ORIGINAL ARTICLE

Radiographic Assessment of Skeletal Maturation Stages for Orthodontic Patients: Hand-wrist Bones or Cervical Vertebrae?

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Background/Purpose: The skeletal maturation status of a growing patient can influence the selection of orthodontic treatment procedures. Either lateral cephalometric or hand-wrist radiography can be used to assess skeletal development. In this study, we examined the correlation between the maturation stages of cervical vertebrae and hand-wrist bones in Taiwanese individuals.

Methods: The study group consisted of 330 male and 379 female subjects ranging in age from 8 to 18 years. A total of 709 hand-wrist and 709 lateral cephalometric radiographs were analyzed. Hand-wrist maturation stages were assessed using National Taiwan University Hospital Skeletal Maturation Index (NTUH-SMI). Cervical vertebral maturation stages were determined by the latest Cervical Vertebral Maturation Stage (CVMS) Index. Spearman's rank correlation was used to correlate the respective maturation stages assessed from the hand-wrist bones and the cervical vertebrae.

Results: The values of Spearman's rank correlation were 0.910 for males and 0.937 for females, respectively. These data confirmed a strong and significant correlation between CVMS and NTUH-SMI systems ($p < 0.001$). After comparison of the mean ages of subjects in different stages of CVMS and NTU-SMI systems, we found that CVMS I corresponded to NTUH-SMI stages 1 and 2, CVMS II to NTUH-SMI stage 3, CVMS III to NTUH-SMI stage 4, CVMS IV to NTUH-SMI stage 5, CVMS V to NTUH-SMI stages 6, 7 and 8, and CVMS VI to NTUH-SMI stage 9.

Conclusion: Our results indicate that cervical vertebral maturation stages can be used to replace hand-wrist bone maturation stages for evaluation of skeletal maturity in Taiwanese individuals. [*J Formos Med Assoc* 2008;107(4):316–325]

Key Words: cervical vertebrae, hand-wrist radiography, lateral cephalometric radiography, skeletal maturation

In orthodontics and dentofacial orthopedics, the skeletal maturation status of a growing patient influences the selection and execution of treatment procedures. Favorable orthopedic effects for patients with mandibular retrognathism only occur when the treatment begins at his or her optimal maturation stage. Whereas, it is recommended that the best time for correction of mandibular prognathism is after the completion of mandibular growth.

Considerable variations in the development among individuals of the same chronological age have led to the concept of assessing biological or physiological maturity. Several biological indicators

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have been proposed to assess individual physiological maturity.[1–4] The hand-wrist radiograph has been one of the most popular biological indicators used by orthodontists to assess skeletal development.[4–6] It has been reported that there is an intimate relationship between hand-wrist bone maturation stages and facial growth or changes in statural height during pubertal growth.[7–10] However, these results were obtained based on studies of Caucasian subjects. Because there may be differences in the shapes of bones and ossification timing among various ethnic groups, the National Taiwan University Hospital Skeletal Maturation Index (NTUH-SMI) has been developed to assess the hand-wrist skeletal development in the Taiwanese population.[11]

The routine use of hand-wrist radiographs has recently been questioned due to ethical issues. Additional radiation exposure is the primary concern. Recently, skeletal-maturation evaluation using cervical vertebrae has gained rising popularity because it has the advantage of eliminating additional radiation exposure, because the cervical vertebrae are already shown on the lateral cephalometric film routinely used in orthodontics. Many studies have confirmed the validity of skeletal maturation evaluation using cervical vertebrae instead of hand and wrist bones.[12–15] In 2005, Baccetti and coworkers proposed a modified and refined version of the Cervical Vertebral Maturation Stage (CVMS).[16] They evaluated only those cervical vertebrae (C2, C3, C4) that could be visualized when a protective radiation collar was worn. The development of this new method makes the evaluation of skeletal maturation easier and more applicable than before.

Because racial variations in skeletal maturation may exist, the objective of this study was to assess whether there was an intimate relationship between the skeletal maturation stages evaluated by either cervical vertebrae (CVMS) or hand-wrist bones (NTUH-SMI stage) in Taiwanese individuals. If NTUH-SMI stage and CVMS are highly correlated, the evaluation of cervical vertebrae maturation only may be used to replace the evaluation of hand-wrist bone maturation to avoid additional radiation exposure.

