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Age-RelatedCompositionofBMIandBodyCompositionBasedonFujimmon'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 tochangeswithageinBMI.However,therearenodirectfindings onage-relatedchangesinbodyfatpercentageandmusclepercent- age. In this study, wavelet interpolation model was applied to the valuesformusclepercentage,bodyfatpercentage,andage-related changeinBMI.Then,tocomparetheage-relatedchangecurvesof musclepercentageandbodyfatvolumewiththedescribedage-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 Fujimmongrowthcurves.Muscleandbodyfatpercentagesinboys 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 resultspresentthenovelfindingsthatbodyfatpercentageingirlsis 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 andwomen.Bodyweightisexpressedasthetotalofbodyfatmass, bonemass,andmusclemass.Inmales,musclemassshowsarapid increase during puberty, but in females it is body fat mass that increases and the increase is not that rapid. We therefore thought thatinplaceoftheabsoluteindicesofmusclepercentageandbody fatpercentageastheproportionofthebodyaccountedforbymus- cle 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 fundamentallyclassedinthegeneral-typegrowthpatterninScammon'sgrowthcurves[1].Tanner[2,3]andTakaishietal.[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'sgrowthcurveswereproposedmorethan90 yearsago,andthetheorywasconstructedinanagewhencomputersdidnotexist.Today,whensomuchmoreisunderstoodscientifically,itisnaturalthatweshouldtotryandverifythevalidityofa theoryproposedmorethan90yearsago.Noreporthasyetclearly validatedthistheory.Giventheabove,inthisstudythetheoryproposedbyScammonwasfirstre-examinedtoinvestigatethestandardization of the human growth system, and a new growth curve model was constructed for the standard human growth pattern by Fujii[5].ThatgrowthmodelpatternisproposedastheFuijimmon growthcurve.Fujimmongrowthcurveisconstructedbyawavelet interpolation model, and sigmoid curve in which the growth of body size belongs to the general type can be described. In other words,attributedeterminationofgrowthpatternsbelongingtothe neural,lymphoid,andgeneraltypebasedontheFujimmongrowth curve can be established.

Therefore,withregardtotheage-relatedchangesinBMI,asindi- catedbyFujii[6],Fujiietal.[7],andFujiietal.[8],theage-related distancecurveisshownasasigmoidalcurve,andaclearpubertal peak is detected when judging from the behavior of the velocity curve.Therefore,thecurveofage-relatedchangesinBMIinboys and girls depends on Fujimmon’s general type growth pattern. Muscleandbodyfatpercentagesarenotabsolutechangesinmass, andsothereissomedoubtastowhethertheycanbeclassified in Fujimmon’s three growth curve patterns, but there is a need to investigatethepatternsofage-relatedchangesinmuscleandbody 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 withageinBMI.However,therearenodirectfindingsonage-re- lated changes in body fat percentage and muscle percentage. In thisstudy,referencingtheage-relatedchangesinBMIthatarede- pendent on the general growth curve of Fujimmon [5], wavelet interpolation model was applied to the values for muscle percent- age,bodyfatpercentage,andage-relatedchangeinBMI.Then,to compare the age-related change curves of muscle percentage and body fat volume with the described age-related curve of BMI, a crosscorrelationfunction(Matsuuraetal.,[11]Yamadaetal.,[12])wasappliedandthesimilaritiesanddissimilaritiesbetweenBMI, 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 reproductivetype,databelongingtothesethreepatternsshownby Fujii et al. [7] are cited.

3. Methods

SubjectsandMaterials

The subjects were first to sixth grade students in one elementary schoolandfirsttothirdyearstudentsinonejuniorhighschool in Aichi Prefecture. They included 331 elementary school boys, 329elementaryschoolgirls,392juniorhighschoolboys,and327 juniorhighschoolgirls.Abreakdownisshowninthetablebelow.

Thesurveyandmeasurementswereexplainedtothesubjectsin advanceandtheirinformedconsentwasobtained.Thesubjectsdid notincludeanychildrenwithacuteorchronicdisease(Table1).

