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NISHIKAWA, Hideo
Division of Orthopedic Surgery, Department of Surgery, Saga Medical School

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Evaluation of Increases in Stature, Upper Extremity Length and Hand Length in Children from School Age to the Cessation of Growth in Ogi County, Japan : A Longitudinal Study

Hideo NISHIKAWA

Division of Orthopedic Surgery, Department of Surgery, Saga Medical School, Saga 849-0937, Japan

Abstract Stature, upper extremity length (UEL) and hand length (HL) were measured once yearly in children (171 males and 180 females) in Ogi County, Saga, Japan, from the 1 st grade of primary school (6.5 years of age) for 12 years. Based on the age of growth cessation, the order of growth cessation of stature, UEL and HL was investigated, in addition to the relationship between this order and the measurements obtained at 6.5 years of age.

With regard to the order of growth cessation of stature and UEL, growth cessation of UEL occurred earlier than that of sature in 73.68% of males and 71.67% of females, growth cessation occurred simultaneously in 23.98% of males and 25.56% of females, and growth cessation of UEL occurred later than that of stature in 2.34% of males and 2.78% of females. Accordingly, growth cessation of UEL occurred earlier than that of stature in most subjects.

In males, no significant differences were observed between subjects in whom growth cessation of UEL and HL occurred simultaneously and those in whom growth cessation of UEL occurred later than that of HL. However, in females, significant differences were noted, since the latter case was observed 1.69 times more frequently than the former. Nevertheless, growth cessation of stature, UEL and HL occurred at almost the same age in both males and females when cross-sectional data was used for processing, in agreement with data reported by other researchers.

We also investigated whether there was any relationship between stature and UEL at initial examination and the order of growth cessation. No significant relationship was observed. Each measured value at initial examination tended to be large in subjects in whom growth cessation of sature and UEL occurred earlier. In addition, final stature was significantly taller in both males and females in whom growth cessation of stature occurred later compared to those in whom growth cessation occurred earlier.

Introduction

Stature has been the most frequently used index in studies on human axial growth.[2,4,5,9] For example, several reports comparing stature at each age based on cross-sectional data in different places (Melvin and Birkbeck)[8] and reports on the age of peak height velocity based on longitudinal data (Tanner et al.)[13] have appeared in the literature. In addition, Bortel and Pritchett[1] measured forearm and UEL by radiography to estimate future UEL, based on the relationship between each measured value and the subject's age. However, there have been a few reports on the growth of the upper and lower extremities based on longitudinal data[3].

In our study, growth of stature, UEL and HL was followed in children from school age until growth cessation, and the order of growth ces-

sation of these three parameters was evaluated. In addition, we investigated whether the values of stature and UEL at initial examination were related to differences in the order of growth cessation. Furthermore, regarding stature and UEL, the relationship between the age of growth cessation and measured values at initial examination of each parameter was studied. We also investigated the relationship between final stature and the age of growth cessation. Our findings are summarized below.

Materials and Methods

Materials were male and female children born between 1972 and 1977, free of chronic disease, who attended Sakuraoka Primary School in Ogi County, Saga, Japan. They were healthy and raised in average families without social problems. Their stature, UEL and HL were measured during yearly school check-ups (in April) for 12 years, from the 1 st grade of primary school (6 to 7 years of age, mean 6.5 years of age) until the junior year of high school (17 to 18 years of age, mean 17.5 years of age). In addition, measurements were obtained until 18.5 years of age in 91 male subjects.

A stadiometer was used to measure stature, an anthropometer was used to measure UEL (which was obtained as the difference in height above the floor between the acromial process and the tip of the middle finger), and sliding calipers were used to measure HL. Each parameter was measured by the same examiner (stature measured during school check-ups was used). Each parameter was measured in units of 1 mm. A total of 678 subjects (343 males and 335 females) were entered into the study. However, only 362 subjects (182 males and 180 females) could be followed for 12 years (Table 1).

Table 1 Materials

	Total No. measured	No. of materials
Males	343	182
Females	335	180

※ (Eleven of the 182 male materials were excluded because they were in the growth stage.)

We evaluated the order of growth cessation of stature, UEL and HL, in addition to the relationship between the order of cessation and stature or UEL at 6.5 years of age. We also evaluated the relationship between the age of growth cessation of stature and UEL, and stature and UEL at 6.5 years of age. The relationship between final stature and the age of growth cessation was also studied.

