

Distribution of Lengths of the Normal Femur and Tibia in Korean Children from Three to Sixteen Years of Age

To develop a standard growth curve of the lower extremity in Korean children from 3 to 16 yr of age, the lengths from a total of 2087 normal long bone segments (582 femurs and 645 tibias in boys, and 417 femurs and 443 tibias in girls) were measured. Children were grouped by years of bone age, which was determined by using the Korean specific bone age standard; TW2-20 method. The growth spurt occurred in girls from eight to eleven years by bone age, and in boys from eleven to thirteen years. The mean tibial length relative to the mean femoral length was 0.78 in boys and 0.79 in girls. The overall growth pattern was similar to that observed in American children in the 1960s. Korean children and adolescents appear to have a different tempo of skeletal maturation during pubertal growth from that of English and American children and adolescents. The Korean standard growth curve and the Korean bone age chart allow determination of the presence of any existent growth abnormalities and prediction of future remaining growth in lower extremities. These normative growth standards can be used for leg-length equalization purposes in children with anisomelia.

Key Words : Bone age Measurement; Age Determination by Skeleton; Growth; Children; Korea

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INTRODUCTION

Many factors, i.e., era, ethnic origin, and socioeconomic status, can affect characteristics of growth. Therefore, the development of a standard growth curve is essentially required on a basis of country for the more accurate assessment of existing growth abnormality, the prediction of future growth and for calculating any residual discrepancy of limb-length at skeletal maturity. Some authors in the oriental region have reported growth-related data by focusing on different characteristics of skeletal growth from those used in the West (1, 2). Through nationwide survey by cross-sectional study, a Korean specific bone age standard based on the Tanner-Whitehouse 2 method (3) was established by the Korean Radiological Society in 1997 (4). The present study was undertaken in order to develop a standard growth chart of the lower extremity in Korean children from 3 to 16 yr of age. For this purpose, the lengths of the normal femur and tibia were measured and standardized by bone age, which was determined by using the Korean bone age standard (4).

METHODS AND MATERIALS

For the nationwide cross-sectional study conducted to determine and measure the bone age and the lengths of femurs and tibias, six centers were selected. The six centers selected were evenly distributed around the country. In order to investigate the distribution of femur and tibia lengths according to bone age, Korean boys and girls, ranging from two to eighteen years old, were enrolled in the study from 1999 to 2002. The lengths of a total of 2087 normal long bone segments (582 femurs and 645 tibias in boys, and 417 femurs and 443 tibias in girls) were measured. This population contained unilaterally involved patients, e.g. those having post-traumatic and post-infectious diseases, and congenital diseases such as anisomelia, developmental dysplasia of the hip, Legg-Perthes disease. Patients having systemically involved metabolic or genetic diseases, or neuromuscular diseases were excluded. We used the atlas of the Korean specific bone age standard on the TW2-20 method published in 1999 (5). A total of 965 anteroposterior radiographs (553 boys, 412 girls) of the left hand were evaluated for determination of bone ages. When an image of the left hand

in the atlas was identical to the actual radiograph of a given child, the corresponding standard bone age set equal to the real bone age. But, when the actual image was not identical to that in the atlas, two consecutive images of standard bone ages, which best fitted the actual image, were selected to determine the bone age, which was calculated from the ratio of the TW-2 maturity scores of the two corresponding standard bone ages. The reliability in determining the bone age was tested by using Kappa statistics on 25 randomly selected radiographs.

