Standard Bone-Age of Infants and Children in Korea.*

To evaluate the developmental status of children and adolescents, a bone-age chart based on the radiograph of hand and wrist has been used in many countries. Bone-age reflects not only the functional status of various hormones but also the influence of chronic disease and it has been used more widely than other indeces such as the height-weight-age table. As a standard bone-age chart has not been established in Korea, a foreign bone-age chart has been used in clinics. To make a Korean standard bone-age chart, we took the radiographs of the left hand of about 5400 children covering the whole country, and 3407 radiographs of 1830 boys and 1577 girls ranging from two months to 16 years of age were selected and analyzed for bone maturity scores by the TW2-20 method. The range of ages were divided into 27 groups, and the radiographs of 50th percentile score were chosen as the standard bone-ages for the median age of each group. The youngest and oldest chronological age which had the same TW2-20 score of the standard bone-age were decided as the range of variation from the median age. We hope that a Korean standard bone-age chart can be used as the radiological index in the evaluation of the developmental status in Korean children and adolescents. *(JKMS 1997; 12: 9~16)*

Key Words : *Bone, Bone Growth, Bone Development, Infant, Children*

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INTRODUCTION

In the assessment of the developmental status of children and adolescents, a height-weight-age table and bone-age chart have generally been used(1). In Korea, a standard table of height-weight-age has been used for the evaluation of developmental status. However height and weight depend upon not only the hormonal and nutritional status but also the genetic factor, and their range of variation is wide. Therefore it is difficult to decide the developmental status only by a height-weight-age table(2). The bone-age based on the left hand and wrist is not correlated to the body size and its maturity reflects the development of the reproductive system such as menarche, growth hormone and thyroid hormone. Therefore it was chosen as the gold standard for the assessment of developmental status resulting from endocrinologic or chronic diseases and for the estimation of developmental status in the future(3~5).

Since a Korean standard bone-age chart has not been established, the foreign atlas of standard bone-age has been used in clinics. There may be a significant difference in bone maturation between races and cultures(3, 6). We have made a standard atlas of bone-age in Korean children.

MATERIALS AND METHODS

Simple radiographs of the left hand were analysed for determination of standard bone age in infants and children.

The children, ranging from 2 months to 16 years old, were divided into 27 groups. Children under 32 months of age were grouped in 3 months groups, those under 78 months in 6 months groups, and those over 78 months in year groups. In each group, we tried to collect a hundred children of each sex from all over the country, including Seoul National University Children's Hospital, Kyung-Hee Medial Center, Korea University Anam Hospital, Yonsei University Shinchon Severance Hospital, Yongdong Severence Hospital, St Mary's Hospital, Ulsan Medical College Central Hospital, Inha Hospital in Seongnam City, Kyungsang University Hospital in Jinju, Baik Hospital in Pusan, Gil Hospital in Incheon, Chungnam National University Hospital in Daejeon, Kyungbuk National University Hospital in Daegu, etc. However some groups had over a hundred children, whilst others under a hundred. About 5400 children had roentgenograms of the left hand taken including the roentgenograms of the fingertips and the distal ulna and radius in the prone position. All the children were from

middle-class families socioeconomically and healthy in nutritional condition at the time of the radiography. Children, who had congenital, endocrinological or other serious diseases or who were under 25 percentile or over 75 percentile in height and weight, were excluded from the study. Roentgenograms of 1993 children were excluded from the study due to poor position, inadequate quality or inadequate information of chronological age and sex. A total of 3407 roentgenograms were analysed for the standard bone-age which included 1830 boys and 1577 girls(Table 1).

Two expert radiologists in a team analyzed bone-age by discussion with each case without information about chronological ages. In cases of disagreement, the bone-age was decided by consulting another radiologist.

