ORIGINAL ARTICLE

Mandibular growth as related to cervical vertebral maturation and body height

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The purpose of this study was to analyze the validity of 6 stages of cervical vertebral maturation (Cvs1 through Cvs6) as a biologic indicator for skeletal maturity in 24 subjects (15 females, 9 males). The method was able to detect the greatest increment in mandibular and craniofacial growth during the interval from vertebral stage 3 to vertebral stage 4 (Cvs3 to Cvs4), when the peak in statural height also occurred. The prevalence rate of examined subjects who presented with the peak in body height at this interval was 100% for boys and 87% for girls. Statural height and total mandibular length (Co-Gn) showed significant increments during the growth interval Cvs3 to Cvs4 when compared with the growth interval Cvs2 to Cvs3, and significant growth deceleration occurred during the interval Cvs4 to Cvs5 when compared with Cvs3 to Cvs4. Ramus height (Co-Goi) and S-Gn also showed significant deceleration of growth during the interval Cvs4 to Cvs5 when compared with Cvs3 to Cvs4. Cervical vertebral maturation appears to be an appropriate method for the appraisal of mandibular skeletal maturity in individual patients on the basis of a single cephalometric observation and without additional x-ray exposure. The accuracy of the cervical vertebral method in the detection of the onset of the pubertal spurt in mandibular growth provides helpful indications concerning treatment timing of mandibular deficiencies. (Am J Orthod Dentofacial Orthop 2000;118:335-40)

The appraisal of the biological aspects of mandibular growth is of fundamental importance in dentofacial orthopedics, especially with regard to the use of functional appliances to correct Class II skeletal discrepancies. The main goal of functional therapy of mandibular deficiencies is to induce supplementary lengthening of the mandible by stimulating increased growth at the condylar cartilage. The effectiveness of therapy with functional appliances strongly depends on the responsiveness of the condylar cartilage, which in turn depends on the growth rate of the mandible.[1] Therefore, the evaluation of mandibular skeletal maturation and growth potential in the individual patient provides essential information for the anticipation of treatment results.

It is well known that the growth rate of the human mandible is not constant throughout development. A peak in mandibular growth velocity (pubertal growth spurt) has been described in many previous cephalometric studies.[2-7] The intensity, onset, and duration of the pubertal peak in mandibular growth are characterized by great individual variations. Clinical research has demonstrated that the greatest effects of functional appliances take place when the peak in mandibular growth is included in the treatment period.[1,8-10] In particular, Hägg and Pancherz[9] found that sagittal growth at the condyle in patients treated with the Herbst appliance at the peak in pubertal growth was twice that observed in patients treated 3 years before or 3 years after the peak.

Mandibular skeletal maturity can be assessed by means of a series of biologic indicators: increase in body height[2,4]; skeletal maturation of the hand and wrist[11-13]; dental development and eruption[6,12,14]; menarche, breast, and voice changes[15]; and cervical vertebral maturation.[16-17] In the majority of subjects, the peak in the adolescent increments in maxillary and mandibular size occurs at the same time as does the growth peak in height,[12,18] or slightly after that.[2,19] According to Nanda,[20] the changes in body height show the least variability for the assessment of skeletal age throughout the progression of growth (the predictive efficiency of height age at 9 years of age for S-Gn length at 13 years of age is 94%).

With respect to the cervical vertebral method, 6 stages corresponding to 6 different maturational phases in the cervical vertebrae can be identified during the pubertal period.[16] This procedure has proved to be

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Table I. Descriptive statistics for computed measurements at the 6 stages in cervical vertebral maturation (n = 24)