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)Measurementofphysiqueandbodycomposition(bodyfatper- centage, muscle percentage)

Height was measured using a Tanita digital stadiometer. Body weightwasmeasuredduringbodycompositionmeasurementsus- ing 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.Musclepercentagewascalculatedasmusclemass (kg) ÷ body weight (kg) × 100. SLM was calculated with the ad- ditionofproteinmass,andfatmasswascalculatedbysubtracting SLM and mineral mass from body weight. SLM, bone mass, and fatmasswerealltakenasvaluesrelativetoheightinordertoelim- inate the effects of height.

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 bydata- datainterpolationwithawaveletfunctionandbyderiving thegrowthvelocitycurveobtainedbydifferentiatingthedescribe d 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 lo- calevents.Detailsontheoreticalbackgroundandthebasisforthis effectiveness are omitted here as they have already been set forth in prior studies by Fujii [6, 13, 14, 15].

Crosscorrelationfunction: Acrosscorrelationfunctionis usedtoshowthesimilaritybetweentwowaveforms,andthecross correlationfunctionmaybeevaluatedbyconvolvingonefunction as shown below. In addition, the degree of time lag can be exam- ined when there are similar regions (Matsuura et al [11],Yamada etal.[12]).Inthisstudy,acrosscorrelationfunctionwasassumed fromthevelocitycurvevaluesfoundfromdifferentiationusingthe 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 val- ue-subtractedtransformationx(t)andy(t),isgivenasx(t)=x’(t)-μ andy(t)=y’(t)-μ.Usingthetransformationsx(t)andy(t),thecross covarianceisdefinedasfollows,withτasthetimelagassignedto 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 bythestandarddeviationofthevaluesforthetwovelocitycurves x’(t) and y’(t), and is given as follows:

$$R_{xy}(\tau)=\frac{C_{xy}(\tau)}{}=\frac{\overline{x(t)y(t+\tau)}}{\sqrt{\overline{x^2}}\sqrt{\overline{y^2}}}$$

$C_x(0)C_y(0)N{-}j$

Analysiswasconductedusingthecrosscorrelationfunction Rxy(τ)calcul ated

asoutlined above.

Fujimmon growth curve: Fujii [5] re-examined Scam- mon'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 growthcurves.Figure1showsFujimmongrowthcurvesclassified asneural,lymphoid,andgeneralcurves.Figure2showscompared with the traditional Scammon growth curves, the growth in the neural type growth reaches a value near the adult value in early childhood.Inthelymphoidtype,itmaybemorevalidtoconsider a growth peak up to about 130%, not to 200%, in puberty. The generaltypeisnotallthatdifferentfromthegeneraltypeinScam- mon'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 thedifferencebetweencurvesdrawnfreehandandbymathemati- cal functions.

Figure 3 shows the morphological/visceral type and genital type curves classified within the general growth type.The genital type remainsclassifiedinthegeneraltypeandisrecognizedasagrowth typethatissplitofffromthegeneraltype.Atfirstglancetheyap- peartobequitedifferent,buttheyhaveaveryhighdegreeofsimi- larityinthatapubertalpeakappears.Thesemorphological/viscer- al and genital type curves also resemble a logistic curve. In other words,thesetwocurvesalsohavechangesthatresemblealogistic curve,likethechangesinthecurvedependingonthecoefficientof thedenominatorinalogisticequation.Intheframeworkofalogis- ticcurve,therefore,boththemorphological/visceralcurveandthe genital curve are thought to be the same general type curve.