To assess the bone-age, the TW2-20 methods by Tanner et al.(5) were used. We analysed 20 bones-distal ulna and radius, 7 carpal bones(capitate, hamate, triquetral, lunate, scaphoid, trapezium, trapezoid), 1st, 3rd and 5th metacarpals, proximal and distal phalanges, and 3rd and 5th middle phalanges. Each bone was graded into 8 or 9 stages (from stage A to stage H or I) according to the TW2-20 method by their maturity. Staging were assigned by comparing the bone with the descriptions and diagrams of criteria suggested by a rating system of the TW2 method. If no sign of the bone was present the rating A was given, and the epiphyseal regions were staging from B to H or I by distinction of the density, size, shape, smoothness or thickening of border, thickness of epiphyseal line, extent of fusion and capping(7, 8). All the individual scores of 20 bones by the biological weight corresponding to the stages were summed up according to the reference tables(Table 2-a, b).

The total score of each roentgenogram was arrayed in the order of the size by the group and then the radiograph with the score corresponding to the 50th percentile was chosen as the standard bone-age for the median age of each group. The radiographs of the youngest and oldest age who had the same TW2-20 scores of the standard bone-age were chosen as the normal range of variation from median age.

Table 1. Range of age and number of the group

Group No	Range of age in group (M)	BOYS			GIRLS		
		No	MDA (M)	MA (M)	No	MDA (M)	MA (M)
1	2 - 4	100	3.0	2.6	100	2	2.4
2	5 - 7	48	6.0	6.0	24	6	5.7
3	8 - 10	22	9.0	8.9	18	9	8.5
4	11 - 13	21	11.5	11.7	13	12	11.9
5	14 - 16	34	15	15.9	22	15	15.2
6	17 - 19	27	18	17.9	19	18	18.0
7	20 - 22	22	21	21.0	17	21	21.0
8	23 - 25	25	23	23.6	20	24	24.8
9	26 - 28	23	27	26.8	13	27	27.3
10	29 - 32	49	30	30.1	46	30	30.0
11	33 - 38	88	36	35.6	58	36	35.7
12	39 - 44	93	41	41.2	58	41	41.2
13	45 - 50	91	48	47.6	95	48	47.8
14	51 - 56	80	53	53.5	79	53	53.4
15	57 - 62	98	59	59.4	87	60	59.5
16	63 - 68	81	66	65.3	70	65.5	65.3
17	69 - 78	107	73	73.1	77	72.5	72.4
18	79 - 90	93	85	84.6	93	86	85.2
19	91 - 102	100	96	96.5	92	95	95.5
20	103 - 114	90	109	108.4	80	108	108.0
21	115 - 126	90	120	120.6	90	122.5	121.9
22	127 - 138	90	131	132	78	132	133.1
23	139 - 150	79	144	143.6	76	144	144.0
24	151 - 162	104	157	156.6	82	157	156.9
25	163 - 174	69	170	169	74	169	169.0
26	175 - 186	68	180	179.8	67	180	180.6
27	187 - 198	38	192	190.4	29	192	191.0
		1,830			1,577		

M = Months
CA = Chronological age
MDA = Median age of group
MA = Mean age of C.A in group

Table 2-a. TW2 20-Bone Maturity Scores

BOYS

RATINGS	A	B	C	D	E	F	G	H	I
BONES									
Radius	0	15	17	21	27	48	77	96	106
Ulna	0	22	26	30	39	56	73	84	
Metacarpal I	0	4	5	11	19	24	28	30	32
III	0	3	4	6	10	16	22	23	25
V	0	3	3	6	12	17	21	23	25
Proximal Phalanges I	0	4	5	8	15	23	28	30	32
III	0	3	4	6	13	20	23	24	26
V	0	3	3	6	13	19	22	23	25
Middle Phalanges III	0	3	4	7	13	19	22	23	25
V	0	4	4	8	14	19	21	22	23
Distal Phalanges I	0	4	4	7	14	23	30	31	33
III	0	3	4	6	10	16	21	22	24
V	0	3	4	7	11	16	20	21	23
Capitate	0	60	62	65	71	79	89	116	
Hamate	0	42	44	49	59	70	81	92	106
Triquetral	0	7	10	17	28	38	45	62	
Lunate	0	10	13	20	27	36	44	60	
Scaphoid	0	14	18	23	30	35	42	58	
Trapezium	0	12	15	21	28	34	39	47	59
Trapezoid	0	14	16	20	23	32	39	56	