Table 1. Distribution of subjects by chronological age and gender

Age (yr)	Sex, *n* (%)	
	Male	Female
8	27 (8.2)	44 (11.6)
9	38 (11.5)	41 (10.8)
10	40 (12.1)	46 (12.1)
11	51 (15.5)	49 (13.0)
12	34 (10.3)	44 (11.6)
13	37 (11.2)	41 (10.8)
14	25 (7.6)	32 (8.4)
15	30 (9.0)	28 (7.4)
16	17 (5.2)	20 (5.3)
17	10 (3.0)	19 (5.0)
18	21 (6.4)	15 (4.0)
Total	330 (100)	379 (100)

Methods

The study group consisted of 330 adolescent males and 379 females (all aged 8–18 years). The distribution of the subjects by chronological age and gender is shown in Table 1. These subjects were retrospectively acquired from the files of the Orthodontic Division of the NTUH from 1999 to 2006. Each subject had to fulfill the following criteria: Chinese ancestry, no general developmental anomaly, no abnormal cervical vertebral bodies, and possession of good-quality hand-wrist radiographs (right hand) (Figure 1) and lateral cephalogram (projected from the right side) (Figure 2) taken on the same date.

Each hand-wrist radiograph was evaluated and assigned to one of the nine skeletal maturation stages according to the NTUH-SMI.[11] The definitions of the nine skeletal maturation stages in NTUH-SMI were described as follows:

- stage 1 (PP2=)—epiphysis of the proximal phalanx of the index finger as wide as the diaphysis;
- stage 2 (MP3=)—epiphysis of the middle phalanx of the middle finger as wide as the diaphysis;
- stage 3 (S)—visible ossification of adductor sesamoid bone of the thumb;

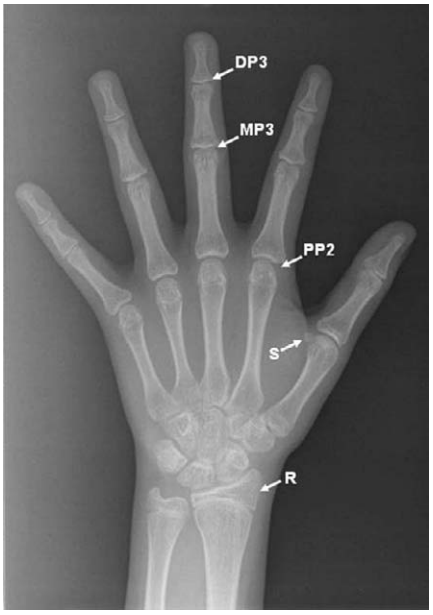

Figure 1. Developmental sites on hand-wrist radiograph for evaluation of skeletal maturation. DP3 is the distal phalanx of the middle finger; MP3 is the middle phalanx of the middle finger; PP2 is the proximal phalanx of the index finger; S is the adductor sesamoid bone of the thumb; R is the radius.

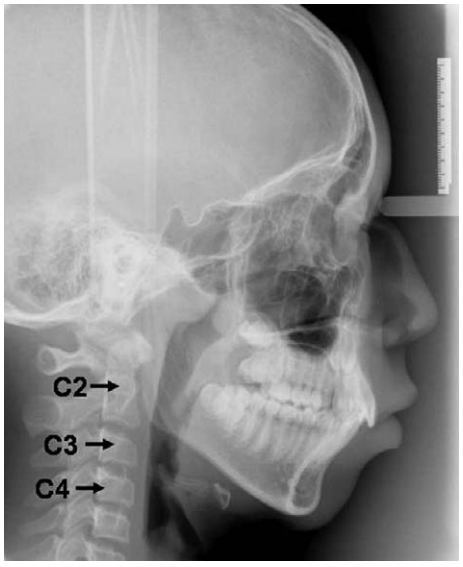

Figure 2. Cervical vertebrae: C2, C3 and C4, revealed on lateral cephalometric radiograph for evaluation of skeletal maturation.

- stage 4 ($MP3_{cap}$)—diaphysis of the middle phalanx of the middle finger covered by a cap-shaped epiphysis;
- stage 5 ($DP3_u$)—visible union of epiphysis and diaphysis at the distal phalanx of the middle finger;
- stage 6 ($MP3_u$)—visible union of epiphysis and diaphysis at the middle phalanx of the middle finger;
- stage 7 (R_{iu})—initial union of epiphysis and diaphysis of the radius;
- stage 8 (R_{au})—almost complete union of epiphysis and diaphysis of the radius;
- stage 9 (R_{cu})—complete union of epiphysis and diaphysis of the radius.