The age of growth cessation of sature was defined as the age when stature increased by 1 cm or less per year. With regard to UEL and HL, the age of growth cessation was defined as the age when the increase remained at the same level on a graph plotting the UEL and HL on the vertical axis and age on the horizontal axis.

Results

In 11 male subjects, both stature and UEL were thought to be in the growth stage at the age at which growth cessation was defined. These subjects were therefore excluded from the evaluation. As a result, the total number of subjects was 351, including 171 males and 180 females.

For evaluation, both males and females were classified into 3 groups based on the relationship between the age of growth cessation of the UEL and stature. Subjects in whom growth cessation of UEL occurred earlier than that of stature were categorized as group MA

Table 2 Relationships between UEL, stature, or HL and the age of growth cessation

Male				Female			
Classification	N 171	%		Classification	N 180	%	
MA	126	73.68		FA	129	71.67	
MA-1	73	42.69		FA-1	48	26.67	**
MA-2	53	30.99		FA-2	81	45.00	
MB	41	23.98		FB	46	25.56	
MB-1	10	5.85	**	FB-1	10	5.56	**
MB-2	31	18.13		FB-2	36	20.00	
MC	4	2.34		FC	5	2.78	
MC-1	1	0.58		FC-1	2	1.11	
MC-2	3	1.75		FC-2	3	1.67	

** : $p<0.01$

(for males) or group FA (for females), subjects in whom growth cessation of UEL and stature occurred simultaneously were categorized as group MB (for males) or group FB (for females), and subjects in whom growth cessation of UEL occurred later than that of stature were categorized as group MC (for males) or group FC (for females). In addition, within each group, subjects in whom growth cessation of UEL and HL occurred simultaneously were categorized as group 1, and subjects in whom growth cessation of UEL occurred later than that of HL were categorized as group 2. In no subjects did growth cessation of UEL occur earlier than of HL, since UEL includes HL.

With regard to the relationship between age of growth cessation of UEL and stature, growth cessation of UEL occurred earlier than that of sature (MA and FA groups) in 73.68% of males and 71.67% of females, and growth cessation of both UEL and stature occurred simultaneously (MB and FB groups) in 23.98% of males and 25.56% of females. Growth cessation of UEL occurred later than that of stature (MC and FC groups) in 2.34% of males and 2.78% of females.

In the MA and FA groups, no significant differences were noted in males between subjects in whom growth cessation of both UEL and HL occurred simultaneously (MA-1 : 42.69%) and subjects in whom growth cessation of UEL occurred later than that of HL (MA-2 : 30.99%). However, in females, statistically significant differences were observed between subjects in whom growth cessation of UEL occurred later than that of HL (FA-2 : 45.00%) and subjects in whom growth cessation of both UEL and HL occurred simultaneously (FA-1 : 26.67%). The former case was observed 1.69 times as frequently as the latter case ($p<0.01$). However, statistically significant differences were noted in both males and females in group B, since group 2 included three times as many subjects as group 1. In group C, no significant differences were obsreved between groups 1 and 2 in both males and females, although the number of subjects was small.

With regard to subjects in whom growth cessation of UEL and stature occurred simultaneously (MB-1 and FB-1), growth cessation of HL was also observed in 5.85% of males and 5.56% of females. Accordingly, there were few subjects in whom growth cessation of these three parameters occurred simultaneously

(Table 2).

Comparing the growth cessation of UEL and HL, in males, growth cessation of UEL and HL occurred simultaneously in 49.12%, and growth cessation of UEL occurred later than that of HL in 50.88%, which was not a statistically significant difference. However, in females, growth cessation of UEL occurred later than that of HL in 66.67%, and growth cessation of both parameters occurred simultaneously in 33.33%, which was a statistically significant difference ($p<0.05$) (Table 3).

Table 3 Relationship between growth cessation of UEL and HL

	Male			Female		
	N	%		N	%	
1	84	49.12	NS	60	33.33	*
2	87	50.88		120	66.67	

*: $p<0.05$

1 ; Growth cessation of UEL and HL occurred simultaneously.

2 ; Growth cessation of UEL occurred later that of HL.