Table 2-b. TW2 20-Bone Maturity Scores

GIRLS

RATINGS	A	B	C	D	E	F	G	H	I
BONES									
Radius	0	17	19	25	33	54	85	99	106
Ulna	0	22	26	30	39	60	73	80	
Metacarpal I	0	5	6	11	18	24	29	31	33
III	0	3	5	7	11	17	23	24	26
V	0	3	4	7	12	18	22	24	25
Proximal Phalanges I	0	5	5	8	14	24	29	30	32
III	0	4	4	7	13	20	24	25	26
V	0	4	4	7	13	19	23	24	25
Middle Phalanges III	0	4	4	7	13	20	23	24	25
V	0	4	5	8	14	20	22	22	23
Distal Phalanges I	0	5	5	8	15	24	31	32	34
III	0	3	4	6	10	17	22	23	24
V	0	3	4	7	11	17	21	22	23
Capitate	0	53	56	61	67	76	85	113	109
Hamate	0	44	47	53	64	74	85	97	
Triquetral	0	8	12	19	28	36	46	63	
Lunate	0	10	14	20	27	35	46	60	
Scaphoid	0	13	17	23	29	36	44	57	59
Trapezium	0	12	14	20	25	32	39	49	
Trapezoid	0	13	16	20	24	31	40	57	