The lengths of femurs and tibias were measured on an orthoscannogram of the lower extremity (Fig. 1). Femur length was defined as the distance between the horizontal lines passing the most proximal point of the capital femoral epiphysis to the horizontal line bisecting the medial joint space of the knee. The length of the tibia was defined as the distance between the horizontal line bisecting the medial joint space of the knee and the line drawn along the sclerotic rim of distal tibial plafond. Children were grouped by bone age years. The

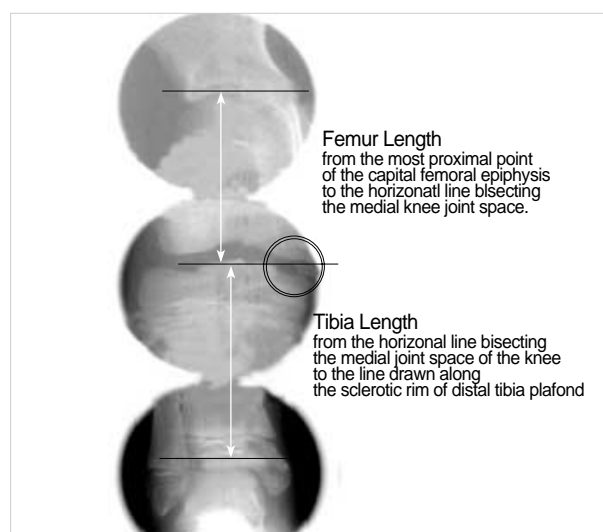


Fig. 1. A diagram showing how to measure the lengths of the femur and tibia on an orthoscannogram.

Table 1. Length (cm) of the long bones according to Korean bone age in boys

Femur									
Number of cases	Age	Mean	SD*	SE [†]	Median	Distribution			
						+2SD	+1SD	-1SD	-2SD
23	3 (30-42 mo)	22.31	1.455	0.303	22.50	25.22	23.77	20.86	19.40
33	4 (43-54 mo)	24.62	1.431	0.249	24.70	27.48	26.05	23.19	21.76
53	5 (55-66 mo)	27.91	1.744	0.240	28.10	31.40	29.65	26.17	24.42
42	6 (67-78 mo)	30.09	1.750	0.270	29.70	33.59	31.84	28.34	26.59
52	7 (79-90 mo)	31.66	1.926	0.267	31.55	35.51	33.59	29.73	27.81
91	8 (91-102 mo)	33.24	1.944	0.204	33.20	37.13	35.18	31.30	29.35
39	9 (103-114 mo)	35.25	1.809	0.290	35.00	38.87	37.06	33.44	31.63
32	10 (115-126 mo)	36.77	1.721	0.304	36.10	40.21	38.49	35.05	33.33
39	11 (127-138 mo)	38.19	1.656	0.265	38.00	41.50	39.85	36.53	34.88
32	12 (139-150 mo)	40.21	1.812	0.320	40.25	43.83	42.02	38.40	36.59
43	13 (151-162 mo)	42.80	1.663	0.254	42.50	46.13	44.46	41.14	39.47
31	14 (163-174 mo)	43.74	1.864	0.335	43.80	47.47	45.60	41.88	40.01
31	15 (175-186 mo)	44.65	1.763	0.317	44.90	48.18	46.41	42.89	41.12
41	16 (187-198 mo)	45.46	1.884	0.294	45.20	49.23	47.34	43.58	41.69
Tibia									
Number of cases	Age	Mean	SD*	SE [†]	Median	Distribution			
						+2SD	+1SD	-1SD	-2SD
23	3 (30-42 mo)	17.95	0.864	0.180	17.90	19.68	18.81	17.09	16.22
31	4 (43-54 mo)	19.90	1.236	0.222	19.80	22.37	21.14	18.66	17.43
63	5 (55-66 mo)	21.60	1.548	0.195	21.60	24.70	23.15	20.05	18.50
48	6 (67-78 mo)	23.35	1.541	0.222	23.40	26.43	24.89	21.81	20.27
48	7 (79-90 mo)	24.64	1.704	0.246	24.60	28.05	26.34	22.94	21.23
87	8 (91-102 mo)	26.02	1.723	0.185	26.00	29.47	27.74	24.30	22.57
44	9 (103-114 mo)	27.28	1.577	0.238	27.15	30.43	28.86	25.70	24.13
33	10 (115-126 mo)	28.77	1.737	0.302	28.70	32.24	30.51	27.03	25.30
47	11 (127-138 mo)	30.08	1.590	0.232	29.90	33.26	31.67	28.49	26.90
38	12 (139-150 mo)	31.45	1.655	0.269	31.15	34.76	33.11	29.80	28.14
52	13 (151-162 mo)	33.40	1.620	0.225	33.30	36.64	35.02	31.78	30.16
39	14 (163-174 mo)	33.89	1.667	0.267	34.00	37.22	35.56	32.22	30.56
41	15 (175-186 mo)	34.72	1.678	0.262	34.90	38.08	36.40	33.04	31.36
51	16 (187-198 mo)	35.34	1.673	0.234	35.00	38.69	37.01	33.67	31.99