Since apparent differences were observed between MA, MB, and MC in stature measured at 6.5 years of age, analysis of variance was performed, but the difference was not statistically significant. The same result was obtained in females (Fig. 1-1, -2). In addition, the same test was performed for UEL, but there was no statistically significant difference in either males or females (Fig. 2-1, -2). As a result, stature and UEL at 6.5 years of age were not related to the order of growth cessation of stature and UEL.

In male subjects, excluding 11 subjects in

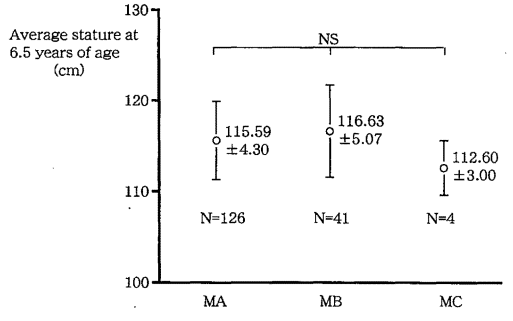

Fig. 1-1 Comparison of average stature at 6.5 years of age in MA, MB, MC groups

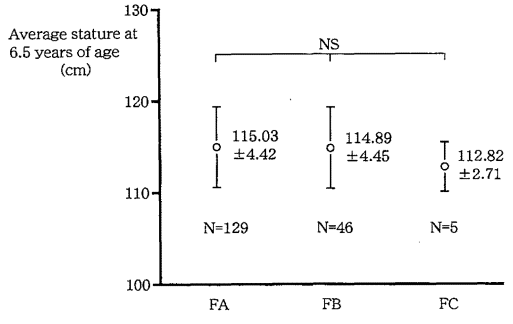

Fig. 1-2 Comparison of average stature at 6.5 years of age in FA, FB, FC groups

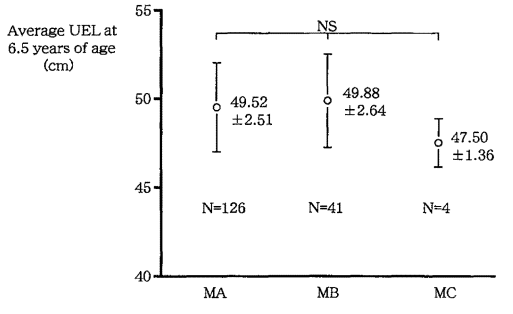

Fig. 2-1 Comparison of average UEL at 6.5 years of age in MA, MB, MC groups

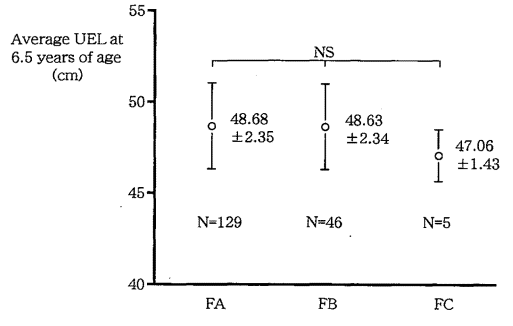

Fig. 2-2 Comparison of average UEL at 6.5 years of age in FA, FB, FC groups

whom both stature and UEL were in the growth stage, growth cessation of stature occurred between 14.5 and 17.5 years of age, while in females, it occurred between 12.5 and 16.5 years of age. Growth cessation in females therefore occurred earlier than in males, as is generally believed. In 3 female subjects, only stature was in the growth stage. Growth cessation of UEL was between 13.5 and 17.5 years of age in males and between 11.5 and 15.5 years of age in females. Compared with growth cessation of stature, growth cessation of UEL occurred slightly earlier.

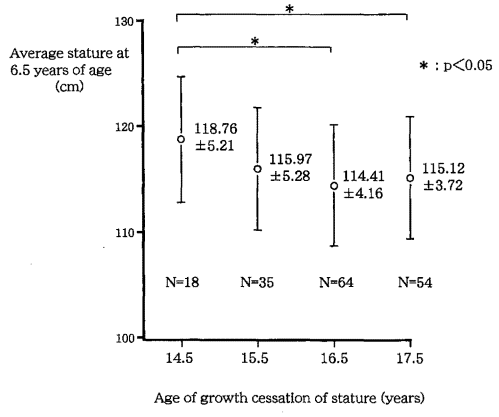

Fig. 3-1 Stature at 6.5 years of age according to age of growth cessation of stature (males)

