Use of cervical vertebral maturation to determine skeletal age

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Introduction: The purpose of this study was to evaluate the validity of the cervical vertebral maturation (CVM) method as an indicator of skeletal age in the circumpubertal period by correlating it to the hand-wrist method (HWM). **Methods:** Hand-wrist and lateral cephalometric radiographs of 400 Chinese subjects were randomly selected. Their ages were 10 to 15 years for girls and 12 to 17 years for boys, so they were within the circumpubertal period. Skeletal ages were assessed according to the CVM method and the HWM. **Results:** The CVM was significantly correlated with HWM skeletal age (Spearman $r = 0.9521$ [boys] and 0.9408 [girls]). All patients in cervical vertebral stage 3 of the CVM corresponded to stages MP3-FG or MP3-G (around the peak of the growth spurt) in the HWM. **Conclusions:** The CVM is a valid indicator of skeletal growth during the circumpubertal period, providing information for timing of growth modification. (Am J Orthod Dentofacial Orthop 2009;136:484.e1-484.e6)

In orthodontics, the use of a dentofacial orthopedic appliance is a main treatment modality in the correction of mandibular deficiency. The mechanism depends on the modification of the growth of the mandible and the maxilla. In assessing skeletal responses, both animal and clinical studies have been performed.[1,2] They have shown that functional appliance therapy can stimulate growth of the mandibular condyle[3] and remodeling of the glenoid fossa.[1] The effectiveness of these growth modifications depends on skeletal maturity. In the study by Ruf and Pancherz,[3] using the Herbst appliance for jaw growth modification therapy to correct mandibular deficiency, the optimal time for growth modification was around the peak of the pubertal growth spurt, which corresponds to hand-wrist maturity stages MP3-FG and MP3-G determined by Hägg and Taranger.[4] The skeletal responses were less in subjects both before and after maximum pubertal growth.[4,5] Therefore, various maturity indicators were used to assess growth spurts to determine optimal timing for growth modification treatment. These methods include sexual maturation characteristics,[5-7] facial growth and peak height velocities, chronologic age,[4] dental development,[8] body height,[9,10] body weight,[10] and hand-wrist maturity.[4,7,11,12]

Hand-wrist radiographs have been used routinely in orthodontics to assess the peak of the growth spurt.[13-15] However, there are concerns about extra radiation exposure. In addition, the British Orthodontic Society guideline stated that the use of hand-wrist radiographs to predict the onset of the pubertal growth spurt was not indicated.[16] Because of this, cervical vertebral maturation (CVM) in lateral cephalometric radiographs was evaluated for its correlation to skeletal maturity as an alternative to the hand-wrist method (HWM).[17-24] One obvious advantage the CVM method is that a lateral cephalometric radiograph is routinely required for orthodontic diagnosis and treatment planning, so no additional radiograph is required.

However, this method is not sensitive for detecting growth maturity except in the growth-spurt period. Previous studies correlating the CVM method with skeletal maturity often included subjects with a wide age range, such as 5 to 18 years.[22] This might affect the correlation coefficient obtained because of inclusion of subjects with skeletal maturity far from the pubertal growth spurt. Therefore, we investigated the correlation between the CVM method and hand-wrist maturity by including only subjects near or in the pubertal growth spurt; southern Chinese people were our study subjects.

MATERIAL AND METHODS

Hand-wrist and lateral cephalometric radiographs of 400 southern Chinese patients (200 boys, 200 girls) were randomly selected from the files at Prince Philip Dental Hospital of the University of Hong Kong.