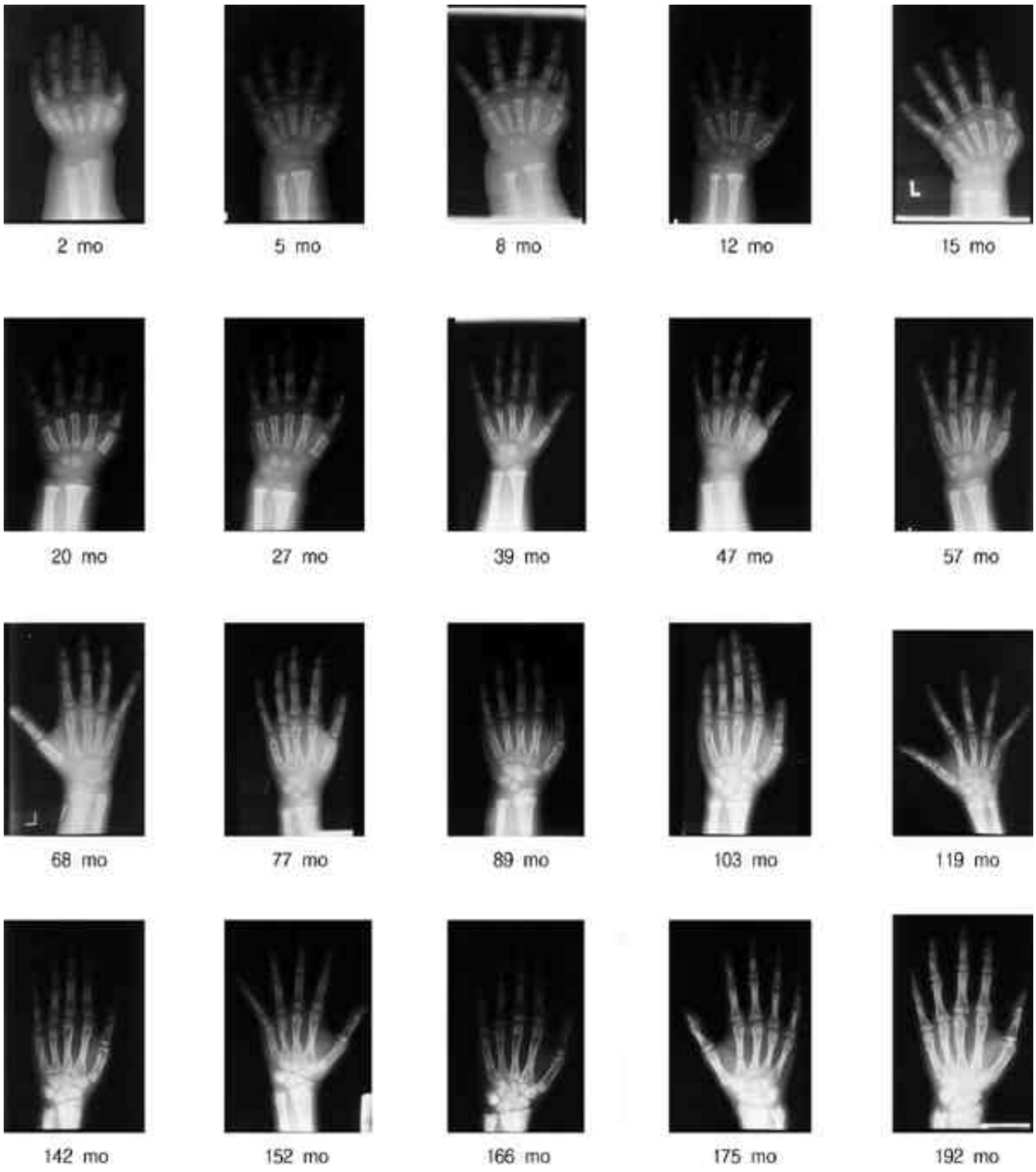

Fig. 1-a. Hand Radiographs for the Representative Ages (Male)

RESULTS

The standard bone-ages corresponding to the median age of each group were represented with the radiographs (Fig. 1). The median and mean TW2-20 scores with standard deviation were shown with median bone-age and normal range(Table 3, Fig. 2).

DISCUSSION

As the maturity of the skeletal system is closely related to height and weight which are the indices of development during childhood and adolescence, skeletal maturity is at a peak when the increased velocity of the height and weight is at a peak(4, 5). And it reflects the functional status of reproductive, growth and thyroid hormones(2). Therefore, in many other countries the atlas of standard bone-age of the hand and wrist have been