The morphology of the three cervical vertebrae (C2, C3, C4) on each cephalogram was evaluated by visual inspection. The six cervical vertebral maturation (CVM) stages were decided according to Baccetti et al's definition[16] and described as follows:

- CVMS I—flat C2, C3 and C4 inferior vertebral body borders, as well as bodies of both C3 and C4 being trapezoid in shape;
- CVMS II—concavities present at the lower border of C2, flat lower borders of C3 and C4, and both C3 and C4 being trapezoid in shape;
- CVMS III—concavities present at the lower borders of C2 and C3, no concavity present at the lower border of C4, and C3 and C4 being either trapezoid or rectangular, horizontal in shape;
- CVMS IV—concavities present at the lower borders of C2, C3 and C4, as well as both C3 and C4 being rectangular, horizontal in shape;
- CVMS V—concavities present at the lower borders of C2, C3 and C4, as well as both C3 and C4 being rectangular, horizontal to square in shape;
- CVMS VI—concavities present at the lower borders of C2, C3 and C4, as well as both C3 and C4 being square to rectangular, vertical in shape.

The lateral cephalograms and hand-wrist radiographs of all the 709 subjects were assessed by an examiner (designated as examiner A) for skeletal maturation staging according to the CVMS and NTUH-SMI, respectively.

To evaluate interexaminer reliability, 30 hand-wrist radiographs and 30 lateral cephalometric radiographs were randomly selected and read by three examiners (examiner A and another two examiners, B and C) independently according to

the evaluation criteria, with consensus among the three examiners. Intraexaminer reliability was determined only for examiner A. The time interval between two independent assessments of the same image was 3 weeks.

Before the assessment of these radiographic images, each subject was given a subject number. Then, the images of all subjects were randomized separately for the determination of NTUH-SMI and CVMS stage. The hand-wrist bone and cervical vertebral maturation was determined in a fully blinded fashion, in which the patient-specific information was blinded to the examiners. A statistician completed the statistical analysis without specific knowledge of the coding of maturation stages.

Statistical analysis

All statistical analyses were performed using SPSS version 13.0 (SPSS Inc., Chicago, IL, USA) for Windows. Descriptive statistics were obtained for the mean chronological ages of subjects in nine hand-wrist maturation stages and six CVM stages. Comparisons of differences in the mean chronological ages among the nine hand-wrist maturation stages were made with one-way analysis of variance (ANOVA) for both genders. Similar comparisons were made for the six CVM stages. For significant *F* ratios, Scheffé's test was performed to find out exactly where the significant differences lay. Spearman's rank correlation test was used to correlate the respective maturation stages assessed from the hand-wrist bones and the cervical vertebrae.

Results

The intraexaminer agreement of determination of NTUH-SMI stages was 93.3%. Spearman's rank correlation coefficients between any two of the three examiners were in the range of 0.997–0.998 ($p < 0.0001$). The percentage of interexaminer agreement was 90% between examiners A and B as well as between examiners A and C. As to the CVMS, the intraexaminer agreement was 90.0%. Spearman's rank correlation coefficients between any two of the three examiners were in the range of 0.963–0.981 ($p < 0.0001$). The percentage of interexaminer agreement was 93.3% between examiners A and B and 90% between examiners A and C. All the differences in the assessment by two examiners were within one stage for both NTUH-SMI and CVMS methods.

The difference in the mean chronological age of subjects in different hand-wrist bone maturation stages was significant for both males and females (one-way ANOVA, $p < 0.001$). This was also true in the case of CVM stages. The results of *post hoc* Scheffé's test demonstrating the mean chronological age and mean age differences between two maturation stages are shown in Table 2 for the NTUH-SMI and Table 3 for the CVMS system. The age difference between two adjacent stages in the NTUH-SMI system did not reach a statistically significant level as frequently as that in the CVMS system. In Table 2, it is noted that the mean age of stage 5 ($DP3_u$) for male subjects was not significantly different from that of stage 6 ($MP3_u$), stage 7 (R_{iu}) and stage 8 (R_{au}).