	Cvs1			*Cvs2*			*Cvs3*			*Cvs4*		
	Mean	*SD*	*SE*	*Mean*	*SD*	*SE*	*Mean*	*SD*	*SE*	*Mean*	*SD*	*SE*
Age (months)	103.7	14.4	2.9	115.2	14.1	2.9	128	14.4	2.9	140.2	13.6	2.8
Body height (cm)	132.2	9.3	1.9	137.6	9.3	1.9	143.6	9.8	2	152.3	9.9	2
Co-Gn (mm)	106.9	6.1	1.2	109.2	6.3	1.3	111.3	6.5	1.3	116.6	6.5	1.3
Co-Goi (mm)	50.9	4.5	0.9	52	4.9	1	52.9	4.9	1	56.6	5.2	1.1
Goi-Gn (mm)	70.7	5.2	1.1	72.9	4.8	0.9	74.4	5.1	1	77.4	5.3	1.1
S-Gn (mm)	116.2	7	1.4	119	7.3	1.5	121.7	7.3	1.5	126	7.6	1.5
N-Me (mm)	111.4	6.3	1.3	113.9	6.3	1.3	116.2	6.4	1.3	119.6	6.4	1.3
ANS-Me (mm)	63.4	4.6	0.9	64.3	4.6	0.9	65.3	4.8	0.9	66.9	4.9	1
S-Goi (mm)	71	6.3	1.3	72.9	6.7	1.4	75	7.1	1.4	78.2	7.1	1.4

effective and clinically reliable for the appraisal of mandibular skeletal maturation in growing subjects, as the stages of cervical vertebral maturation are related to the growth changes in the mandible that occur during puberty.[17] The 6 stages in cervical vertebral maturation include observations before the peak, ie, during the accelerative growth phase (vertebral stages 1 to 3), and observations after the peak, ie, during the decelerative phase of growth (vertebral stages 4 to 6). Pubertal growth peak occurs on average between vertebral stages 3 and 4.

Hellsing[21] in 1991 demonstrated that during adulthood there is significant correlation between height and length of the cervical vertebral bodies and statural height. Similar results were found by Mitani and Sato,[22] who also reported that changes in the cervical vertebrae correlated significantly with increases in mandibular size. The effectiveness of the cervical vertebrae as maturational indicator has been corroborated by Hassel and Farman[23] and Garcia-Fernandez et al,[24] who found a high correlation between cervical vertebral maturation and the skeletal maturation of the hand-wrist.

The aim of the present study is to assess the validity of the cervical vertebrae method for the evaluation of mandibular skeletal maturity in the individual patient by analyzing concomitant variations in an efficient growth indicator such as statural height.

SUBJECTS AND METHODS

The sample used in this study was made up of 24 individuals (15 females and 9 males) selected from the files of the University of Michigan Elementary and Secondary School Growth Study (UMGS).[25] The UMGS archives include annual cephalograms and dental casts of orthodontically untreated children (ages 3 to 18) who were enrolled in the University School, a laboratory school located on the Ann Arbor campus from the mid-1930s through the late 1960s. Interesting additional developmental data are represented by the annual measurements of body height and weight that were performed by school medical personnel at approximately the same time the orthodontic records were obtained. The examination of the UMGS archives provided the longitudinal data for statural height corresponding to the consecutive cephalograms for all the examined subjects.

Lateral cephalograms for each of the 24 subjects were available at the 6 consecutive stages in cervical vertebral maturation (Cvs1 through Cvs6). The original method by Lamparski[16] was adopted with a modification allowing for the appraisal of skeletal age in both boys and girls, regardless of the chronological age (Fig 1).

Stage 1 (Cvs1). The inferior borders of the bodies of all cervical vertebrae are flat. The superior borders are tapered from posterior to anterior.

Stage 2 (Cvs2). A concavity develops in the inferior border of the second vertebra. The anterior vertical height of the bodies increases.

Stage 3 (Cvs3). A concavity develops in the inferior border of the third vertebra.

Stage 4 (Cvs4). A concavity develops in the inferior border of the fourth vertebra. Concavities in the lower borders of the fifth and of the sixth vertebrae are beginning to form. The bodies of all cervical vertebrae are rectangular in shape.

Stage 5 (Cvs5). Concavities are well defined in the lower borders of the bodies of all 6 cervical vertebrae. The bodies are nearly square in shape and the spaces between the bodies are reduced.