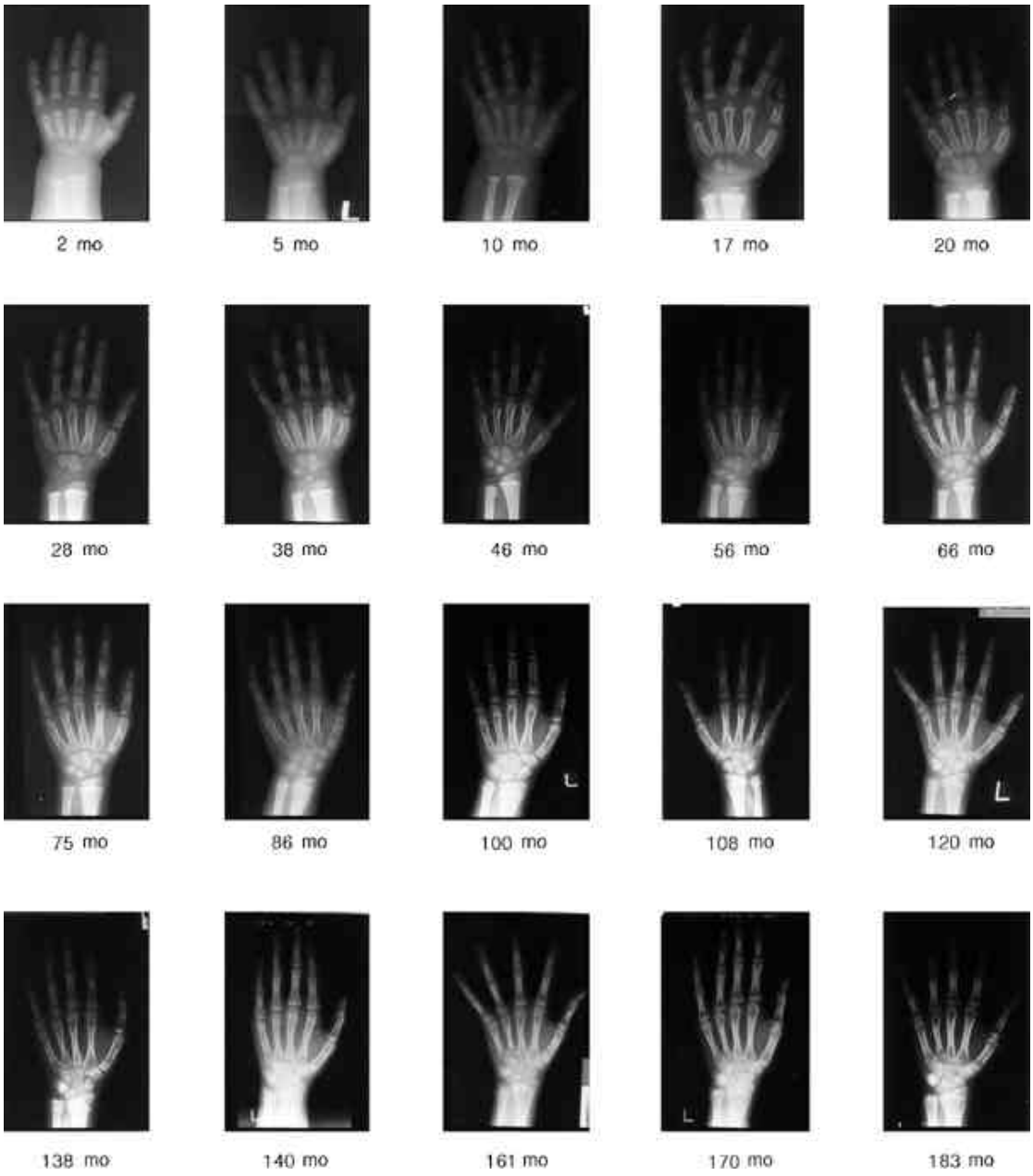

Fig. 1-b. Hand Radiographs for the Representative Ages (Female)

used as a diagnostic criteria for endocrinologic diseases or growth arrest for a long time. As the growth and development of children is becoming a more important issue along with the development of the socioeconomic status, it is much more important to know the correct criteria and spectrum of normal variation of skeletal maturity.

As a standard bone-age has not been established yet in Korea, a foreign bone-age chart has been used as a diagnostic criterion in clinical situations. There are many problems considering that the standard bone-age of Korea should be much different from those of Western countries(3, 6). Representing all the skeletal system, radiographs of the hand and wrist has been used to represent bone-age for the following reasons ; First, it is easy to take a radiograph. Second, the development of the hand and wrist is not different from that of other bones such as knee, foot or pelvis. Third, the accuracy of an analysis of skeletal maturity of only the hand and wrist is not inferior to that of many other bones

Table 3-a. Median and mean TW2-20 scores of the standard bone age

BOYS

Group	TW2-20 scores		Age (month)	
	Median	Mean (SD)	Median bone age	Range
1	60	60 (45.34)	3.0	- 6
2	106	92.51 (26.86)	6.0	2 - 17
3	106	102.16 (30.97)	9.0	2 - 17
4	109	95.75 (41.39)	11.5	5 - 18
5	117	120.74 (24.41)	15	8 - 19
6	124	127.89 (21.57)	18	9 - 20
7	137	150.67 (29.88)	21	11 - 27
8	153	152.44 (34.06)	23	22 - 32
9	155	165.00 (40.15)	27	22 - 32
10	167	170.33 (28.04)	30	23 - 38
11	186	186.33 (31.94)	36	26 - 42
12	221	230.25 (46.85)	41	38 - 56
13	241	245.16 (50.80)	48	39 - 60
14	267	266.38 (45.80)	53	40 - 66
15	283	290.98 (55.19)	59	44 - 70
16	316	325.13 (58.14)	66	57 - 75
17	350	345.98 (65.47)	73	66 - 88
18	406	398.03 (76.81)	85	75 - 96
19	455	453.04 (73.97)	96	79 - 115
20	534	529.47 (75.31)	109	103 - 122
21	588	587.31 (139.84)	120	106 - 137
22	685	675.33 (100.28)	131	115 - 143
23	769	763.39 (105.10)	142	138 - 150
24	887	866.02 (94.73)	157	151 - 180
25	942	905.29 (84.04)	170	153 - 186
26	946	937.87 (75.91)	180	153 -
27	983	971.42 (37.20)	192	167 -