The mean ages of subjects in different successive NTUH-SMI and CVM stages followed a gradual chronological progression during the adolescent growth period (Tables 2 and 3). The mean ages of subjects in each of the nine NTUH-SMI stages and the six CVM stages showed no significant difference between male and female subjects. However, sexual dimorphism did exist in the mean chronological age for each skeletal maturation stage. The mean ages of subjects in each stage were consistently younger in the female than in the male group. For the NTUH-SMI system, the difference in the mean age between males and females was approximately 1 year at stage 1 (PP2=), increased to approximately 2 years at stages 4 ($MP3_{cap}$) and 5 ($DP3_u$), and then decreased to approximately 0.5 years at stage 9 (R_{cu}). For the CVMS system, the difference in the mean age between males and females was approximately 1 year at stage I, increased to approximately 2 years at stage III, and then decreased to approximately 0.8 years at stage VI.

Table 2. Differences in mean chronological ages between two hand-wrist maturation stages

NTUH-SMI stage	Sex	Age (yr)	Mean age differences between two NTUH-SMI stages								
			1	2	3	4	5	6	7	8	9
1 (PP2=)	M	9.58±1.13	–	1.43*	2.14*	3.75*	4.88*	5.15*	5.45*	6.14*	8.03*
	F	8.49±0.41	–	1.08	1.95*	2.62*	3.86*	4.60*	4.96*	6.35*	8.58*
2 (MP3=)	M	11.01±1.40		–	0.70	2.32*	3.45*	3.72*	4.02*	4.71*	6.59*
	F	9.58±1.05		–	0.86	1.54*	2.78*	3.52*	3.87*	5.26*	7.50*
3 (S)	M	11.71±1.02			–	1.61*	2.75*	3.01*	3.31*	4.01*	5.89*
	F	10.44±1.11			–	0.67	1.91*	2.65*	3.01*	4.40*	6.63*
4 ($MP3_{cap}$)	M	13.33±1.15				–	1.13	1.40	1.70*	2.39*	4.28*
	F	11.12±1.09				–	1.24*	1.98*	2.33*	3.72*	5.96*
5 ($DP3_{u}$)	M	14.46±0.92					–	0.27	0.57	1.26	3.15*
	F	12.35±1.07					–	0.74	1.10*	2.49*	4.72*
6 ($MP3_{u}$)	M	14.73±1.15						–	0.30	0.99	2.88*
	F	13.09±1.07						–	0.36	1.74*	3.98*
7 (R_{iu})	M	15.03±1.21							–	0.69	2.58*
	F	13.45±1.12							–	1.39*	3.62*
8 (R_{au})	M	15.72 ± 1.38								–	1.89*
	F	14.84±1.45								–	2.24*
9 (R_{cu})	M	17.61±1.11									–
	F	17.07±1.21									–

$p < 0.05$, based on Scheffé's test. M = male; F = female.

Table 3. Differences in mean chronological ages between two cervical vertebral maturation (CVM) stages

CVM stage	Sex	Age (yr)	Mean age differences between other CVM stages					
			I	II	III	IV	V	VI
I	M	10.30 ± 1.44	–	0.88*	2.30*	3.63*	5.71*	6.28*
	F	9.22 ± 0.97	–	1.06*	1.58*	3.38*	5.57*	6.58*
II	M	11.18 ± 1.21		–	1.43*	2.75*	4.84*	5.40*
	F	10.27 ± 1.19		–	0.53	2.32*	4.52*	5.52*
III	M	12.61 ± 1.28			–	1.33*	3.41*	3.98*
	F	10.80 ± 0.96			–	1.80*	3.99*	4.99*
IV	M	13.93 ± 1.04				–	2.09*	2.65*
	F	12.60 ± 1.15				–	2.19*	3.20*
V	M	16.02 ± 1.60					–	0.57
	F	14.79 ± 2.06					–	1.00*
VI	M	16.58 ± 1.71						–
	F	15.79 ± 1.78						–

**p < 0.05, based on Scheffé's test. M = male; F = female.*

Table 4. Distribution of all study subjects grouped by gender, NTUH-SMI stage and CVM stage*