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The authors report no commercial, proprietary, or financial interest in the products or companies described in this article.
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Submitted, June 2007; revised and accepted, August 2007.
0889-5406/$36.00

doi:10.1016/j.ajodo.2007.08.033

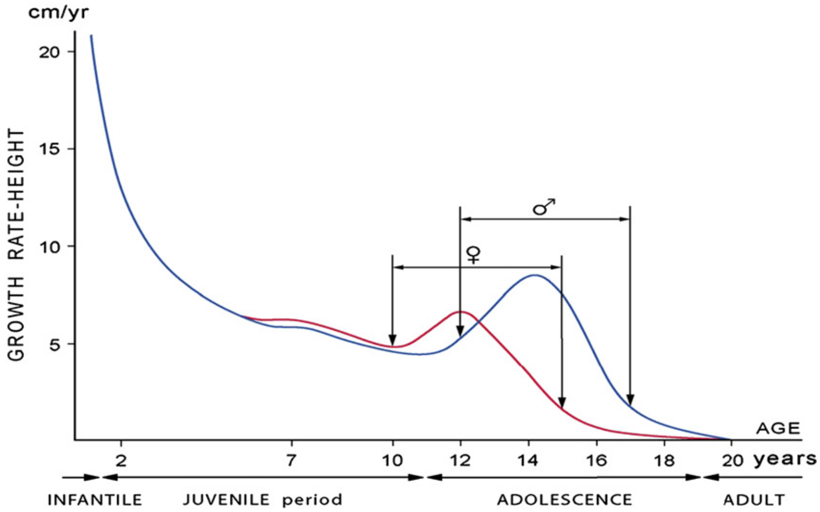

Fig 1. Age ranges of subjects in the study.

Table I. Numbers of subjects at various ages

Age (y)	*Boys*	*Girls*
10	0	15
11	0	33
12	20	37
13	44	47
14	37	33
15	29	35
16	45	0
17	25	0

The selection criteria for the radiographs were as follows: (1) the radiographs were taken in the circumpubertal period (Fig 1) at ages 10 to 15 years for girls and 12 to 17 years for boys (Table I), (2) the bones appeared clearly and were unaffected by systemic disease, (3) the interval between the hand-wrist and the lateral cephalometric radiographs did not exceed 1 month, (4) the inferior borders of the first 4 vertebrae were clear, and (5) the radiograph was of the right hand.

The CVM was evaluated by using the method developed by Baccetti et al[23] (Fig 2). This method depends on the morphology of the 3 cervical vertebrae (C2, C3, and C4), which were analyzed visually according to (1) presence or absence of concavity of the inferior border (odontoid process); and (2) differences in the shape of the body of the cervical vertebrae with age, with 4 shapes considered—trapezoid, rectangular horizontal, square, and rectangular vertical.

These 2 variables were subdivided into 6 consecutive cervical vertebral stages (CVS) of maturation: CVS1, flattened inferior border of the bodies of the cervical border, with trapezoid shape at the superior border; CVS2, concavity at the inferior border of the odontoid process (C2) and increased anterior vertical height of the bodies, with a rectangular horizontal shape; CVS3, significant concavity appears at the inferior border of the third vertebra; CVS4, concavity at the inferior border of C4, and all vertebrae are rectangular; CVS5, the concavities are well defined in the inferior borders of all 6 cervical vertebrae and nearly square shaped; and CVS6, increased depth of the concavities of all cervical vertebrae, with rectangular vertical bodies.

The HWM was evaluated according to the method of Hägg and Taranger.[4] This method includes 8 stages of bone ossification at 2 anatomic sites on the radius and the third finger (Fig 3). The radius represents 3 growth events: onset, peak, and end of the pubertal growth spurt.

In the third middle phalanx (MP3), 5 stages of bone ossification were used (Fig 3): (1) MP3-F, the epiphysis is as wide as the metaphysis; (2) MP3-FG, same as stage F, but the medial or lateral border of the epiphysis forms a line of demarcation at right angles to the distal border; (3) MP3-G, the sides of the epiphysis have thickened, forming capita metaphysis, with a sharp edge distally on at least 1 side; (4) MP3-H, fusion of the epiphysis and metaphysis has begun; (5) MP3-I, fusion of the epiphysis and metaphysis is completed. In the distal epiphysis of the radius, 3 stages of bone ossification were used (Fig 3): (6) R-I, fusion of the epiphysis and the metaphysis has begun; (7) R-IJ, fusion is almost completed, but there is still a gap in at least 1 margin; and (8) R-J, fusion of the epiphysis and metaphysis is completed.