SD : Standard deviation

Table 3-b. Median and mean TW2-20 scores of the standard bone age

GIRLS

Group	TW2-20 scores		Age (month)	
	Median	Mean (SD)	Median bone age	Range
1	56	57.08 (43.29)	2	- 4
2	103	99.96 (15.49)	6	2 - 10
3	105	108.14 (45.60)	9	2 - 10
4	133	122.75 (40.78)	12	10 - 15
5	147	151.56 (52.33)	15	11 - 17
6	191	182.95 (30.64)	18	15 - 27
7	199	220.94 (43.91)	21	15 - 27
8	201	213.28 (68.53)	24	15 - 28
9	204	238.92 (54.18)	27	18 - 35
10	248	235.47 (58.14)	30	28 - 43
11	263	247.06 (45.91)	36	29 - 45
12	284	295.48 (67.32)	41	32 - 49
13	290	295.71 (49.90)	48	33 - 50
14	364	358.22 (66.32)	53	40 - 65
15	379	372.77 (57.21)	60	51 - 75
16	411	411.00 (90.34)	65.5	55 - 77
17	438	438.90 (77.68)	72.5	63 - 87
18	490	498.99 (79.14)	86	66 - 89
19	584	580.30 (86.28)	95	81 - 102
20	711	703.56 (91.76)	108	103 - 124
21	746	755.31 (99.82)	122.5	105 - 126
22	879	861.19 (82.69)	132	127 - 145
23	946	909.54 (81.55)	144	139 - 155
24	975	929.63 (60.68)	157	144 - 169
25	983	976.68 (26.07)	169	146 - 187
26	1000	992.08 (18.05)	180	161 -
27	1000	989.13 (27.35)	192	161 -

SD : Standard deviation

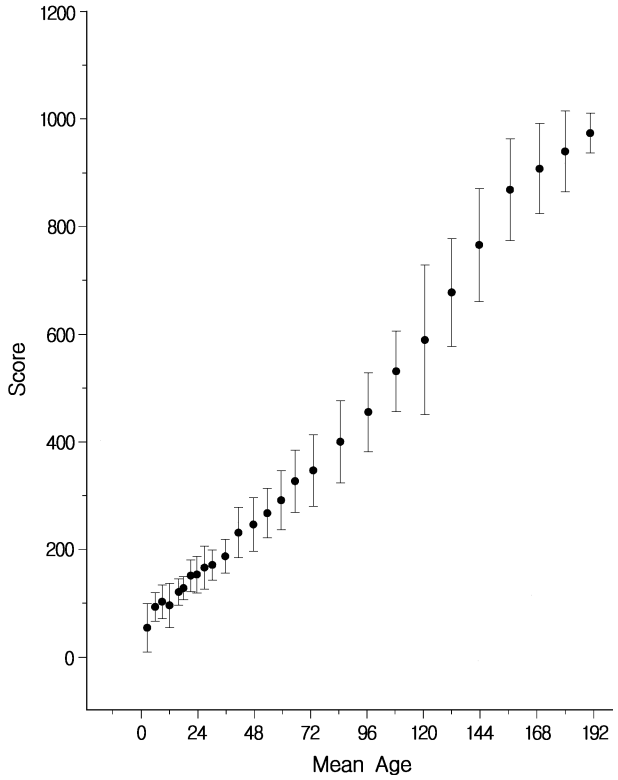

Fig. 2-a. Mean TW2-20 Scores of the Standard Bone Ages (Male)