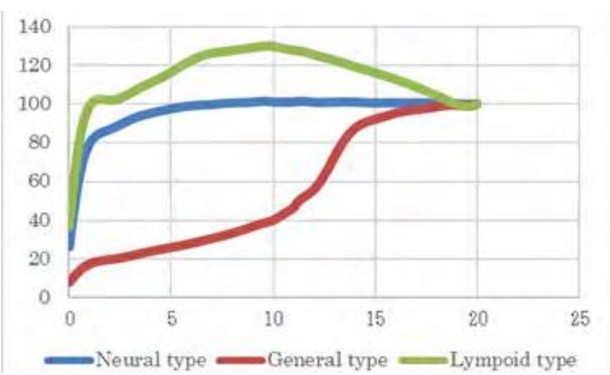

Figure 1: Fujimmon growth curve described by wavelet interpolation model

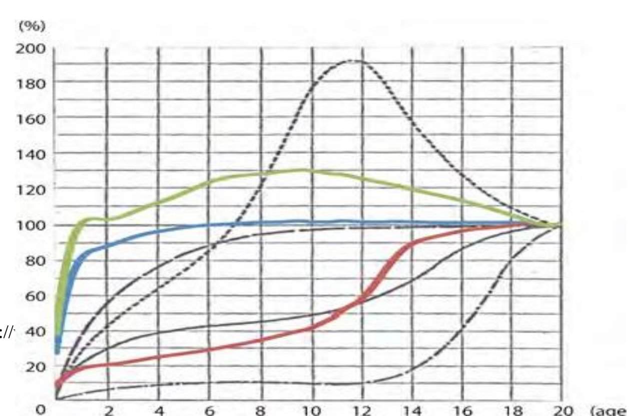

Figure2: Comparisonbetween Fujimmonand Scammongrowth curve

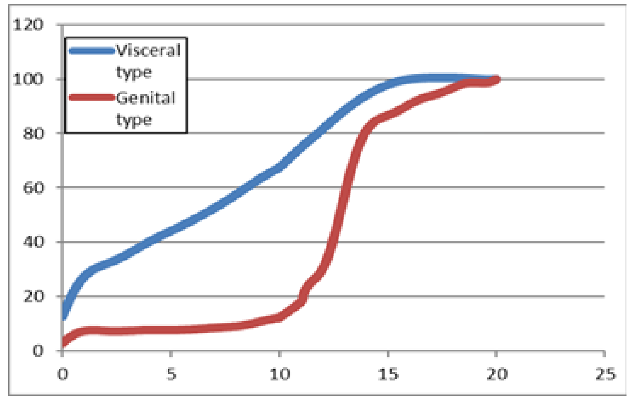

Figure3: Visceralandgenitaltypecurveinvolvedingeneraltypeof Fu- jimmon growth curve

4. Result

Age-related Changes in Muscle Percentage, Fat Percent- age, and BMI in Boys and Girls

The changes with age in muscle percentage in boys are shown in Figure4.Thereisarapiddecreasefromthefirsttothirdgradesof elementaryschool,afterwhichthetrendisflatforatime.Another increase is then shown from about the sixth grade of elementary school,andthedistancevaluereachesapeakinthefirstorsecond year of junior high school. Looking at the behavior of the veloc- ity curve, there is judged to be a purbertal peak. The age-related changesinmusclepercentageingirlsareshowninFigure5.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 girlsareshowninFigure6and7.Inboystheage-relatedchanges in body fat percentage are the direct opposite of those in muscle percentage. From the first to third grades of elementary school bodyfatpercentageincreasesrapidly,thenshowsaflattrenduntil 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 aroundeightyearsoldandapurbertalpeakisshownataround 13.5 years old. In girls, body fat percentage exhibits a steady in- crease that is the opposite of muscle percentage. Looking at the behaviorofthevelocitycurve,peaksappearinthreelocationsbut thepeakthatappearsataround13.5yearsmaybejudgedtobethe 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.