SD*: standard deviation, SE[†]: standard error.

mean, median, standard error, and standard deviation of the lengths of femurs and tibias at each bone age year were calculated. The bone age initially determined in months was then converted to the age in years after rounding off to the nearest integer.

We evaluated the growth characteristics of the lower extremities in Korean children aged from 3 to 16 yr by bone age. The disparity between the chronological age and the bone age, and the velocity of annual longitudinal growth (cm/year) of the femur and tibia in each gender was calculated. The growth velocity of each proximal and distal epiphyses of the femur was presumed based on the assumption that the proximal physis of the femur contributes a constant 29%, and the distal physis, a constant 71% to the total growth of the femur (6). The growth rates of the proximal and distal tibia were calculated in a similar manner, assuring that the proximal physis of the tibia attributes 57%, and the distal physis attributes 43% to the total tibial growth (6). The relative length ratios of the femur and tibia were evaluated and compared with previously published Caucasian data (7). An example how to use the Korean

growth chart in limb length equalization is provided in the Appendix.

RESULTS

When the reliability in determining the bone age was analyzed, the kappa score of inter-observer variation was found to be 0.66. The kappa scores of intra-observer variation were 0.83 for an experienced reader and 0.71 for a novice. Table 1 and 2 present the mean, median, standard error, and standard deviation, of normal femoral and tibial lengths by bone age for Korean boys and girls (Fig. 2, 3). The disparity between chronological age and bone age was within one year for all subjects. Two growth rate maxima occurred during the different growing stages after a bone age of three years, namely early growing phase, before growth spurt, growth spurt, and after spurt phase (Table 3). The first growth rate peak, which occurred in early growing phase, was observed at bone ages of three to six years in both boys and girls. The second highest

Table 2. Length (cm) of the long bones according to Korean bone age in girls

Femur									
Number of cases	Age	Mean	SD*	SE [†]	Median	Distribution			
						+2SD	+1SD	-1SD	-2SD
20	3 (30-42 mo)	22.85	1.748	0.391	23.05	26.35	24.60	21.10	19.35
30	4 (43-54 mo)	25.24	1.689	0.308	25.20	28.62	26.93	23.55	21.86
36	5 (55-66 mo)	26.87	1.788	0.298	26.95	30.45	28.66	25.08	23.29
30	6 (67-78 mo)	29.34	1.707	0.312	29.20	32.75	31.05	27.63	25.93
30	7 (79-90 mo)	30.52	1.714	0.313	30.15	33.95	32.23	28.81	27.09
37	8 (91-102 mo)	32.16	1.729	0.284	32.00	35.62	33.89	30.43	28.70
34	9 (103-114 mo)	34.56	1.747	0.300	34.50	38.05	36.31	32.81	31.07
33	10 (115-126 mo)	36.52	1.777	0.309	36.10	40.07	38.30	34.74	32.97
45	11 (127-138 mo)	38.31	1.806	0.269	38.50	41.92	40.12	36.50	34.70
30	12 (139-150 mo)	39.90	1.808	0.330	40.10	43.52	41.71	38.09	36.28
31	13 (151-162 mo)	41.37	1.817	0.327	41.50	45.00	43.19	39.55	37.74
31	14 (163-174 mo)	41.87	1.819	0.327	41.90	45.51	43.69	40.05	38.23
30	15 (175-186 mo)	42.23	1.840	0.336	42.20	45.91	44.07	40.39	38.55