CVMS	Sex	1	2	3	4	5	6	7	8	9	Subjects, *n*
I		59	56	3	1	0	0	0	0	0	119
II		2	18	33	1	0	0	0	0	0	54
III		1	7	3	26	0	0	0	0	0	37
IV	M	1	1	1	12	8	5	1	0	0	29
V		0	0	0	4	6	9	9	13	14	55
VI		0	0	0	1	0	0	2	9	24	36
Subjects, *n*		63	82	40	45	14	14	12	22	38	330
I		21	47	2	1	0	0	0	0	0	71
II		2	10	28	3	0	0	0	0	0	43
III		0	2	2	44	3	0	0	0	0	51
IV	F	0	0	1	15	27	9	9	1	1	63
V		0	0	0	0	4	13	24	31	21	93
VI		0	0	0	0	0	0	6	20	32	58
Subjects, *n*		23	59	33	63	34	22	39	52	54	379

**Spearman's rank correlation: 0.910 for males and 0.937 for females (p < 0.001). M = male; F = female.*

The distribution of all study subjects grouped by gender, NTUH-SMI stages and CVMS is shown in Table 4. For each CVMS, the column with the maximal number of subjects matching to the corresponding NTUH-SMI stage is shaded gray. From Table 4, we see that CVMS I spanned over NTUH-SMI stage 1 (PP2 =) and stage 2 (MP3 =). CVMS II spanned over NTUH-SMI stage 2 (MP3 =) and stage 3 (S). CVMS III corresponded to NTUH-SMI stage 4 ($MP3_{cap}$). CVMS IV extended from NTUH-SMI stage 4 ($MP3_{cap}$) to stage 6 ($MP3_u$). CVMS V scattered from NTUH-SMI stage 5 to stage 9 ($DP3_u$ to R_{cu}). CVMS VI spanned over NTUH-SMI stage 8 (R_{au}) and stage 9 (R_{cu}).

Further comparison of the mean ages of subjects in different stages of CVMS and NTU-SMI systems revealed that CVMS I corresponded to NTUH-SMI stages 1 and 2, CVMS II to NTUH-SMI

stage 3, CVMS III to NTUH-SMI stage 4, CVMS IV to NTUH-SMI stage 5, CVMS V to NTUH-SMI stages 6, 7 and 8, and CVMS VI to NTUH-SMI stage 9. Spearman's rank correlation (0.910 for males, 0.937 for females) confirmed a strong and significant correlation between CVMS and NTUH-SMI systems ($p < 0.001$).

Discussion

The intraexaminer difference in determination of NTUH-SMI or CVM stages was statistically insignificant, and the interexaminer reliability of determination of skeletal maturation stages by both systems was found to be very high. This implied that the criteria used for these two systems appeared to be valid and clear. However, slight variations in determination of NTUH-SMI and CVM stages did exist among the three examiners. The instances of disagreement fell within one NTUH-SMI or CVM stage. Clinically, each stage of skeletal maturation blended into the next. For borderline cases, these slight disagreements among different examiners were negligible.[12]

Our study demonstrated that the mean chronological age difference between two adjacent NTUH-SMI stages was not statistically significant as frequently as that in the CVMS system (Tables 2 and 3), especially in the range of NTUH-SMI stage 5 to NTUH-SMI stage 8 for males. This finding implied that a large variation of skeletal maturation did exist among boys at the age of 14.46 (stage 5) to 15.72 years (stage 8). Moreover, it was noted that the maximal difference in the mean chronological age between males and females occurred at stage $MP3_{cap}$ (2.21 years) for the NTUH-SMI system and at stage III (1.18 years) for the CVMS system. According to previous reports, the stage $MP3_{cap}$ occurs at the age of maximum pubertal growth.[2,17–20] This finding substantiates a prominent sexual difference in the chronological age of maximal growth spurt, which corresponds to CVM stages III and IV.

The test for Spearman's rank correlation showed a strong correlation between hand-wrist bone and CVM stages. These findings were in agreement with the results from several previous studies.[13–15] From the results of the present and previous studies,[11–15] we found that CVMS I or NTUH-SMI stages 1 and 2 occurred sometime between the initiation and midpoint of the acceleration phase of the pubertal growth spurt. CVMS II or NTUH-SMI stages 2 and 3 occurred approximately 1 year before maximum pubertal growth spurt. Adolescent growth has reached peak height velocity at CVMS III or NTUH-SMI stage 4. CVMS IV or NTUH-SMI stages 5 and 6 represented the decelerating phase of the pubertal growth spurt following the peak height growth. CVMS V or NTUH-SMI stages 7 and 8 represented the terminal phase of pubertal growth. Pubertal growth is considered to be completed at CVMS VI or NTUH-SMI stage 9.