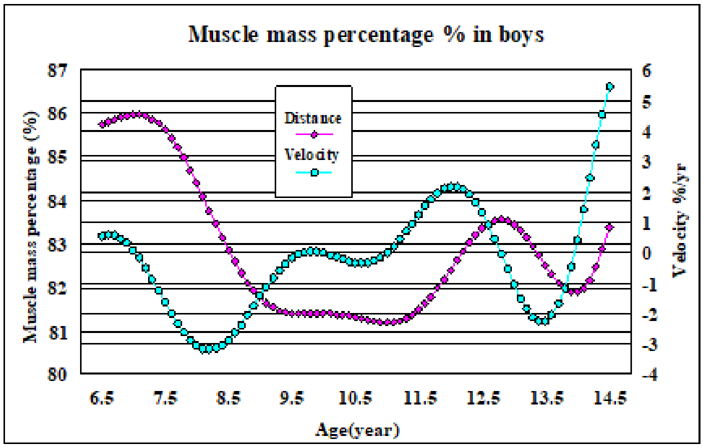

Figure4: Changeofmusclepercentagewithageinboysbywaveletinter- polation method

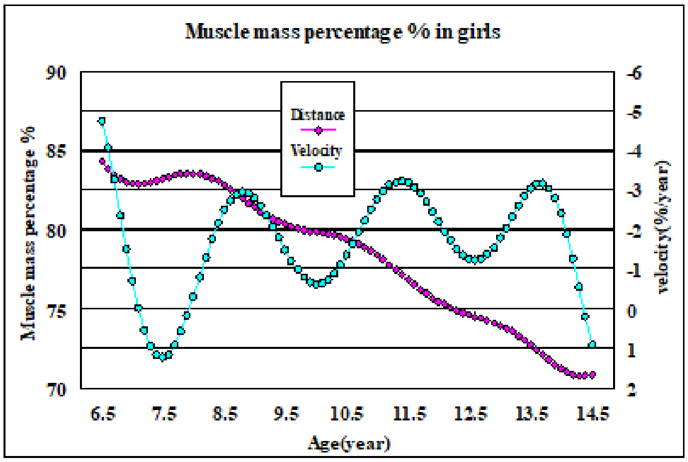

Figure 5: Change of muscle percentage with age in girls by wavelet in- terpolation method

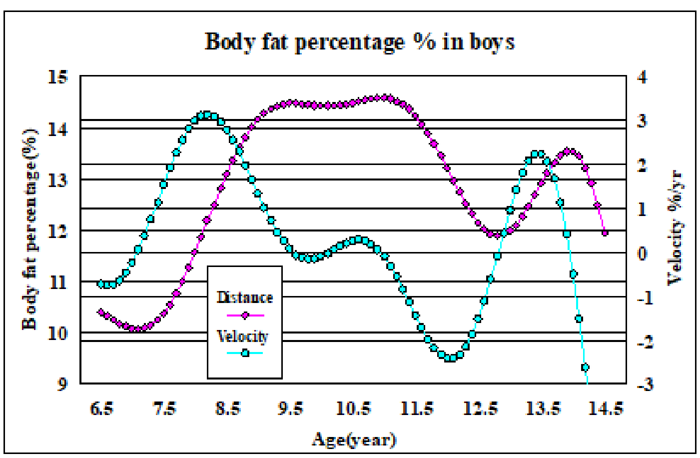

Figure 6: Change of fat percentage with age in boys by wavelet interpo- lation method

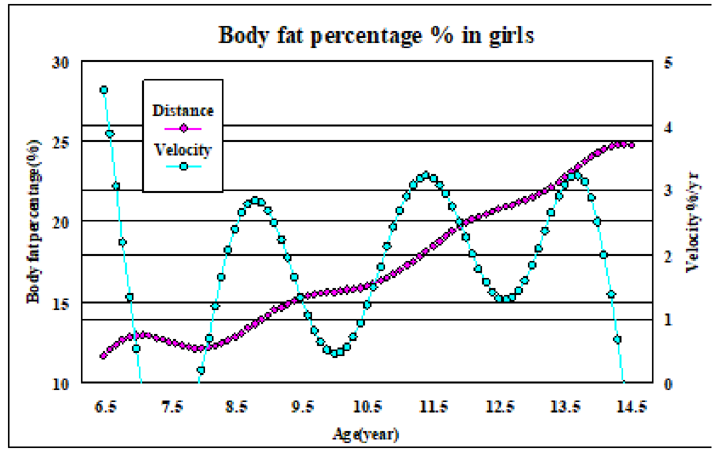

Figure 7: Change of fat percentage with age in girls by wavelet interpo- lation method