In comparing stature at 6.5 years of age and age of growth cessation of stature, stature tended to be taller in both male and female subjects in whom growth cessation of stature occurred earlier rather than later. In males, stature at 6.5 years of age according to the age of growth cessation varied as follows: 118.76 ±5.32 cm for 14.5 years of age, 114.41±4.16 cm for 16. 5 year of age, and 115.12±3.72 cm for 17.5 year of age. The tallest stature at 6.5 years of age was observed in subjects in whom growth cessation occurred at 14.5 years of age. Statistically significant differences were therefore noted (Fig. 3-1). In females, stature at 6.5 years of age was taller in subjects in whom growth cessation of stature occurred at 12.5 years of age (117.09±5.93 cm), compared with those in the growth stage (108.97±1.50 cm).

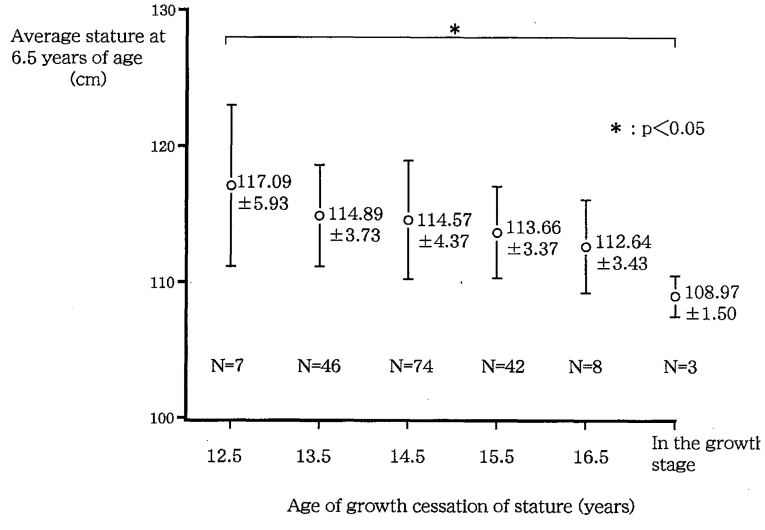

Fig. 3-2 Stature at 6.5 years of age according to age of growth cessation of stature (females)

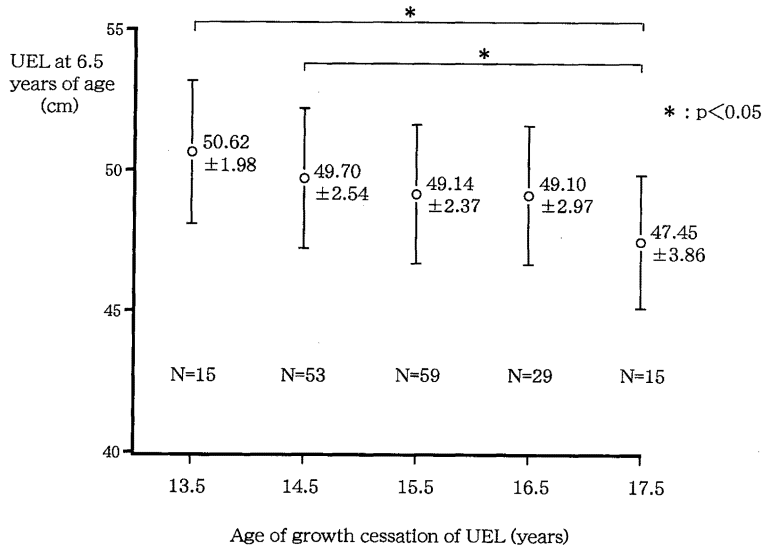

Fig. 4-1 UEL at 6.5 years of age according to age of growth cessation of UEL (males)

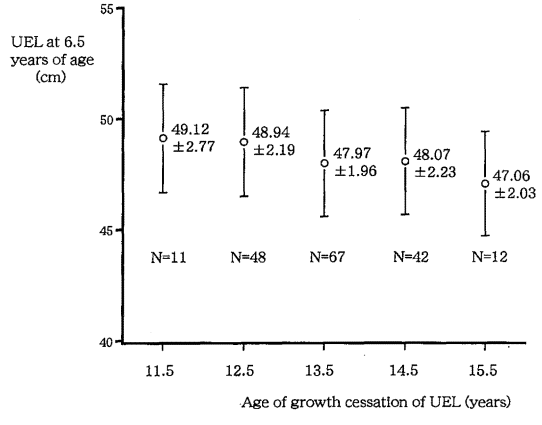

Fig. 4-2 UEL at 6.5 years of age according to age of growth cessation of UEL (females)

Statistically significant differences were therefore recognized (Fig. 3-2).