Stage 6 (Cvs6). All concavities have deepened. The vertebral bodies are now higher than they are wide.

The traced lateral cephalograms were analyzed by means of a digitizing tablet (Numonics, Lansdale, Pa) and of a digitizing software (Viewbox, ver 2.5). The following linear cephalometric variables were selected (Fig 2): (1) measurements of mandibular size, Co-Gn, Co-Goi, Goi-Gn; and (2) measurements of mandibular

Cvs5			*Cvs6*		
Mean	*SD*	*SE*	*Mean*	*SD*	*SE*
152.7	13.7	2.8	165.1	13.1	2.7
157.2	9.7	2	160.6	9.4	1.9
118.4	6.8	1.4	120.7	7.3	1.5
57.9	5.8	1.2	59.8	6.2	1.3
78.7	5.2	1.1	80.3	5.4	1.1
128.6	7.8	1.6	131.5	7.7	1.6
122.8	6.7	1.4	125.5	6.9	1.4
68.4	5.0	1.0	69.8	5.2	1.1
80.7	7.4	1.5	83.4	7.8	1.6

position in relation to other craniofacial structures, S-Gn, S-Goi, N-Me, ANS-Me.

Dahlberg's formula[26] was used to assess the method error for the cephalometric parameters on 20 repeated measurements randomly selected from the total of the observations. The error ranged from 0.15 to 0.81 mm.

As for the reliability and reproducibility of the assessment of cervical vertebral stages, the percentage of interoperator agreement was 98.6%, as the staging performed by the 2 operators (L.F. and T.B.) was not concordant in 2 observations. Intraoperator agreement was assessed by re-evaluating 50 radiographs 2 weeks later by the same operator (L.F.), and it was 100%.

Descriptive statistics were obtained for statural height and cephalometric measures at each developmental stage (Cvs1 through Cvs6). The changes for all computed variables at the 5 observation intervals (Cvs1 to Cvs2, Cvs2 to Cvs3, Cvs3 to Cvs4, Cvs4 to Cvs5, Cvs5 to Cvs6) were tested for significance by means of ANOVA for repeated measurements with post hoc Scheffé test ($P < .05$).

Statistical computations were performed by means of computer software (SPSS for Windows, release 8.0.0, SPSS, Inc).

RESULTS

Descriptive statistics for statural height and for the cephalometric measurements at the 6 stages in cervical vertebral maturation are reported in Table I. The individual changes in body height in the 24 examined subjects at the 5 intervals between the stages in cervical vertebral maturation are depicted in Fig 3. The results of the statistical comparison of the changes for all computed variables at different growth intervals are shown in Table II.

Changes in body height showed increments from Cvs1 to Cvs2 through Cvs3 to Cvs4, whereas they decreased during subsequent intervals Cvs4 to Cvs5 and Cvs5 to Cvs6 (Table II). On average, the greatest increment in statural height occurred at growth interval Cvs3 to Cvs4 (Fig 3*A*, Table II). The prevalence rate of examined subjects who presented with the peak in statural height at this interval was 100% for boys (Fig 3*C*) and 87% for girls (Fig 3*B*). Only 2 females had their peak during interval Cvs4 to Cvs5 (Fig 3*B*).

The greatest increment for all examined cephalometric variables took place at growth interval Cvs3 to Cvs4. From a statistical point of view, statural height and total mandibular length (Co-Gn) showed significant increments during the growth interval Cvs3 to

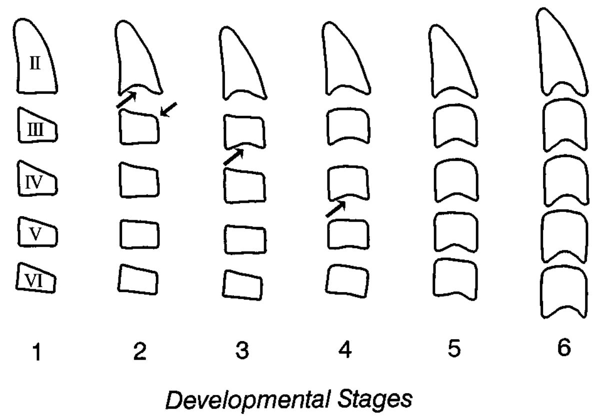

Fig 1. Six stages in cervical vertebral maturation.