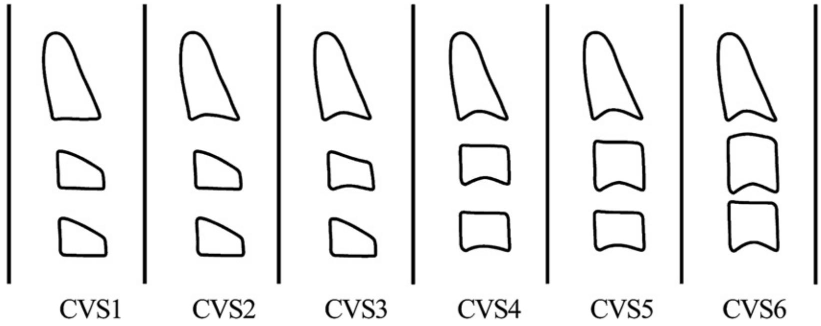

Fig 2. CVM stages.

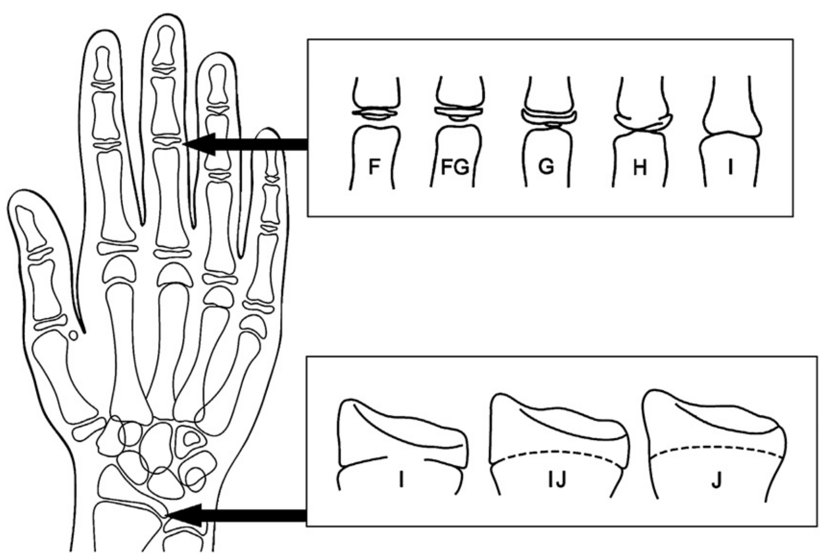

Fig 3. HWM stages.

Since the timing of the mean reading of MP3-I was close to the mean of R-I, the value of MP3-I was not recorded, and only 7 stages in 2 anatomic sites of the third middle phalanx and the radius were recorded in this study.[6]

Statistical analysis

The data of CVM and HWM were analyzed by using statistical software (InStat version 3.00, Graphpad, San Diego, Calif). The Spearman rank correlation coefficient (no assumption of normality of the samples) was used to determine the correlation between skeletal maturation stages obtained by the CVM method and the HWM.

The intraexaminer error was evaluated for 25 patients according to the protocol of Hägg and Taranger.[4] Randomly selected lateral cephalometric and hand-wrist radiographs for both methods were evaluated by the investigator (H.A.A.) and then reevaluated by the same investigator after 3 weeks; 23 of 25 images were the same in the second examination. Interexaminer error was evaluated by using the radiographs of the same 25 patients and reevaluated by another orthodontist. There was agreement of skeletal maturity in 23 of 25 cases with the same results as the first examiner's. Paired *t* tests were performed between the results from the first and second evaluations. For the interexaminer evaluation, the *P* values were 0.161 for CVM and 0.161 for HWM. For the intraexaminer evaluation, the *P* values were 0.574 for CVM and 0.083 for HWM. Their differences were not statistically significant.