Optimal treatment timing in orthodontics and dentofacial orthopedics can be assessed and determined by skeletal maturation.[16] After acquisition of skeletal maturation data for the Taiwanese population, we could determine the optimal treatment timing for different types of malocclusion in Taiwanese patients. For example, it has been advocated that orthopedic treatment of Class III malocclusion for maxillary protraction is more effectively performed at the prepubertal stage than at puberty.[21] Thus, if maxillary protraction is indicated, treatment should be performed before CVM stages I and II. In transverse maxillary deficient cases, the skeletal effects of rapid maxillary expansion are greater at prepubertal stages.[22] Therefore, treatment should start before CVMS III for correction of transverse maxillary deficiency. Furthermore, the treatment of Class II malocclusion patients is more effective when the growth spurt is included in the treatment interval.[23] Thus, CVMS III represented the ideal stage to begin functional jaw orthopedics, which is approximately 0.5 years after CVMS II for females and approximately 1.5 years after CVMS II for males. In a radiographic hand-wrist image, the completed fusion of epiphysis and diaphysis of the radius, corresponding to NTUH-SMI stage 9, was generally taken as an indicator for the completion of facial growth. However, it has recently

Table 5. Mean chronological ages of hand-wrist maturation stages in five different studies*

NTUH-SMI stage	Sex	Chronological age (yr)				
		This study	Chang et al, 1990[11]	Chang et al, 2001[14]	Fishman, 1982[7†]	Hägg & Taranger, 1982[19]
1 (PP2=)	M	9.58±1.13 (63)	10.55±0.98 (84)	–	–	–
	F	8.49±0.41 (23)	8.11±0.93 (79)	–	–	–
2 (MP3=)	M	11.01±1.40 (82)	12.04±0.94 (101)	9.87±1.33 (31)	11.68±1.06	–
	F	9.58±1.05 (59)	9.80±1.00 (128)	8.81±0.75 (11)	10.58±0.88	–
3 (S)	M	11.71±1.02 (40)	13.06±0.91 (81)	11.38±0.76 (13)	12.33±1.09	13.12±1.12 (122)
	F	10.44±1.11 (33)	11.20±0.80 (91)	10.10±0.81 (24)	11.22±1.11	10.73±1.03 (90)
4 ($MP3_{cap}$)	M	13.33±1.15 (45)	14.07±0.87 (86)	12.71±0.92 (21)	13.75±1.06	14.62±0.99 (122)
	F	11.12±1.09 (63)	12.57±0.85 (103)	11.10±0.99 (25)	12.06±0.96	12.42±1.02 (90)
5 ($DP3_u$)	M	14.46±0.92 (14)	14.96±1.00 (45)	14.10±0.78 (10)	15.11±1.03	15.61±1.06 (122)
	F	12.35±1.07 (23)	13.45±1.03 (79)	12.40±1.03 (11)	13.10±0.87	13.33±0.91 (90)
6 ($MP3_u$)	M	14.73±1.15 (34)	15.91±0.96 (41)	15.66±1.59 (27)	16.40±1.00	16.29±1.02 (122)
	F	13.09±1.07 (22)	14.32±1.05 (54)	14.22±1.50 (45)	14.77±0.96	14.32±0.99 (90)
7 (R_{iu})	M	15.03±1.21 (12)	16.84±0.97 (18)	–	–	16.54±0.95 (122)
	F	13.45±1.12 (39)	14.87±0.75 (31)	–	–	14.79±1.09 (90)
8 (R_{au})	M	15.72±1.38 (22)	17.54±0.61 (48)	–	–	17.58±0.80 (122)
	F	14.84±1.45 (52)	16.07±1.31 (34)	–	–	15.79±1.06 (90)
9 (R_{cu})	M	17.61±1.11 (38)	18.16±1.22 (69)	16.45±1.05 (20)	17.37±1.26	18.01±0.92 (122)
	F	17.07±1.21 (54)	17.73±1.33 (153)	16.10±1.24 (37)	16.07±1.25	16.73±1.19 (90)

**Data presented as mean ± standard deviation (number of subjects); †information on the number of subjects not available.*

Table 6. Mean chronological ages of different cervical vertebral maturation stages (CVMS) in our study and the study of Chang et al[14]*