Tibia									
Number of cases	Age	Mean	SD*	SE [†]	Median	Distribution			
						+2SD	+1SD	-1SD	-2SD
21	3 (30-42 mo)	17.87	1.269	0.277	18.30	20.41	19.14	16.60	15.33
30	4 (43-54 mo)	20.12	1.456	0.266	20.00	23.30	21.58	18.66	17.21
35	5 (55-66 mo)	20.93	1.630	0.276	20.80	24.19	22.56	19.30	17.67
35	6 (67-78 mo)	22.53	1.521	0.257	22.50	25.57	24.05	21.01	19.49
31	7 (79-90 mo)	23.78	1.448	0.260	23.60	26.68	25.23	22.33	20.88
42	8 (91-102 mo)	25.16	1.602	0.247	25.45	28.36	26.76	23.56	21.96
34	9 (103-114 mo)	27.02	1.489	0.255	26.80	30.00	28.51	25.53	24.04
42	10 (115-126 mo)	28.66	1.668	0.257	28.60	32.00	30.33	27.00	25.32
48	11 (127-138 mo)	30.15	1.595	0.230	30.25	33.34	31.75	28.56	26.96
30	12 (139-150 mo)	31.85	1.692	0.309	31.85	35.23	33.54	30.16	28.47
34	13 (151-162 mo)	32.60	1.575	0.270	32.60	35.75	34.18	31.03	29.45
30	14 (163-174 mo)	32.83	1.599	0.292	32.65	36.03	34.43	31.23	29.63
31	15 (175-186 mo)	33.54	1.684	0.302	33.60	36.91	35.22	31.86	30.17

SD*: standard deviation, SE[†]: standard error.

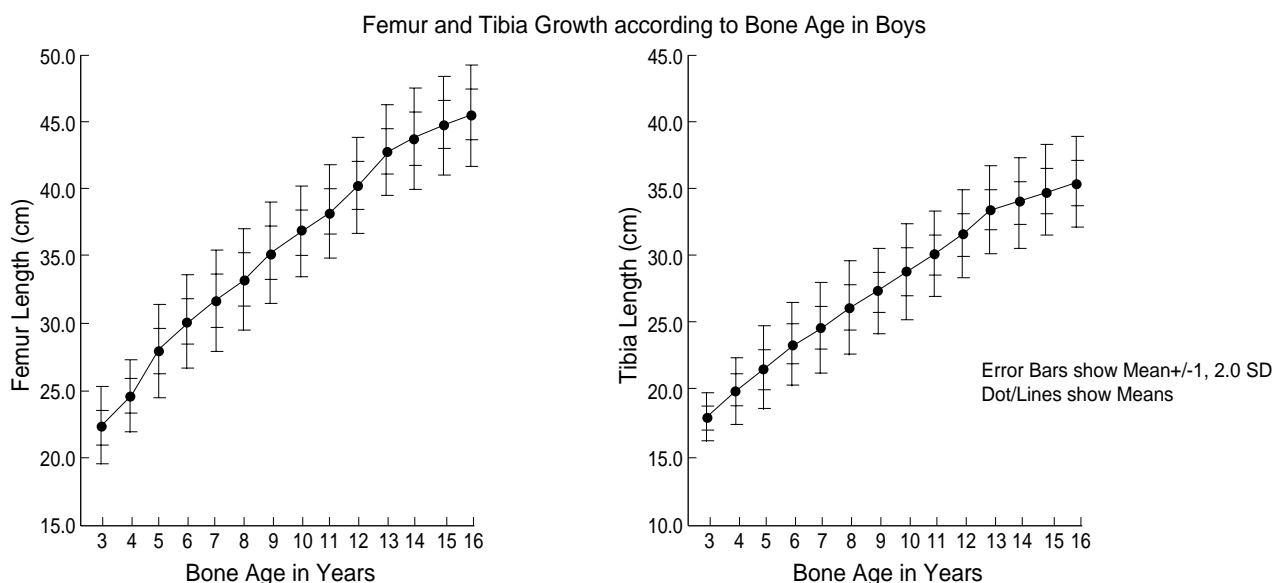


Fig. 2. A bone length chart for the normal femur and tibia in Korean boys from bone age three years through to sixteen years. (Mean, +1SD, +2SD, -1SD, -2SD curves)