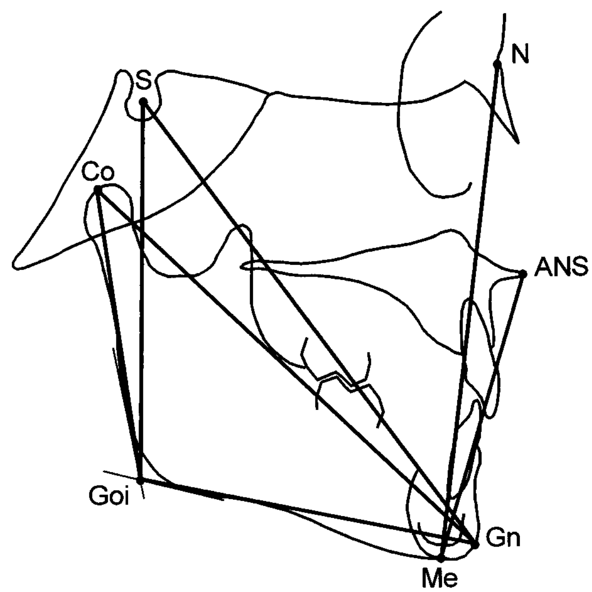

Fig 2. Cephalometric landmarks and measurements.

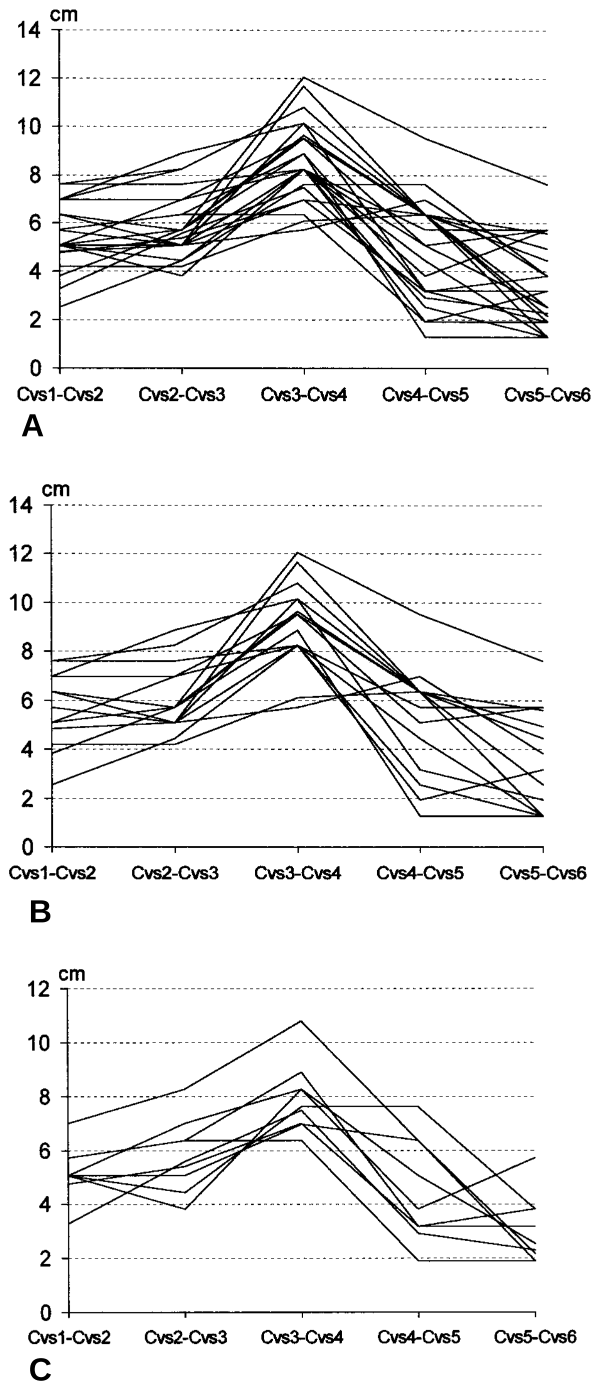

Fig 3. Individual changes in body height at intervals between stages in cervical vertebral maturation (**A**) in 24 subjects examined, (**B**) in subgroup of 15 females, and (**C**) in subgroup of 9 males.