UEL at 6.5 years of age also tended to be longer in subjects in whom growth cessation occurred earlier. In males, UEL at 6.5 years of age according to the age of growth cessation was as follows: 47.45±3.86 cm for 17.5 years of age, 50. 62±1.98 cm for 13.5 years of age, and 49.70±2.54 cm for 14.5 years of age. The shortest UEL at 6.5 years of age was observed in subjects in whom growth cessation of UEL occurred at 17.5 years of age. Statistically significant differences were therefore recognized (Fig. 4-1). In females, no significant differences were noted (Fig. 4-2).

Comparing final stature according to the age of growth cessation of stature, in males, final stature was 169.30±5.68 cm for 16.5 years of age and 171.97±6.03 cm for 17.5 years of age. The final stature was the tallest in males in whom growth cessation of stature occurred at 17.5 years of age. Statistically significant differences were observed (Fig. 5-1). In females, final stature was 154.01±4.58 cm for 13.5 years of age, 156.65±5.23 cm for 14.5 years of age, 157.76±5.16 cm for 15.5 years of age, and 158.61±2.96 cm for 16.5 years of age. Among these subjects, the shortest final stature was seen in those in whom growth cessation of stature occurred at 13.5 years of age, and the

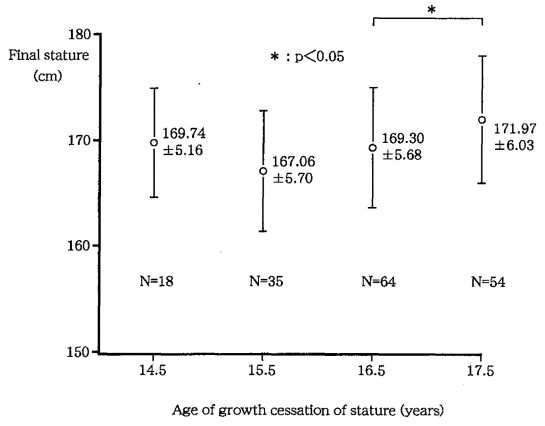

Fig. 5-1 Final stature according to age of growth cessation of stature (males)

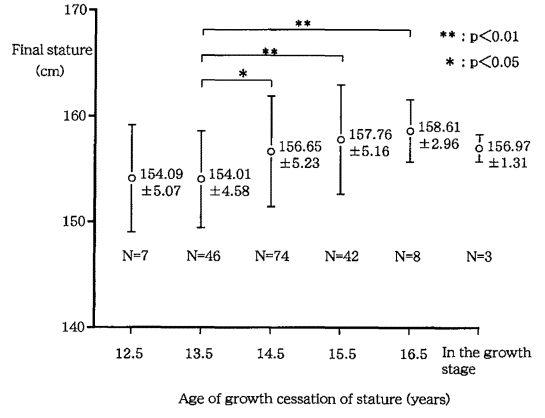

Fig. 5-2 Final stature according to age of growth cessation of stature (females)

difference was statistically significant (Fig. 5-2). Comparing male subjects in whom growth cessation of stature occurred at 14.5 and 15.5 years of age, the stature in the former group was taller, but the difference was not statistically significant. In general, the later the age of growth cessation, the taller the stature in both males and females.

The main points can be summarized as follows:

1. Order of growth cessation of stature and UEL

In both males and females, growth cessation of UEL tended to occur earlier than that of stature. In males, the mumber of subjects in whom growth cessation of UEL and HL occurred simultaneously and the number of subjects in whom growth cessation of UEL occurred earlier than that of stature were almost identical, while in females, the number of subjects in whom growth cessation of HL occurred earlier was significantly larger.

2. Relationship between the order of growth cessation of stature and UEL and stature and UEL at 6.5 years of age

No significant differences were found.