RESULTS

Good correlation was found between the CVM method and the HWM.

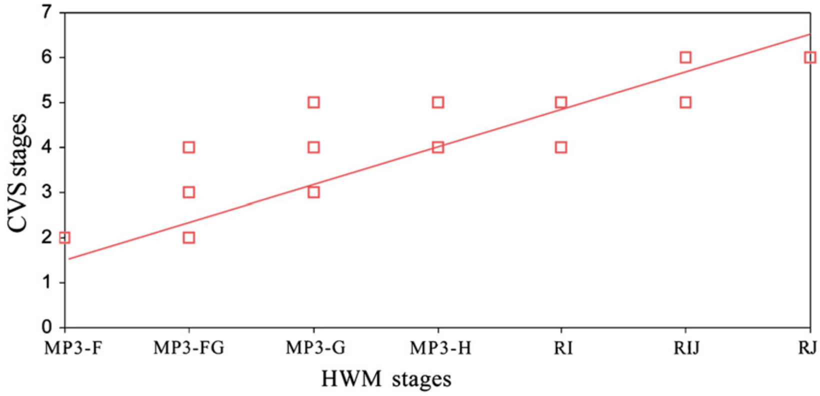

Fig 4. Correlation between CVM and HWM in boys.

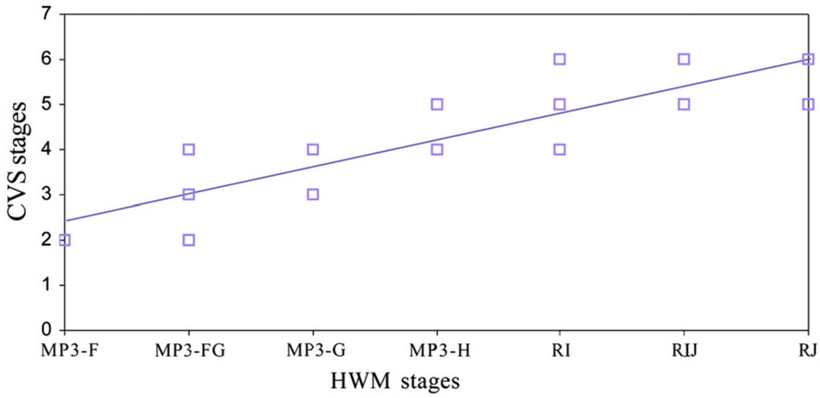

Fig 5. Correlation between CVM and HWM in girls.

A linear relationship was found between the CVM and the HWM in both boys (Fig 4) and girls (Fig 5). The CVM was significantly correlated with the HWM (Spearman r: = 0.9521 [boys] and 0.9408 [girls]).

In all subjects investigated, the CVS3 subjects corresponded mainly to the MP3-FG stage (35 boys, 21 girls), and a few to the MP3-G stage (1 boy, 2 girls) in the HWM who were around the peak of the growth spurt (Fig 1, Table II). For boys, $r = 0.9521$, and $r^2 = 0.9065$. For girls, $r = 0.9408$, and $r^2 = 0.8851$.

DISCUSSION

This is the first study evaluating the correlation between CVM and HWM at the circumpubertal period. Both methods of skeletal maturity measurements were sensitive and precise in evaluating the maturity changes in this period (Fig 1). The wide age range of the subjects might affect the correlation result because of the inability of skeletal maturity methods to detect changes in skeletal maturity precisely when the subjects are either too young or too old. There are a number of studies correlating the HWM and the CVM with a wide range of ages covering the circumpubertal period. The special point about this study is that it is narrowed to the circumpubertal period. The sensitivity of the CVM away from the circumpubertal period is low. Therefore, studies correlating the HWM and the CVM with a wide range of ages resulted in lower correlation coefficients than this study. In the study of Hassel and Farman,[18] the age range was 8 to 18 years, and the correlation coefficients were 0.77 for boys and 0.84 for girls. In the study of Roman et al,[22] the age range was 5 to 18 years, and the correlation coefficients were 0.79 for boys and 0.85 for girls. In the study of Uysal et al,[24] the age range was 5 to 24 years, and the coefficient correlations were 0.78 for males and 0.88 for females.