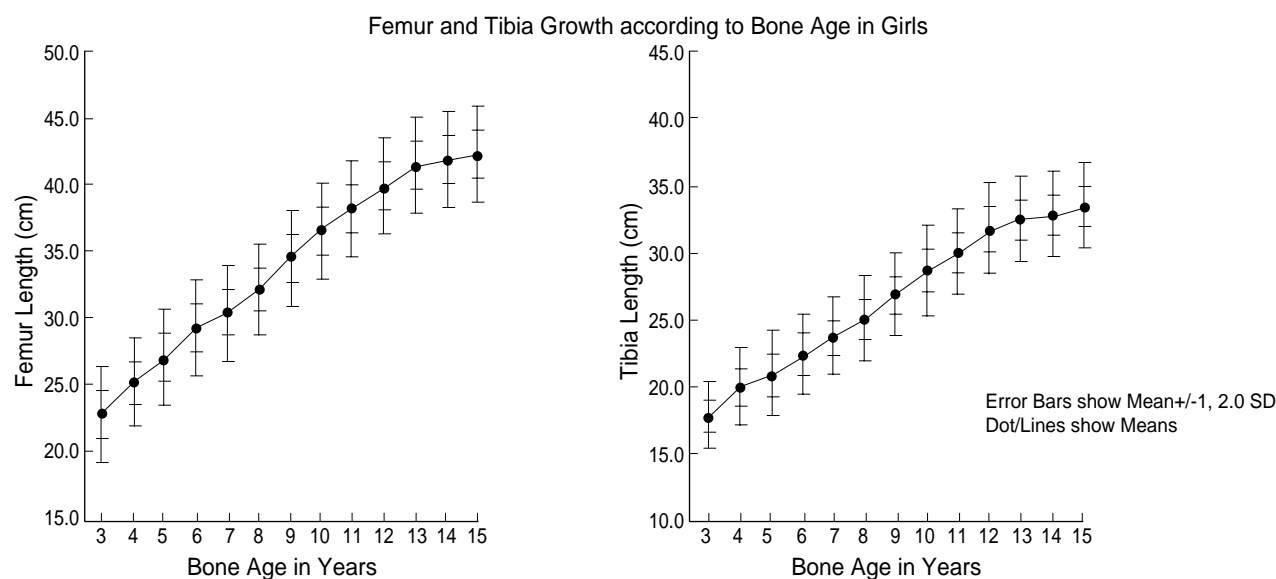


Fig. 3. A bone length chart for the normal femur and tibia in Korean girls from bone age three years through to fifteen years. (Mean, +1SD, +2SD, -1SD, -2SD curves)

peak occurred in puberty. In Korean boys, the second highest peak extended from eleven to thirteen years bone age. In contrast, this peak occurred in Korean girls from eight to eleven years, i.e., it was more prolonged than observed in boys. The growth rates of the proximal and distal physes of the femur and tibia are shown in Table 4. The mean tibial length was 78% relative to the femur in boys and 79% in girls, shorter than that of Caucasian (7).