Cvs4 when compared with the growth interval Cvs2 to Cvs3, and significant growth deceleration during the interval Cvs4 to Cvs5 when compared with Cvs3 to Cvs4. Ramus height (Co-Goi) and S-Gn also showed significant deceleration of growth during the interval Cvs4 to Cvs5 when compared with Cvs3 to Cvs4.

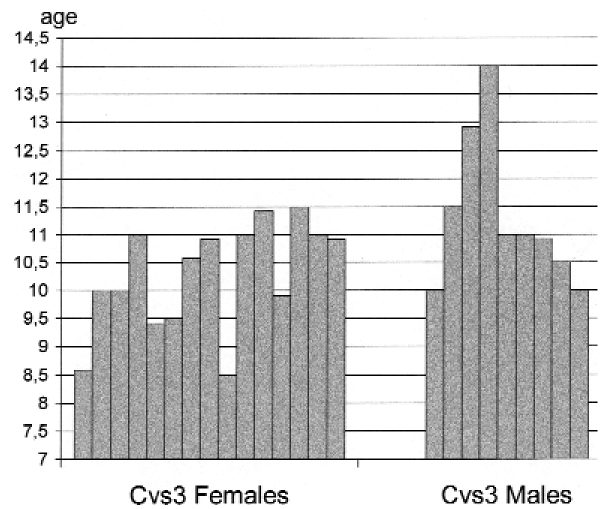

Fig 4. Distribution of individual chronological age at stage 3 in cervical vertebral maturation (Cvs3) in females (Cvs3 females) and males (Cvs3 males).

DISCUSSION

The issue of optimal treatment timing for mandibular deficiencies is a widely debated topic in contemporary orthodontics. The definition of treatment timing in Class II disharmony too often relies on misleading variables such as chronological age or some kind of categorization of dentitional phases rather than individual biologic factors. It has been demonstrated clearly that the evaluation of individual skeletal maturity is fundamental in dentofacial orthopedics, as the greatest effects of functional/orthopedic appliances occur when the peak in mandibular growth is included in the treatment period.[1,8-10]

A few biologic indicators are available for the appraisal of individual skeletal maturity and, consequently, for the detection of the pubertal growth spurt in the mandible.[2,4,6,11-17] Among these, the changes in statural height present with the least variability for the assessment of skeletal age throughout the progression of growth, thus showing the highest reliability as biologic indicator of skeletal maturity. The practical limitation of this method, however, is that it requires several measurements repeated at regular intervals (eg, every 3 months) to construct an individual curve of growth velocity. Radiographic methods have been proposed to overcome this limitation that allow for an appraisal of skeletal maturation on the basis of a single observation. The features of an ideal radiographic indicator should

Table II. Changes at the 5 intervals between consecutive stages in cervical vertebral maturation and statistical comparison (n = 24)

