ELSEVIER

Seminars in
ORTHODONTICS

The Cervical Vertebral Maturation (CVM) Method for the Assessment of Optimal Treatment Timing in Dentofacial Orthopedics

Tiziano Baccetti,[*,†] Lorenzo Franchi,[*,†] and James A. McNamara, Jr.[†,‡,§]

The present study introduces a further modified version of the Cervical Vertebral Maturation (CVM) method for the detection of the peak in mandibular growth, based on the analysis of the second through fourth cervical vertebrae in a single cephalogram. The morphology of the bodies of the second (C2 –odontoid process), third (C3), and fourth (C4) cervical vertebrae were analyzed in 6 consecutive cephalometric observations (T_1 through T_6) of 30 orthodontically untreated subjects. Observations for each subject consisted of two consecutive cephalograms comprising the interval of maximum mandibular growth (as assessed by means of the maximum increment in total mandibular length, Condylion –Gnathion: Co-Gn), together with two earlier consecutive cephalograms and two later consecutive cephalograms. The analysis consisted of both visual and cephalometric appraisals of morphological characteristics of the three cervical vertebrae. The construction of this new modified version of the CVM method was based on the results of both ANOVA for repeated measures with post hoc Scheffé's test ($P < 0.05$) and discriminant analysis. The new clinically improved CVM method is comprised of six maturational stages (cervical stage 1 through cervical stage 6, ie, CS1 through CS6). CS1 and CS2 are prepeak stages; the peak in mandibular growth occurs between CS3 and CS4. CS6 is recorded at least 2 years after the peak. The use of the CVM method enables the clinician to identify optimal timing for the treatment of a series of dentoskeletal disharmonies in all three planes of space.
Semin Orthod 11:119–129 © 2005 Elsevier Inc. All rights reserved.

In the organization, differentiation, development, and growth of any somatic structure, time plays a crucial role in determining the final morphological and dimensional result. In orthodontics and dentofacial orthopedics, it is becoming increasingly evident that the timing of the treatment onset may be as critical as the selection of the specific treatment protocol, as will be discussed below. By beginning a protocol at the individual patient's optimal maturational stage, the most favorable response with the least potential morbidity can be anticipated.

The issue of optimal timing for dentofacial orthopedics is linked intimately to the identification of periods of accelerated growth that can contribute significantly to the correction of skeletal imbalances in the individual patient. Cephalometric investigations on longitudinal samples have identified a pubertal spurt in mandibular growth that is characterized by wide individual variations in onset, duration, and rate.[1-6] Individual skeletal maturity can be assessed by means of several biologic indicators: increase in body height[1-3]; skeletal maturation of the hand and wrist[7-10]; dental development and eruption[8,11,12]; menarche or voice changes[9,13,14]; and cervical vertebral maturation.[15,16] The biologic indicators of skeletal maturity refer mainly to somatic changes at puberty, thus emphasizing the strict interactions between the development of the craniofacial region and the modifications in other body regions.

The reliability and efficiency of a biologic indicator of skeletal maturity can be evaluated with respect to several fundamental requisites.[17] An "ideal" biologic indicator of individual mandibular skeletal maturity should be characterized by at least five features.

1. Efficacy in detecting the peak in mandibular growth. The method should present with a definite stage or

---

*Department of Orthodontics, University of Florence, Florence, Italy.
†Department of Orthodontics and Pediatric Dentistry, School of Dentistry, University of Michigan, Ann Arbor, MI.
‡School of Medicine, University of Michigan, Ann Arbor, MI.
§Center for Human Growth and Development, University of Michigan, Ann Arbor, MI.
Address correspondence to Tiziano Baccetti, DDS, PhD, Università degli Studi di Firenze, Via del Ponte di Mezzo, 46-48, 50127, Firenze, Italy. E-mail: t.baccetti@odonto.unifi.it

1073-8746/05/$-see front matter © 2005 Elsevier Inc. All rights reserved.
doi:10.1053/j.sodo.2005.04.005

phase that coincides with the peak in mandibular growth in the majority of subjects.
2. No need for additional x-ray exposure.
3. Ease in recording.
4. Consistency in the interpretation of the data. The interexaminer error in the appraisal of the defined stages or phases should be as low as possible.
5. Usefulness for the anticipation of the occurrence of the peak. The method should present with a definable stage or phase that occurs before the peak in mandibular growth in the majority of subjects.