To ensure that the subjects were in or close to the circumpubertal period, different age ranges for the sexes were selected for this study. This is because of the difference in the onset of the circumpubertal periods between boys and girls.

Table II. Correlations between CVM and HWM by sex

SMI	MP3-F	MP3-FG	MP3-G	MP3-H	R-I	R-IJ	R-J
CVS6					0 (2)	26 (14)	33 (52)
CVS5			5 (11)	12 (9)	25 (21)	13 (10)	
CVS4		2 (3)	40 (38)	2 (8)	1 (1)		
CVS3		35 (21)	1 (2)				
CVS2	3 (3)	2 (3)					

The first numbers refer to boys in the CVM and HWM stages; the numbers in parentheses refer to girls in the same stages.
SMI, Skeletal maturity indicators.

This was the first study of the CVM method and HWM in this population. The high correlation between the CVM method and the HWM might be due to confining the correlation to the circumpubertal period or to the ethnic characteristics of southern Chinese people. Further studies are needed to evaluate the correlation between these indicators in other ethnic groups in the circumpubertal period.

The CVM method can be used to determine the optimal treatment time for various orthodontic procedures. The CVM method has an advantage for the assessment of the stages of mandibular growth because they can be determined on the lateral cephalometric radiograph that is regularly taken for orthodontic treatment.

As stated, treatment for a retrognathic mandible with dentofacial orthopedic appliances was more effective when it is included in the peak.[3] Our findings provide the basis for evaluation of the timing for growth modification treatment. If the CVM of a patient is CVS3, it is an optimal time for growth modification, and maximum growth response to treatment can be expected. If the CVM is CVS4 or above, growth modification can still be performed, but the growth response might be less. If the CVM is CVS2 or below, the patient should be reviewed at 3-month intervals, and standing height should be recorded to determine the pubertal growth spurt. The growth modification treatment should be started around the peak of the growth spurt.

In addition to mandibular deficiency, in case of maxillary transverse deficiencies, maxillary expansion has a greater effect at prepubertal stages. The application of the CVM method is that rapid maxillary expansion induces clinically significant and reproducible transverse changes at the dentoalveolar level when the patient is treated before or after the peak. But, in patients treated before the pubertal peak, there are significant and more effective long-term changes at the skeletal level.[25]

In maxillary protraction treatment for maxillary deficiency, the findings showed that orthopedic treatment of Class III malocclusion was more effective when it began at an early developmental phase of the dentition (CVS1-CVS3) on the theory that early is best because the maxilla is significantly hypoplastic, and the midpalatine suture is incompletely fused.[26] In the correction of vertical problems of the face caused by deficiency of the mandibular ramus, height can be controlled with orthopedic treatment at the peak in mandibular growth (CVS3).

The CVM method also provides information to the clinician in assessing the timing for orthognathic surgery. However, since the most mature stage in CVM is CVS6, it can be either stage R-I, R-IJ, or R-J. It is impossible to determine the stage when growth is completed. Additional indicators (eg, standing height, changes in intermaxillary relationship) are needed to supplement the CVM method.

CONCLUSIONS

The CVM method showed high correlation with the HWM in southern Chinese subjects, and it can be used to replace hand-wrist radiographs for determining the skeletal maturity in the circumpubertal period.

CVS3 stage in CVM is around the peak of the growth spurt, when growth modification treatment by dentofacial orthopedic appliances can start.

This also gives the orthodontist needed information for the timing of various treatment procedures other than growth modification therapy and for obtaining a more objective diagnosis and treatment plan. Thus, treatment will be more optimally timed, and a better result can be expected.

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