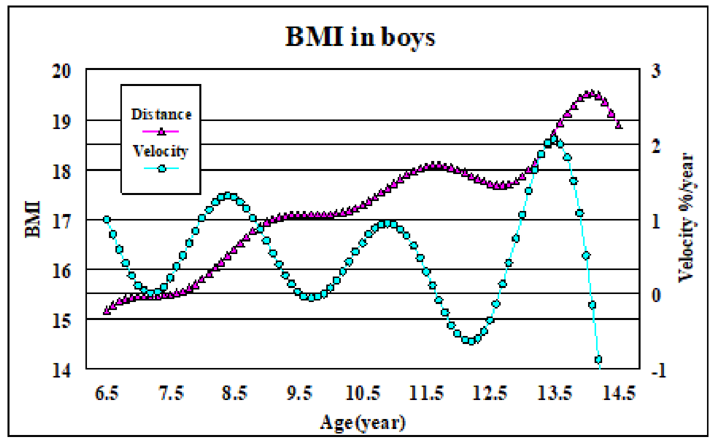

Figure8: ChangeofBMIwithageinboysbywaveletinterpolation method

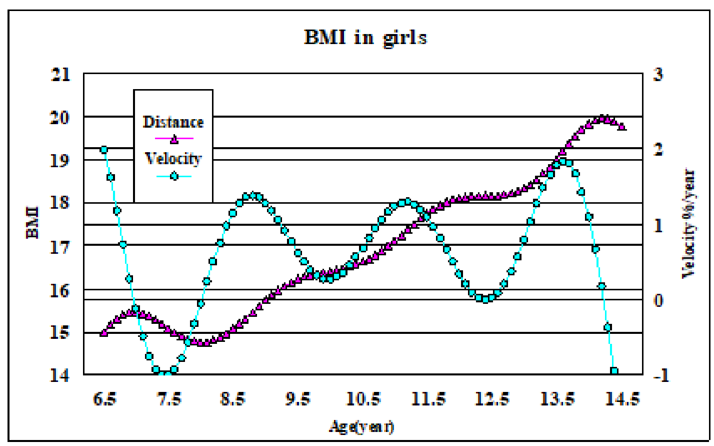

Figure9: ChangeofBMIwithageingirlsbywaveletinterpolationmeth- od

Similarities and dissimilarities between the curves ofage-related changes in muscle percentage, body fat percent- age, and BMI

Whentheage-relatedchangesinmusclepercentage,bodyfatper- centage,andBMIinboysandgirlsarejudgedwithuseofthesim- pleage-relatedchangesinBMIasthereference,verycleartrends are seen in girls. The changes in the age-related distance curves forBMIandbodyfatpercentagearenearlythesame.Toexamine the similarity in these two traits, a cross-correlation function was appliedtothechangecurvesoftheage-relateddistancevaluesfor BMI and body fat percentage. As shown in Figure 10, r = 0.99 andthecurvesalmostcompletesoverlap.Next,across-correlation functionwasappliedtothevelocitycurvesforthesetwotraits,and averyhighsimilaritywasseenwithr=0.92(Figure11).However, whenacross-correlationfunctionwasappliedtothechangecurves fortheage-relateddistancevaluesinBMIandmusclepercentage, a completely opposite relation was seen with r = −0.99 (Figure 12). Similarly, when a cross-correlation function was applied to thevelocitycurves,averyhighinversecorrelationwasseenwithr = −0.94, showing a considerable disparity (Figure 13).

Among boys, very different from girls, the changes in the age-re- lateddistancecurvesforBMIandbodyfatpercentagediffer.The results of application of cross-correlation functions and an anal- ysis of similarities between the two traits showed r = 0.54 in the age-related distance curve, and the degree of similarity was low (Figure14).Therelativelyhighdegreeofsimilarityinthevelocity curve (r = 0.84) (Figure 15) was thought to be due to the fact that fluctuationswereshowninthebehaviorofthevelocitycurve.Ob- vious similarity was judged to be low in the age-related distance curves.Cross-correlationfunctionswereappliedtotheage-related distancecurvesforBMIandmusclepercentage,andconsiderable disparity was shown with r = −0.66. An analysis done using the samemethodforthevelocitycurvesfoundahighdisparitywithr = −0.83 (Figure 16 and17).