DISCUSSION

In the United States, Anderson et al. (6, 8) developed a gro-

wth curve, spanning one to 18-yr-olds. This curve is based upon longitudinal growth data of the normal femurs and tibias of American white children with polio in the 1950s and 1960s by using chronological age and bone age, as determined by the Greulich-Pyle atlas (9). These data have been used with some success to predict leg length discrepancy, although some modifications were later made by Moseley (10), and Paley et al. (11) to simplify its clinical use. Some authors have reported different results that contradict those of Anderson et al. (8), which were attributed to differences in ethnic origin, height, and socioeconomic status (12-14). Maresh (12) and Beumer et al. (13) produced results that differed from those of Anderson et al. (8) within the same ethnic group of Caucasians. These

Table 3. The differences of growth rates (cm/year) at the growing stage

		Early growth	Pre-spurt	Growth spurt	Post-spurt
Boys	Femur	2.59	1.62	2.31	0.89
	Tibia	1.80	1.35	1.66	0.65
Girls	Femur	2.16	1.41	2.05	0.78
	Tibia	1.55	1.32	1.66	0.56

*early growth: from three to six years by bone age.

pre-spurt: in girls, from six to eight years by bone age.

in boys, from six to eleven years by bone age.

growth spurt: in girls, from eight to eleven years by bone age.

in boys, from eleven to thirteen years by bone age.

post-spurt: in girls, after eleven years until maturity by bone age.

in boys, after thirteen years until maturity by bone age.

findings imply that a standard growth curve should be prepared by each country in order to assess any existent growth abnormality and to predict future growth at skeletal maturity, and that these be revised on a regular basis.

Assessment of bone age also depends upon the standards used, e.g., the TW-2 method, the TW-1 method, the Greulich and Pyle atlas, and the Roche-Wainer-Thissen (knee) method (15-18). In the present study, bone age was assessed by the modified TW-2 method (4). Though disparities between chronological age and bone age are known to occur, it is reported that they do not exceed 2 yr (19). In the current study, the disparity of average values between chronological age and bone age were within a year.

Through the current study on the distribution of femur and tibia lengths, the use of the atlas of Korean specific bone age determination may allow a more accurate assessment of growth abnormalities and growth predictions. However, there are some weaknesses in this kind of cross-sectional study as compared to longitudinal studies, because the growth characteristics depicted in the authors' growth chart may only approximate to real growth versus bone age. However, on considering the fact that when the more increase in the sample size, the less error of measurement occurs in a cross-sectional study; the growth curve developed during this cross-sectional study is believed to match those produced by substituting the longitudinal methods. Moreover, other authors have used cross-sectional study to determine bone age (4, 20).

The growth spurt may occur at different times depending on ethnicity, socio-economic status, environmental status (e.g., familial distress condition), and individual characteristics (1, 2, 14, 19, 21, 22). The annual growth rates and growth spurt can be deduced from the data in Tables 1 and 2. Growth spurts in Korean children occurred from bone age 8 to 11 yr in girls and from 11 to 13 yr in boys. These results suggest that in Koreans growth spurt occurs one year earlier in boys, and two years earlier in girls, than in comparative Caucasian children in the 1960s (6). These findings are in agreement to previous reports that Asian children may have a different growth tempo and a relatively earlier growth start than Caucasian children

Table 4. The growth rates (cm/year) of the proximal and distal physes of the femur and tibia at different growing stages

		Early growth	Pre-spurt	Growth spurt	Post-spurt
Femur	Proximal	0.69	0.44	0.63	0.24
	Distal	1.69	1.08	1.55	0.59
Tibia	Proximal	0.95	0.76	0.95	0.34
	Distal	0.72	0.57	0.71	0.26

*early growth: from three to six years by bone age.

pre-spurt: in girls, from six to eight years by bone age.

in boys, from six to eleven years by bone age.

growth spurt: in girls, from eight to eleven years by bone age.

in boys, from eleven to thirteen years by bone age.

post-spurt: in girls, after eleven years until maturity by bone age.

in boys, after thirteen years until maturity by bone age.

(1, 2, 23). The reason for the relatively earlier skeletal maturity of Korean children is unclear. The slightly higher growth rate and the longer growth spurt today seem to be attributed to the improved Korean socio-economic state.