3. Relationship between the age of growth cessation of stature and stature at 6.5 years of age

The younger the age of growth cessation of stature, the taller the stature at 6.5 years of age. Significant differences were observed in both males and females.

4. Relationship between the age of growth cessation of UEL and UEL at 6.5 years of age

In males, the earlier the growth cessation of UEL, the longer the UEL at 6.5 years of age, and statistically significant differences were observed. However, in females, although a similar trend was seen, the difference was not statistically significant.

5. Relationship between the age of growth cessation and final stature

In both males and females, the later the growth cessation of stature, the taller the final stature. The differences observed were statistically significant.

Discussion

Conventionally, it has been said that growth of stature ceases at around 17 years of age in males and at around 14 years of age in females. However, there have been few reports on the age of growth cessation of the upper extremi-

Table 4 Comparison of the data of our study against those obtained by Kimura (stature)

Age	Male(cm)		Female(cm)	
	Our study	Kimura	Our study	Kimura
6.5	115.71	111.66	114.75	110.40
7.5	121.00	117.05	120.31	116.14
8.5	126.69	123.17	126.17	121.78
9.5	131.99	128.06	131.85	127.88
10.5	137.35	132.93	138.56	132.93
11.5	143.20	137.50	145.66	139.80
12.5	150.70	143.63	151.03	146.00
13.5	158.09	151.18	154.46	148.84
14.5	164.19	158.54	156.13	153.14
15.5	167.53	162.07	156.68	154.99
16.5	169.35	168.41	156.85	157.13
17.5	170.25	168.38	157.13	156.38

ties. In 1965, Kimura[7] obtained anthropometric measurements of a number of parameters for male and female children ranging in age from 5 to 18 years living in Tokyo. In his study, he presented a growth curve for UEL with the length at 18 years of age normalized to a value of 100. His results showed that growth of the upper extremities ceased almost at the same age as stature, although growth of the upper extremities was slower than that of stature. In addition, similar growth curves for humerus, forearm and hand lengths were obtained. Among these, forearm length grew most rapidly, followed by humerus length and HL, in that order. Growth of the hand progressed most slowly. In his report, Kimura concluded that growth of these parameters was completed at almost the same age, although the rate of growth differed. No difference was observed between the sexes (Table 4).

Takabu et al. generated growth curves for stature and sleeve length based on data acquired between 1978 and 1979[12]. These curves revealed that growth cessation of both sature and sleeve length occurred at 16 or 17 years of age in males and at 14 or 15 years of age in females.

Cameron et al.[3] suggested that HL were nearer the adult length at any age than forearm or upper arm and the growth of HL ceased 1 year faster than the others in boys but in girls the pattern was less clear. The growth cessation of these parameters occurred almost at same age except HL in boys. He didn't compare the growth cessation of stature with these 3 parameters.

Analyzing these results using the classification system used in our study, the majority of subjects would be classified as MB or FB in Table 2 with regard to the relationship of growth cessation of sature and UEL. In actuality, however, 70% of all subjects were classified as MA or FA. In addition, the relationship between UEL and HL is shown in Table 3. Briefly, no differences were noted in males, in our investigation, between subjects in whom growth cessation of UEL and HL occurred simultaneously and those in whom growth cessation of UEL occurred later than that of HL. On the contrary, in females, the latter case was considerably more frequent than the former. This difference is presumably because our study was based on longitudinal data in which each subject was followed for 12 years, whereas Kimura's data was cross-sectional data obtained from males and females between 5 and 18 years of age. This is probably because growth cessation of each region was evaluated as if it occurred at the sama age, due to averaging of individual growth patterns, as the stature, UEL, etc. are evaluated using mean and standard deviation when cross-sectional data is used.