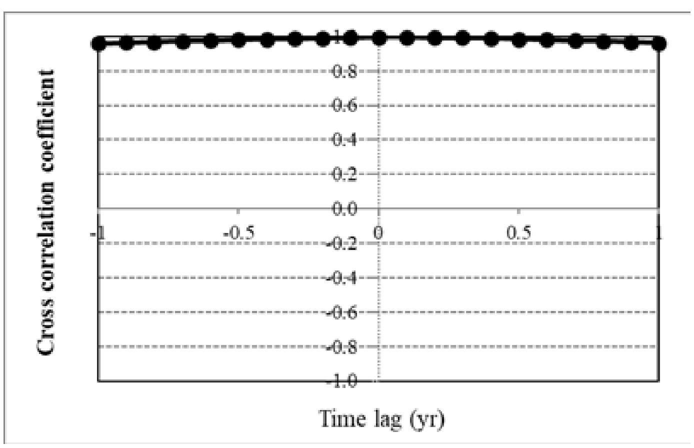

Figure 10: Crosscorrelation coefficientsbetween changedistance curve of BMI and fat percentage with age in girls

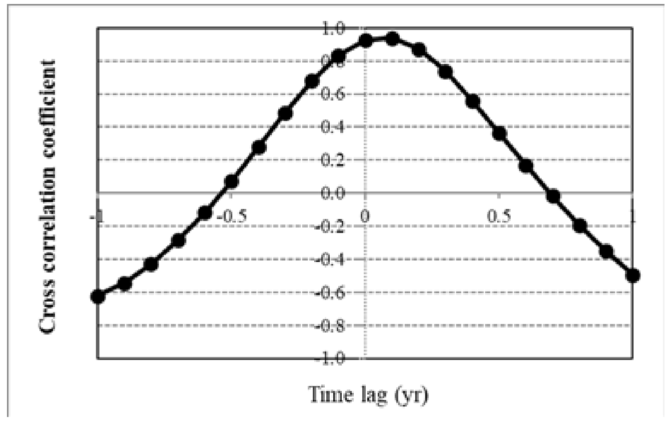

Figure11: Crosscorrelationcoefficientsbetweenchangevelocitycurve of BMI and fat percentage with age in girls

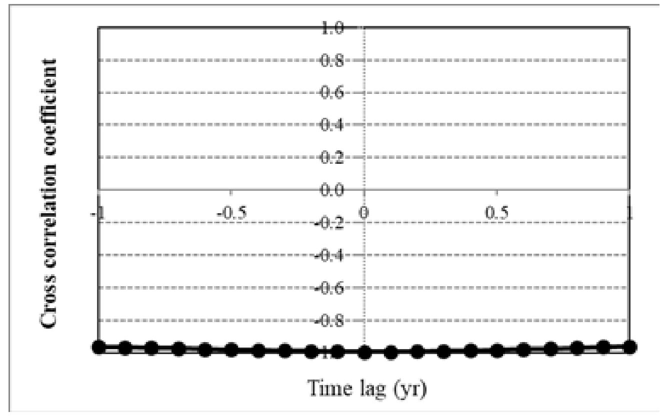

Figure12: Crosscorrelationcoefficientsbetweenchangedistancecurve of BMI and muscle percentage with age in girls

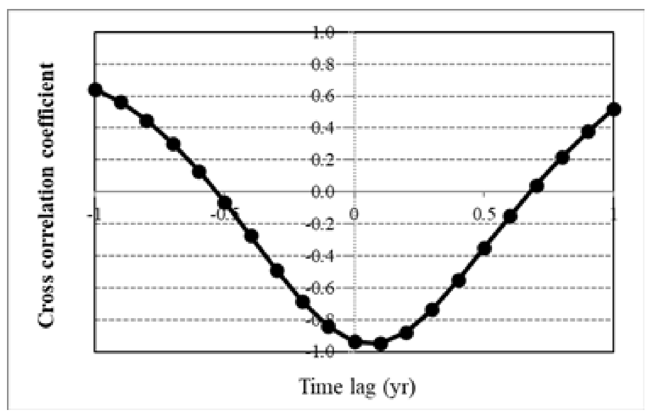

Figure13: Crosscorrelationcoefficientsbetweenchangevelocitycurve of BMI and muscle percentage with age in girls