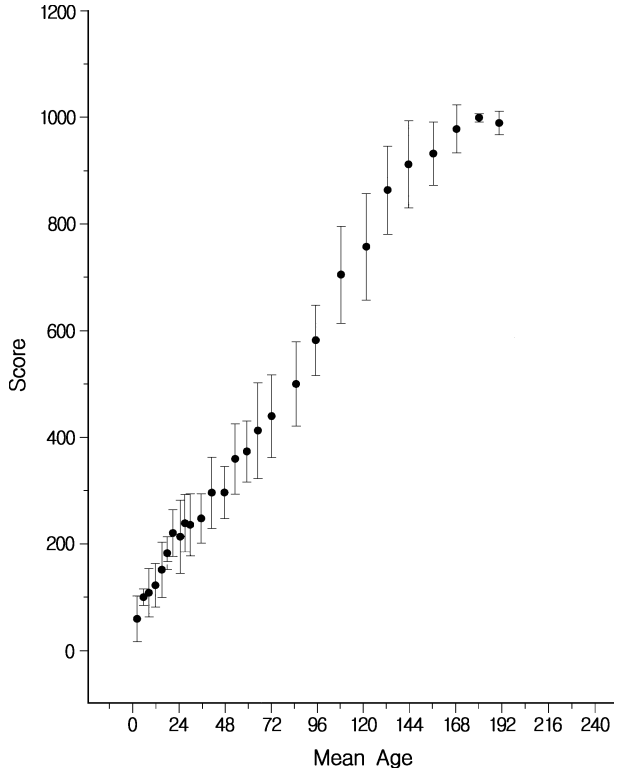

Fig. 2-b. Mean TW2-20 Scores of the Standard Bone Ages (Female)

collectively. And fourth, the ossification of the carpal bones not only appears uniformly in order but also is affected more by illness or inadequate nutritional conditions rather than genetic factors(9, 10).

Generally, the bone-age of the left hand precedes that of the right hand, which is the result of frequent injury in the right hand(11). We analyzed the radiographs of the left hand uniformly to reduce the bias in a group between the left hand and the right hand.

There are two methods for setting up the standard bone-age. First, a longitudinal study in which a few samples are chosen and radiographed at regular intervals over a long period of time like the Greulich-Pyle Atlas(2). Second, a cross-sectional study in which many samples were chosen and analyzed over a short period of time. As the longitudinal study has the disadvantage that it takes a long time to complete and many of the samples are lost and can not be replaced, the cross- sectional study has been used recently for setting up the standard bone-age in many countries including Japan. We adopted the cross-sectional study with 3,407 children.

The TW2 system was made by Tanner-Whitehouse in 1972 by a longitudinal and a cross sectional study. The shape, size, and density of the twenty-bones of the left hand-distal radius, ulna, 1, 3, 5 metacarpal bones, proximal and distal phalanges, 3 and 5 middle phalanges, and 7 carpal bones including capitate, hamate, triquetral, lunate, scaphoid, trapezium and trapezoid were analyzed and graded into 8 or 9 stages from A to H or I according to the degree of maturity and respectively scored from 0 to 1,000 according to the biological weight which indicate the bone maturity by stages(5).

In the TW2 system, the consistent rate of the intraanalyzer is 90 percentage and that of the inter-analyzer 75-85 percentage, and a stage of skeletal maturity makes a difference of about 0.3 year old of bone-age on an average(12, 13).

Although sample size is rather small in some age group, we tried to make this standard bone-age chart to represent the objective criterion of normal development of Korean children. This bone-age chart can give the information of the normal range of age on the standard skeletal maturity, and it will help in clinics for not only the diagnosis of endocrinologic disease or growth arrest but also predicting the prognosis such as estimated height in adulthood. We hope that this standard bone- age can offer a basic information to contribute for the planning of health policy for children and adolescents.

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