Analyzing the results obtained in our study as if they were cross-sectional data, both mean and standard deviation were calculated. Growth curves for stature, UEL, and HL were

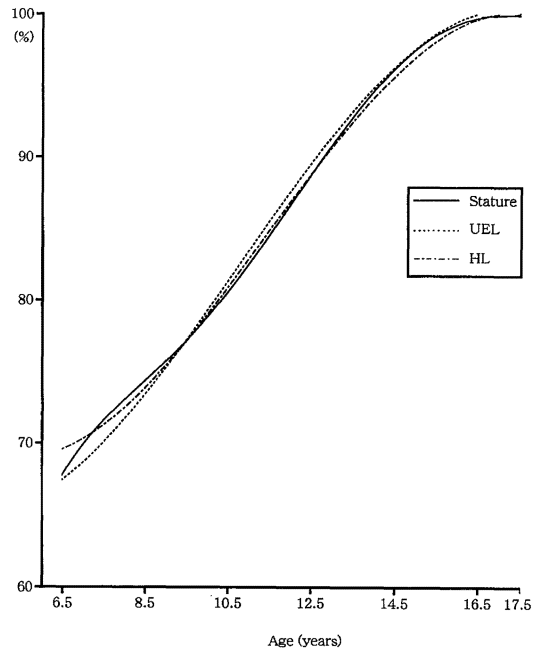

Fig. 6-1 Growth curves of stature, UEL and HL in males, based on cross-sectional data with values normalized to a value of 100% at 17.5 years of age

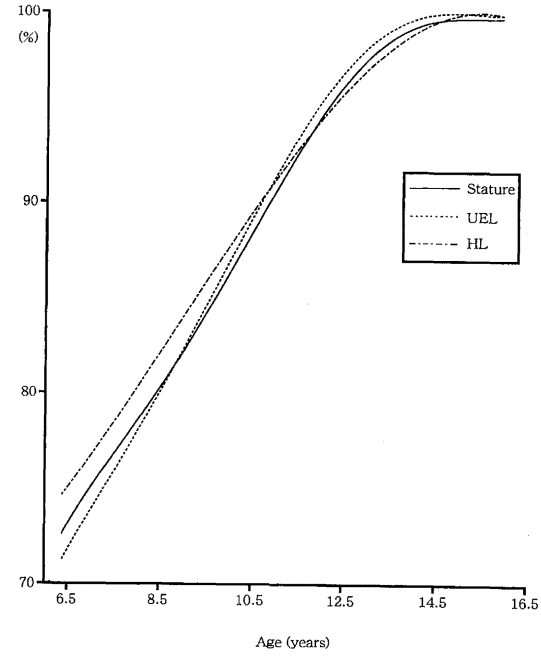

Fig. 6-2 Growth curves of stature, UEL and HL in females, based on cross-sectional data with values normalized to a value of 100% at 16.5 years of age

generated by normalizing the values of these parameters at the age of 17.5 years for males or 16.5 years for females to a value of 100, based on the results shown in Figs. 4-1 and -2 (Figs. 6-1 and -2). These curves revealed that each parameter exhibited almost the same growth rate in males. In females, growth of HL preceded that of the other parameters by around 9.5 years of age, and almost identical growth patterns were observed in the three parameters thereafter. Growth of stature and UEL ceased at 14.5 and HL ceased at 15.5 years of age, respectively. In comparison with the results obtained by Kimura, no difference was observed because the growth of each parameter ceased at almost the same age, although the order of growth of stature, UEL and HL differed slightly. Comparing the data obtained by Kimura and those obtained in our study, it appears that the physical characteristics of both males and females has improved, as the results obtained in our study indicate an increase of 3 to 7 cm in stature in each generation (Table 4). We feel that longitudinal data is more usuful for evaluating growth, and that the results obtained from cross-sectional data should be viewed with caution because differences may arise due to the analytical method used.

In our study, measurements were obtained at the same time of year in all subjects. However, it would have been preferable to obtain measurements on each subject's birthday, or to obtain more detailed results by obtaining individual measurements several times a year. However, given the large number of children to be examined and the labor required, this was judged to be impractical.

Subjects in whom growth cessation of stature and UEL had not occurred, including 11 male subjects (6.04%), were excluded from the evaluation, It would be interesting to follow these subjects for a longer period, but this would be very difficult because young people tend to leave the area when they reach 18 years of age. These 11 subjects were also compared against the other groups with regard to stature and UEL, and no significant differences were observed, although the data are not presented in this paper.

With regard to axial growth, as far as bone maturity is concerned, the humerus, radius and ulna are related to UEL, and the metacarpal bones and phalanges are related to HL.

Prichett[10] performed X-ray examination of the humerus and forearm in 123 males and 121 females between 7 years of age and the age of bone maturity at 6-month intervals. Longitudinal data was thus obtained, and the expected growth of each bone at each age was analyzed based on cross-sectional data to obtain the mean and standard deviation. According to the data, growth cessation of the humerus, radius and ulna occurred at 16 or 17 years of age in males and at 14 or 15 years of age in females.