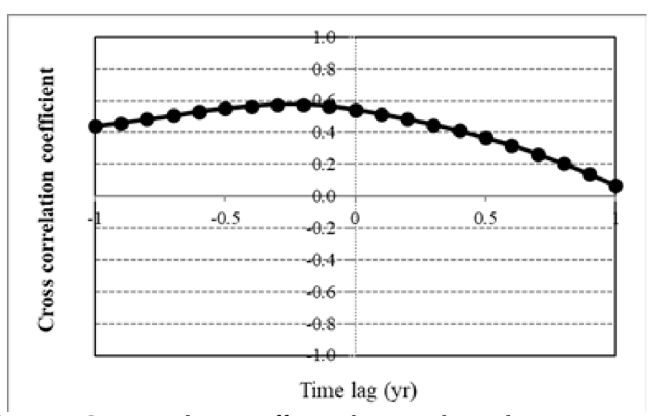

Figure14: Crosscorrelationcoefficientsbetweenchangedistancecurve of BMI and fat percentage with age in boys

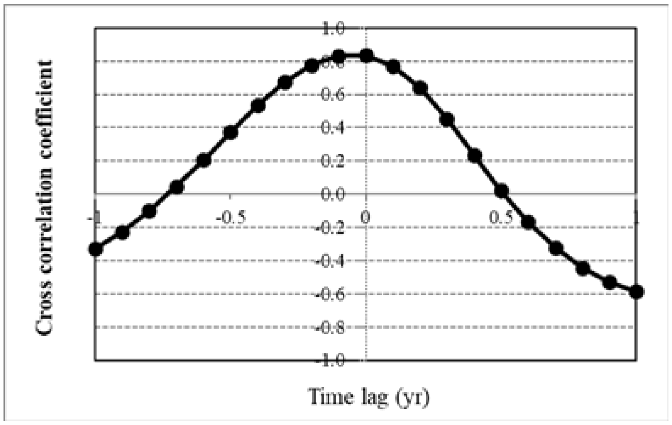

Figure15: Crosscorrelationcoefficientsbetweenchangevelocitycurve of BMI and fat percentage with age in boys

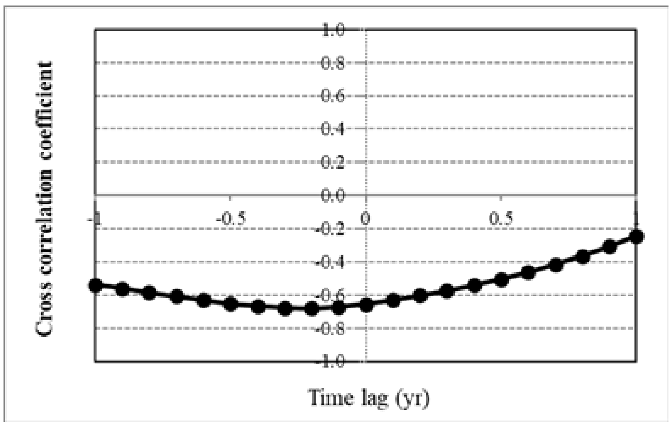

Figure16: Crosscorrelationcoefficientsbetweenchangedistancecurve of BMI and muscle percentage with age in boys

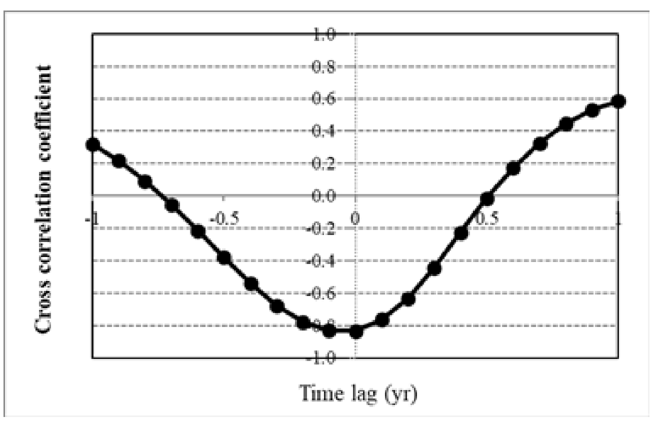

Figure17: Crosscorrelationcoefficientsbetweenchangevelocitycurve of BMI and muscle percentage with age in boys.