	Cvs1-Cvs2		*Cvs2-Cvs3*		*Cvs3-Cvs4*		*Cvs4-Cvs5*		*Cvs5-Cvs6*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Age (months)	11.46	1.32	12.83	2.51	12.21	2.78	12.42	2.26	12.42	3.13
Body Height (cm)	5.42	1.33	5.95	1.35	8.70*	1.7	4.96*	2.1	3.35*	1.78
Co-Gn (mm)	2.39	1.04	2.81	1.51	4.19*	0.9	2.92*	1.56	2.46	1.66
Co-Goi (mm)	1.1	1.58	1.91	1.14	2.93	0.91	1.76*	1.64	1.77	1.01
Goi-Gn (mm)	2.25	1.38	1.47*	1.47	3.08*	1.68	1.27	1.56	1.61	1.78
S-Gn (mm)	2.73	1.33	2.76	1.41	4.23	1.96	2.68*	1.58	2.84	1.86
N-Me (mm)	2.46	1.46	2.24	1.45	3.5	1.59	3.16	1.59	2.68	1.97
ANS-Me (mm)	0.85	0.83	0.96	1.01	1.71	1.21	1.48	1.34	1.36	1.32
S-Goi (mm)	1.95	1.28	2.12	1.62	3.2	2.09	2.52	1.39	2.68	2.03

*$P < .05$ (ANOVA with post hoc Scheffé test).

include the following: (1) the method should present with biologic validity in describing individual skeletal maturity. The information provided should be in agreement with that derived from a reliable indicator such as the changes in body height; (2) it should be efficient in detecting the peak in mandibular growth; and (3) it possibly should not require supplementary radiographic exposure in addition to the lateral cephalogram that is needed for orthodontic diagnosis and treatment planning. The findings of the present study suggest the validity of the stages of cervical vertebral maturation for the evaluation of individual skeletal maturity in fulfillment of the aforementioned requirements.

The peak in skeletal growth occurs at the interval between the stages in cervical vertebral maturation 3 and 4. The greatest increments both in body height and in craniofacial measurements involving the mandible can be observed at this time. Only 2 of the 24 examined subjects (2 females) presented with the peak in statural height between stage 4 and stage 5. Consequently, the peak consistently took place between stages 3 and 4 in 93.5% of the individuals.

Because stage 3 is the maturation stage that is closest to the onset of the peak in statural height for almost all the examined subjects, it is interesting to observe the distribution of chronological age in both boys and girls at this stage. At stage 3, individual chronological age for the girls ranged from 8 years 6 months to 11 years 5 months, whereas for the boys it ranged from 10 years to 14 years (Fig 4). These data clearly demonstrate that chronological age cannot be used as a parameter for the appraisal of individual skeletal maturation and for the definition of treatment timing in dentofacial orthopedics.

The stages in the maturation of the cervical vertebrae have been related to the increments in mandibular dimensions in a previous article.[17] In the present study, the increments for mandibular dimensions during interval Cvs3 to Cvs4 ranged from two thirds to one third more than those during the 2 earlier intervals (Cvs1 to Cvs2 and Cvs2 to Cvs3). Noteworthy, the method of cervical vertebral maturation was able to detect significant deceleration in mandibular and facial (S-Gn) growth during the period from stage 4 to stage 5.

The appraisal of the stage in cervical vertebral maturation is fairly appropriate for the assessment of individual skeletal maturity and for the detection of the onset of the peak in mandibular growth velocity. There are at least 2 main implications of these findings for dentofacial orthopedics: (1) in cephalometric studies on the effects of functional/orthopedic appliances, the method of the stages in cervical vertebral maturation can be used to classify both treated and control groups according to skeletal maturity[27,28]; and (2) as far as the issue of optimal treatment timing of mandibular deficiencies in the individual patient is concerned, the outcome of therapy of Class II disharmonies with functional appliances will greatly benefit from the inclusion of the growth interval Cvs3 to Cvs4 in the active treatment period.

CONCLUSIONS

The findings of this study demonstrate the validity of the method of cervical vertebral maturation for the evaluation of skeletal maturity and for the identification of the pubertal peak in craniofacial growth rate in individual subjects. The greatest increment in body height takes place at a definite interval between 2 morphologic stages in cervical vertebral maturation, from stage 3 (when a concavity develops in the inferior border of the third vertebra) to stage 4 (when a concavity develops in the inferior border of the fourth vertebra, and the bodies of all cervical vertebrae become rectangular in shape) in both boys and girls. The peak in statural height during the interval from stage 3 to stage 4 corresponds to the greatest increments in all dimensional and positional mandibular measurements.

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