The annual growth rates during growth spurt, as determined by the present study, were 1.55 cm/year in the distal femur and 0.95 cm/year in the proximal tibia, which were slightly higher than those in Caucasians (14), but the lengths of femurs and tibias at skeletal maturity were lower in Korean than in Caucasian boys and girls. The average heights of Korean boys and girls in the late 1990s at the ages of maturity were approximately 161 cm and 173 cm, respectively, which are similar to those observed in Caucasians in the 1960s. The average lengths of the femurs and tibias in Caucasian boys and girls in the 1960s at the ages of maturity were 45.6 cm and 43.3 cm, respectively, which are similar to those of the current study, i.e., 45.46 cm for the femur and 42.23 cm for the tibia.

The lengths of the low extremity in Caucasian of the 1990s have been reported to have steadily increased, and now are relatively longer than in the 1960s, though this difference has not been found to be significant (6, 8, 12, 13). One of the reasons for this change in growth may be related to an increase in the average stature at maturity (14). A report, in the times from the 1940s to 1960s, for Irish ancestry with polio in Boston, indicated that the average statures at maturity in girls and boys were 162 cm and 175 cm, respectively (6). Another report for Northwest European descent in the 1990s indicated that the average statures at maturity in girls and boys had increased to approximately 167 cm and 179 cm, respectively (14). Pirchett (14), therefore, recommended that these changes in characteristics of growth should be kept in mind when predicting growth of the lower extremities.

In summary, Korean children appear to have relatively earlier growth spurt and relatively a shorter tibial length relative to the femur versus Caucasian children. It is believed that standard Korean growth curves of the normal femur and tibia, in conjunction with an atlas of Korean specific bone age, would be helpful to determine growth characteristics and to predict growth for leg length equalization purposes.

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APPENDIX

An example of a girl with congenital hemihypotrophy of the left lower extremity is given to predict future growth and final discrepancy using the growth remaining method (6). In order to determine the measurement error when using the American data to predict final discrepancy at skeletal maturity, the calculated data on the basis of Korean standards of the femur and tibia was compared with those calculated using the data of Anderson et al. (6).

Age (yr)	Skeletal age (yr)	Right femur length (cm)	Right tibia length (cm)
7+11	8+5	34.0	27.1
8+11	9+2	35.2	28.0
9+11	10+7	37.8	30.6

Age (yr)	Skeletal age (yr)	Left femur length (cm)	Left tibia length (cm)
7+11	8+5	32.1	26.0
8+11	9+2	33.2	26.9
9+11	10+7	34.5	27.9

Calculation using the length standards of the current study (Korean) (Table 2, Fig. 3)

A. Assessment of Past Growth

1. Growth of Long Leg

$$= (\text{Femur} + \text{Tibia at last visit}) - (\text{Femur} + \text{Tibia at first visit}) \\ = (37.8 + 30.6) - (34 + 27.1) = 68.4 - 61.1 = 7.3 \text{ cm}$$

2. Growth of Short Leg

$$= (\text{Femur} + \text{Tibia at last visit}) - (\text{Femur} + \text{Tibia at first visit}) \\ = (34.5 + 27.9) - (32.1 + 26.0) = 62.4 - 58.1 = 4.3 \text{ cm}$$

$$3. \text{ Present discrepancy} = \text{length of long leg} - \text{length of short leg} \\ = 68.4 - 62.4 = 6 \text{ cm}$$

4. Growth inhibition

$$= (\text{growth of long leg} - \text{growth of short leg}) / \text{growth of long leg}$$

$$=(7.3-4.3)/7.3=0.41$$

B. Prediction of Future Growth and Discrepancy

1. Growth percentage

$$=(\text{length of long bone at last visit}/\text{length of mean population at last visit}) \times 100$$

*The length of mean population can be achieved using the data in the Table 2 or Fig. 3.