Dependenceofcurvesshowingage-relatedchangeinmus- cle 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-typegrowthpattern.Ingirls,theage-relatedchangecurve forbodyfatpercentagehasaveryhighsimilaritytotheage-related growthcurveforBMI,andsomaybeconsideredtoshowagen-eral-type growth pattern. However, the age-related change curve formusclepercentagedoesnotdependonanygrowthpattern.For boys, it was found that the age-related change curve for muscle percentagedoesnotdependonanyofFujimmon'sgrowthcurves. The age-related change curve for body fat percentage appears to be somewhat similar the lymphoid-type growth pattern of Fujimmon'sgrowthcurves,buttheresultofapplicationofacross-correlation function between thymic growth showed a close similarity withr=0.08.Ultimately,theage-relatedchangecurvesformuscle and fat percentages in boys were shown not to depend on any of Fujimmon's growth curve patterns.

5. Discussion

Itisclearthatthegrowthofmusclemassbasicallydependsonthe 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.Thatis,theage-relatedchangesinmusclemassandfatmass 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 musclepercentageandbodyfatpercentage.Inbothboysandgirls theage-relatedchangesinmusclepercentageandbodyfatpercent- age basically have inverse relationships. Since these are percent- ages of body weight, the body fat percentage is obtained by subtracting the muscle percentage from 100%, and a positive inverse relationshipholds.However,theage-relatedchangesinthesetwo traits differ greatly in boys and girls. The muscle percentage in girls gradually decreases while body fat percentage shows an increasingtrend,whereasthemusclepercentageinboysshowslittle changeafteradecrease,andthenincreasesduringpuberty.Thisis the direct opposite of body fat percentage.

Judgingthesetrendsinboysandgirlswiththeage-relatedchange curveforBMIasareferencerevealsaninterestingtrend.Namely that both boys and girls show similar trends for the age-related change curve for BMI. In particular, there is a very high degreeof similarity with the age-related change curve for body fat percentageingirls.Conversely,considerabledisparitiesareshownin 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 disparityisseeninage-relatedchangeinmusclepercentage.With bodyfatpercentage,theage-relateddistancecurvefundamentally differs, and shows low similarity with a cross-correlation coefficientofr=0.54.Whenmakingjudgmentswithage-relatedchange in BMI as the reference in this way, it is found that the age-relat- ed changes in muscle and fat percentages of boys and girls differ greatly.

Thus,wecanfullyunderstandthatwhileage-relatedchangein

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 yearsithascometobeconsideredanindicatorforjudgingobesity fromitshighcorrelationwithbodyfatpercentage(Key;[17],Gar- row and Webster; [18]). However, while that may be applicableto 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 fatpercentageinboysdonotseemtodependonanyofthegrowth patterns. To date there has been little clear discussion on age-relatedchangesinbodycomposition.Therefore,thekindsofgrowth patternshownbymuscleandfatpercentageshavenotbeeninvestigated. 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 donotdependonanyofthegrowthpatterns.Thus,anindependent growthpatternisthoughttobeformed.Similarly,musclepercent- age 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 relatedtoBMIthroughouttheschoolyearsingirls,andshowsthe general-type growth pattern.

6. Conclusion

Referencing the age-related changes in BMI that are dependenton the general growth curve of Fujimmon, wavelet interpolation wasappliedtothevaluesformusclepercentage,bodyfatpercent-age,andage-relatedchangeinBMI.Then,tocomparetheage-re- lated 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 andthesimilaritiesanddifferencesbetweenBMI,musclepercent-age, 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 wereanalyzed,andtheirdependenceonFujimmon’sgrowthcurve was investigated. While the data in this study are cross-sectional, theage-relatedchangesinmusclepercentageandbodyfatpercent- age were analyzed and the results were judged from four growth patterns based on Fujimmon growth curves. Muscle and body fat percentagesinboysdid notdependonanygrowthpatterns. 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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