from Fujimmon's growth curves, it is seen to depend on the general-type growth pattern. In girls, the age-related change curve for body fat percentage has a very high similarity to the age-related growth curve for BMI, and so may be considered to show a general-type growth pattern. However, the age-related change curve for muscle percentage does not depend on any growth pattern. For boys, it was found that the age-related change curve for muscle percentage does not depend on any of Fujimmon's growth curves. The age-related change curve for body fat percentage appears to be somewhat similar the lymphoid-type growth pattern of Fujimmon's growth curves, but the result of application of a cross-correlation function between thymic growth showed a close similarity with r = 0.08. Ultimately, the age-related change curves for muscle and fat percentages in boys were shown not to depend on any of Fujimmon's growth curve patterns.

5. Discussion

It is clear that the growth of muscle mass basically depends on the general-type growth pattern in Fujimmon's growth curves[5]. Of course, the same trends are seen in boys and girls. Body fat mass also depends on the general-type pattern. However, the growth trends in these two traits in boys and girls cannot be understood without making substitutions for the absolute values of these two traits. That is, the age-related changes in muscle mass and fat mass cannot be understood in a true sense without judging from the percentage of body weight. Therefore, we calculated percentages against body weight and investigated the age-related changes as muscle percentage and body fat percentage. In both boys and girls the age-related changes in muscle percentage and body fat percentage basically have inverse relationships. Since these are percentages of body weight, the body fat percentage is obtained by subtracting the muscle percentage from 100%, and a positive inverse relationship holds. However, the age-related changes in these two traits differ greatly in boys and girls. The muscle percentage in girls gradually decreases while body fat percentage shows an increasing trend, whereas the muscle percentage in boys shows little change after a decrease, and then increases during puberty. This is the direct opposite of body fat percentage.

Judging these trends in boys and girls with the age-related change curve for BMI as a reference reveals an interesting trend. Namely that both boys and girls show similar trends for the age-related change curve for BMI. In particular, there is a very high degree of similarity with the age-related change curve for body fat percentage in girls. Conversely, considerable disparities are shown in muscle percentage, which shows a directly opposite age-related change composition. In boys, both muscle and body fat percentages differ from age-related change in BMI, and a considerable disparity is seen in age-related change in muscle percentage. With body fat percentage, the age-related distance curve fundamentally differs, and shows low similarity with a cross-correlation coefficient of r = 0.54. When making judgments with age-related change in BMI as the reference in this way, it is found that the age-related changes in muscle and fat percentages of boys and girls differ greatly.

Thus, we can fully understand that while age-related change in

BMI is change in an index based on body height and weight, the age-related changes in those body compositions differ. BMI is an index of physique originally made by Quetelet [16], but in recent years it has come to be considered an indicator for judging obesity from its high correlation with body fat percentage (Key; [17], Garrow and Webster; [18]). However, while that may be applicable to women it is thought to be somewhat forced in men. Of course, BMI is a simple index for judging obesity in adults, but the present findings perhaps need to be considered when applying it to schoolchildren. In any event, age-related changes in BMI depend on the general type of Fujimmon's growth curve [5] in both boys and girls, and are also thought to depend on body fat percentage in girls. However, muscle percentage in boys and girls and body fat percentage in boys do not seem to depend on any of the growth patterns. To date there has been little clear discussion on age-related changes in body composition. Therefore, the kinds of growth pattern shown by muscle and fat percentages have not been investigated. In this study, although the data were longitudinal, age-related changes in muscle and fat percentages were analyzed and judged from four growth patterns based on Fujimmon's growth curves [5]. It was found that in boys muscle and fat percentages do not depend on any of the growth patterns. Thus, an independent growth pattern is thought to be formed. Similarly, muscle percentage in girls also formed an independent growth pattern, but body fat percentage is thought to depend on the general-type growth pattern the same as age-related changes in BMI. From these findings it is seen for the first time that body fat percentage is closely related to BMI throughout the school years in girls, and shows the general-type growth pattern.

6. Conclusion

Referencing the age-related changes in BMI that are dependent on the general growth curve of Fujimmon, wavelet interpolation was applied to the values for muscle percentage, body fat percentage, and age-related change in BMI. Then, to compare the age-related change curves of muscle percentage and body fat volume with the described age-related curve of BMI, a cross correlation function (Matsuura et al., [11]; Yamada et al., [12] was applied and the similarities and differences between BMI, muscle percentage, and body fat percentage were investigated. In this study the data for BMI, body fat percentage, and muscle percentage were cross-sectional, but the age of maximum peak velocity (MPV) in these three attributes was derived by applying the wavelet interpolation method (WIM). The cross correlation function was then applied between the three attributes, similarities and differences were analyzed, and their dependence on Fujimmon's growth curve was investigated. While the data in this study are cross-sectional, the age-related changes in muscle percentage and body fat percentage were analyzed and the results were judged from four growth patterns based on Fujimmon growth curves. Muscle and body fat percentages in boys did not depend on any growth patterns. Thus, it is thought that independent growth patterns were formed. Similarly, the muscle percentage in girls also formed an independent growth pattern, but body fat percentage is thought to depend on the general type growth pattern, similar to age-related changes in BMI. These results present the novel findings that body fat percentage in girls is closely related to BMI throughout the school years, and shows a general type growth pattern.

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