CVMS	Sex	Chronological age (yr)	
		Subjects in this study	Subjects in the study of Chang et al[14]
I	M	10.30 ± 1.44 (119)	9.32 ± 1.21 (74)
	F	9.22 ± 0.97 (71)	8.45 ± 0.67 (22)
II	M	11.18 ± 1.21 (54)	10.98 ± 1.01 (54)
	F	10.27 ± 1.19 (43)	9.44 ± 0.92 (68)
III	M	12.61 ± 1.28 (37)	12.42 ± 0.94 (35)
	F	10.80 ± 0.96 (51)	10.60 ± 1.10 (38)
IV	M	13.93 ± 1.04 (29)	14.21 ± 0.91 (19)
	F	12.60 ± 1.15 (63)	11.76 ± 1.25 (30)
V	M	16.02 ± 1.60 (55)	15.18 ± 1.55 (38)
	F	14.79 ± 2.06 (93)	13.95 ± 1.45 (60)
VI	M	16.58 ± 1.71 (36)	16.29 ± 1.12 (24)
	F	15.79 ± 1.78 (58)	15.85 ± 1.40 (41)

**Data presented as mean ± standard deviation (number of subjects).*

been reported that the growth changes of the maxilla, mandible and dentoalveolar process were significantly noted between the hand-wrist maturation stages R-IJ and R-J (corresponding to NTUH-SMI stages 8 to 9 and CVMS VI).[24] Moreover, 81% of subjects showed a growth change of < 1 mm after stage R-J (corresponding to NTUH-SMI stage 9). Although the facial growth change was not great, this amount of growth change might still cause some clinical concern. Thus, it is recommended to wait several years after CVMS VI before placing a dental implant or performing an orthognathic surgery.

Our data of mean chronological ages for various hand-wrist maturation stages were comparable to those obtained from four previous studies (Table 5).[7,11,14,19] Different skeletal maturation indicators were used in these studies, therefore, only identical hand-wrist maturation stages were compared. We found that the mean ages of subjects in different successive stages in the present study were younger than those in the study of Chang et al[11] (0.55–1.82 years younger in males and 0.22–1.45 years younger in females), and older than those in the study of Chang et al[14] (0.33–1.16 years older in males and 0.02–1.13 years older in females). The minor discrepancy in the mean age may be due to differences in the time and the geographic area where study subjects were recruited. The subjects in this study were collected between 1999 and 2006, while the subjects in the study of Chang and coworkers[11] were collected before 1990. Moreover, most of the subjects in our study and in the study of Chang et al[11] lived in Northern Taiwan. It is possible that the difference in the mean age between these two studies is due to secular growth trends. Furthermore, the study subjects in the study of Chang et al[14] were mostly from Southern Taiwan. Therefore, subjects in different geographic areas of Taiwan may have different skeletal maturation times due to minor differences in social, economic and environmental conditions. The mean chronological age of subjects at each hand-wrist bone maturation stage in this study tended to be younger than those in the study of Fishman[7] (0.42–1.67 years younger in males and 0.75–1.68 years younger in females), and in the study of Hägg and Taranger[19] (1.15–1.86 years younger in males and 0.29–1.34 years younger in females), except for the mean age of subjects at the R_{cu} stage. We suggest that these minor discrepancies in the mean age of the study subjects may be due to differences in genetic and environmental factors. NTUH-SMI was used in

this study instead of Fishman's SMI because the NTUH-SMI was developed exclusively for the assessment of skeletal development in the Taiwanese population. Thus, it is more suitable for evaluating the skeletal maturation in our current sample.

Our data of mean chronological ages for various CVM stages were also comparable to those acquired from a similar study performed by Chang et al in 2001 (Table 6).[14] Comparison of both sets of data revealed that male and female subjects in the study of Chang et al[14] matured earlier than corresponding subjects in our study by 0.19–0.98 and 0.02–0.84 years, respectively. We suggest that the minor discrepancy in the mean age may also be due to differences in the time and the geographic area where study subjects were collected.

The findings of this retrospective cross-sectional study demonstrate the validity of using cervical vertebrae for evaluation of skeletal maturation in Taiwanese children and adolescents. This CVMS method may be very helpful clinically in identifying the optimal treatment timing for skeletodental disharmonies. However, a further longitudinal study is needed to address the exact relationships between CVM stages and the growth of craniofacial structures in the Taiwanese population.

In conclusion, we suggest that the CVMS system can be used to replace the NTUH-SMI system for the assessment of skeletal maturation of growing subjects, to avoid additional radiation exposure.

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