$$=\text{mean length of 10 yr} + 0.6 \text{ yr} \times (\text{mean length of 11 yr} - \text{mean length of 10 yr})$$

$$=\{36.52 + 0.6 \times (38.31 - 36.52)\} + \{28.66 + 0.6 \times (30.15 - 28.66)\}$$

$$=37.59 + 28.55 = 66.1$$

$$\text{Growth percentage} = (68.4/66.1) \times 100 = 103.5\%$$

2. Predicted value of long leg length at maturity

$$=(\text{growth percentage} \times \text{length of mean population at maturity})/100$$

$$=\{103.5 \times (\text{femur length} + \text{tibia length at maturity})\}/100$$

$$=\{103.5 \times (42.23 + 33.54)\}/100 = 78.4$$

3. Future growth of long leg=mature length-present length

$$=78.4 - 68.4 = 10 \text{ cm}$$

4. Future increase in discrepancy

$$=\text{future growth of long leg} \times \text{growth inhibition}$$

$$=10 \times 0.41 = 4.1 \text{ cm}$$

5. Predicted discrepancy at maturity

$$=\text{present discrepancy} + \text{future increase}$$

$$=6 + 4.1 = 10.1 \text{ cm}$$

Calculation using the length standards of Anderson et al. (6) (American)

A. Assessment of Past Growth

1. Growth of Long Leg

$$=(\text{Femur} + \text{Tibia at last visit}) - (\text{Femur} + \text{Tibia at first visit})$$

$$=(37.8 + 30.6) - (34 + 27.1) = 68.4 - 61.1 = 7.3 \text{ cm}$$

2. Growth of Short Leg

$$=(\text{Femur} + \text{Tibia at last visit}) - (\text{Femur} + \text{Tibia at first visit})$$

$$=(34.5 + 27.9) - (32.1 + 26.0) = 62.4 - 58.1 = 4.3 \text{ cm}$$

3. Present discrepancy=length of long leg-length of short length

$$=68.4 - 62.4 = 6 \text{ cm}$$

4. Growth inhibition

$$=(\text{growth of long leg} - \text{growth of short leg})/\text{growth of long leg}$$

$$=(7.3 - 4.3)/7.3 = 0.41$$

B. Prediction of Future Growth and Discrepancy

1. Growth percentage

$$=(\text{length of long bone at last visit}/\text{length of mean population at last visit}) \times 100$$

*The length of mean population can be achieved using the data of Anderson et al. (6)

$$=\text{mean length of 9.9 yr} + 0.7 \text{ yr} \times (\text{mean length of 11.1 yr} - \text{mean length of 9.9 yr})/1.2$$

$$=(37 + 29.8) + 0.7 \times \{(39.2 + 31.6) - (37 + 29.8)\}/1.2 = 68.2$$

$$\text{Growth percentage} = (68.4/68.2) \times 100 = 100.3\%$$

2. Predicted value of long leg length at maturity (15 yr)

$$=(\text{growth percentage} \times \text{length of mean population at maturity})/100$$

$$=\{100.3 \times (43.1 + 34.5)\}/100 = 77.8 \text{ cm}$$

3. Future growth of long leg=mature length-present length

$$=77.8 - 68.4 = 9.4 \text{ cm}$$

4. Future increase in discrepancy

$$=\text{future growth of long leg} \times \text{growth inhibition}$$

$$=9.4 \times 0.41 = 3.8 \text{ cm}$$

5. Predicted discrepancy at maturity=present discrepancy+ future increase

$$=6 + 3.8 = 9.8 \text{ cm}$$

*Anderson's data (6) of a complete longitudinal series of 50 girls

Age (yr)	Femur (mean)	Tibia (mean)	Skeletal Age (yr)
8	33.1	26.3	7.6
9	35.0	28.0	8.7
10	37.0	29.8	9.9
11	39.2	31.6	11.1
12	41.1	33.2	12.5
13	42.4	34.2	13.8
14	43.1	34.5	14.8
15	43.2	34.6	15.8
16	43.3	34.6	16.4

Length of mean population is determined by calculating the relative ratio between the two mean values