Concerning closure of the epiphysial line, Joseph[6] reported closure of the epiphysis of the metacarpal bones at 17 years of age in males and 14 years of age in females, although no comparable longitudinal data is available. In his report, closure of the epiphysis in the phalanges was observed at almost the same age.

The results obtained in his investigation are not in agreement with those obtained in our study, in which growth cessation of UEL occurred later than that of HL, although growth cessation of the humerus, radius, ulna and phalanges occurred at almost the same age. The reasons for these differences in results may be that Prichett's data was analyzed cross-sectionally although it was longitudinal and that Joseph's data was cross-sectional.

Based on the results of our study, with respect to growth of UEL and stature, growth cessation of UEL occurs earlier than that of stature in most subjects, irrespective of sex. With regard to HL and UEL, no differences were noted between male subjects in whom growth cessation of HL occurred earlier and those in whom growth cessation occurred simultaneously. On the contrary, in females, subjects in whom growth cessation of HL occurred earlier than that of UEL made up the overwhelming majority. In other words, in females, growth cessation tends to occur from distal to proximal. In the literature, Satake[11] reported that the metacarpal bones and phalanges grow more regularly in females than in males from the viewpoint of relative growth of length and width, based on longitudinal evaluation of X-ray films of the hands. This may be related to our observation that axial growth showed a regular pattern of cessation from distal to proximal in most female subjects.

Mareover, it could be said that stature at 6.5 years of age was tall, in both males and females, in subjects in whom growth cessation occurred earlier (Figs. 3-1, -2), with a statistically significant difference observed. In addition, the UEL in males was long, with a statistically significant difference observed at 6.5 years of age, as was the case for growth of stature. However, the trend observed in females was not statistically significant. Furthermore, the later growth cessation of stature occurs, the taller the final stature in both males and females (Figs. 5-1, -2). Considering

the relationship between stature at 6.5 years of age and the age of growth cessation, we noted that the taller the stature at 6.5 years of age, the shorter the final stature. We cannot assert that sex hormones are involved in the differences observed between the sexes, but there have been no reports suggesting that other factors are involved.

Acknowledgements

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(和文抄録)

縦断的データを用いた小城郡での学童期から成長停止までの身長，上肢長，手長の成長の分析

佐賀医科大学外科学講座整形外科部門

西　川　英　夫

ヒトの成長において，上肢，下肢，体幹の各部は均一に伸びるものではなく，それぞれの最大成長加速期および成長停止時期は同時期ではないといわれてきた．本研究は，長期にわたる縦断資料に基づいて身長，上肢長，手長の成長停止時期を検討し各々の関係を明らかにしようと試みたものである．

資料としては佐賀県小城郡の小学1年生（6.5才時）の男子171例，女子180例を対象とし，12年間にわたって身長，上肢長，手長を1年に1度生体計測した．これらの成長が停止した年齢を中心として，各人の身長，上肢長，手長の成長が停止する順序やその順序と6.5才時の身長，上肢長との関係などを検討した．

成長が停止する時期の比較の順序については，身長と上肢長の比較では上肢長が早く停止するものが男子73.68%，女子71.67%，同時に停止するものが男子23.98%，女子25.56%，上肢長が遅く停止するものが男子2.34%，女子2.78%と，男女とも上肢長が身長より早く停止するものが多かった．

上肢長と手長の比較では，男子では同時に停止するものが49.12%，上肢長が遅く停止するものが50.88%と大きな差はなかったが，女子では33.33%と66.67%で，後者が前者の約2.0倍あり差を認めた．しかし，同じデータを横断的に処理すると男女とも身長，上肢長，手長ともほぼ同年齢で停止した結果となり，他の研究者の横断的データと似たものとなった．

また，身長，上肢長が停止する年齢と初回時の測定値との関係では，停止の年齢が早ければ各々の初回時の測定値は大きい傾向にあった。さらに，最終身長については，身長が遅く止まったものは早く止まったものに比べて男女とも有意に高かった．

以上より，身長と上肢の成長の停止の時期の比較では，末端から停止していく例が多く，特に女子において顕著であるという結論を得た．