The main features of the Cervical Vertebral Maturation (CVM) method as described previously by Franchi and coworkers[18] included:

1. In nearly 95% of North American subjects, a growth interval in CVM coincides with the pubertal peak in both mandibular growth and body height.
2. The cervical vertebrae are available on the lateral cephalogram that is used routinely for orthodontic diagnosis and treatment planning.
3. The appraisal of the shape of the cervical vertebrae is straightforward.
4. The reproducibility of classifying CVM stages is high (>98% by trained examiners).
5. The method is useful for the anticipation of the pubertal peak in mandibular growth.

A subsequent study by our group[19] provided a few improvements of the original CVM analysis to make the method easier and applicable to the vast majority of patients:

1. A more limited number of vertebral bodies was used to perform the staging (as suggested by Hassel and Farman[20]). In particular, the method included only those cervical vertebrae (C2, C3, and C4) that can be visualized when a protective radiation collar is worn by the patient.
2. Definitions of stages were not based on a comparative assessment of between-stage changes, so that stages can be identified easily on a single cephalogram.

A series of investigations performed in different parts of the world have confirmed the validity of the CVM method, mostly by comparing it with the hand and wrist method. Pancherz and Szyska found that the cervical vertebral maturation method has level of reliability comparable to the hand and wrist method.[21] By replacing the hand-wrist method with the CVM method, an additional radiograph can be avoided, thus reducing the patient's total radiation dose. Grave and Townsend also have confirmed the validity of the CVM method in Australian aborigines.[22]

The aim of the present article is to present a further modified and refined version of the CVM method and its validity for the appraisal of mandibular skeletal maturity in the individual patient in light of the findings of recent studies in which the CVM method has been used to assess optimal timing for the treatment of malocclusions in the transverse, sagittal, and vertical planes of space.

Subjects and Methods

The total sample (n = 706) that comprises the cephalometric files of the University of Michigan Elementary and Secondary School Growth Study was evaluated.[23] Due to the longitudinal nature and aim of the present investigation, subjects with less than six consecutive annual cephalometric observations (n = 492) were excluded from the study. Total mandibular length (Co-Gn) was measured on the longitudinal sets of lateral cephalograms for each of the 214 remaining subjects at yearly intervals. The lateral cephalograms were analyzed by means of a digitizing tablet (Numonics, Lansdale, PA) and digitizing software (Viewbox, version 3.0, D. Halazonetis, Athens, Greece). The maximum increase in Co-Gn between two consecutive annual cephalograms was used to define the peak in mandibular growth at puberty in the individual subjects. Two consecutive cephalograms comprising the interval of maximum mandibular growth, together with two earlier consecutive cephalograms and two later consecutive cephalograms, had to be available for each subject and were included in the study. This limited the investigation to 30 subjects (18 males, 12 females).

The morphology of the bodies of the second (C2 –odontoid process), third (C3), and fourth (C4) cervical vertebrae were analyzed in the six consecutive annual observations (T_1 through T_6). The analysis consisted of both visual and cephalometric appraisals of morphological characteristics of the cervical vertebrae.

Visual analysis. The morphology of the three cervical vertebrae (C2, C3, C4) on the six consecutive cephalograms (T_1 through T_6) was evaluated by visual inspection. Two investigators (LF and TB) performed the appraisal independently. The percentage of interexaminer agreement was 96.7%. Two sets of variables were analyzed:

1. Presence or absence of a concavity at the lower border of the body of C2, C3, and C4; and
2. Shape of the body of C3 and C4. Four basic shapes were considered:

trapezoid (the superior border is tapered from posterior to anterior);
rectangular horizontal (the heights of the posterior and anterior borders are equal; the superior and inferior borders are longer than the anterior and posterior borders);
squared (the posterior, superior, anterior, and inferior borders are equal); and
rectangular vertical (the posterior and anterior borders are longer than the superior and inferior borders).

Cephalometric analysis. On the lateral cephalograms, the following points for the description of the morphologic characteristics of the cervical vertebral bodies were traced and digitized (Fig 1):

C2p, C2 m, C2a: the most posterior, the deepest, and the most anterior points on the lower border of the body of C2.

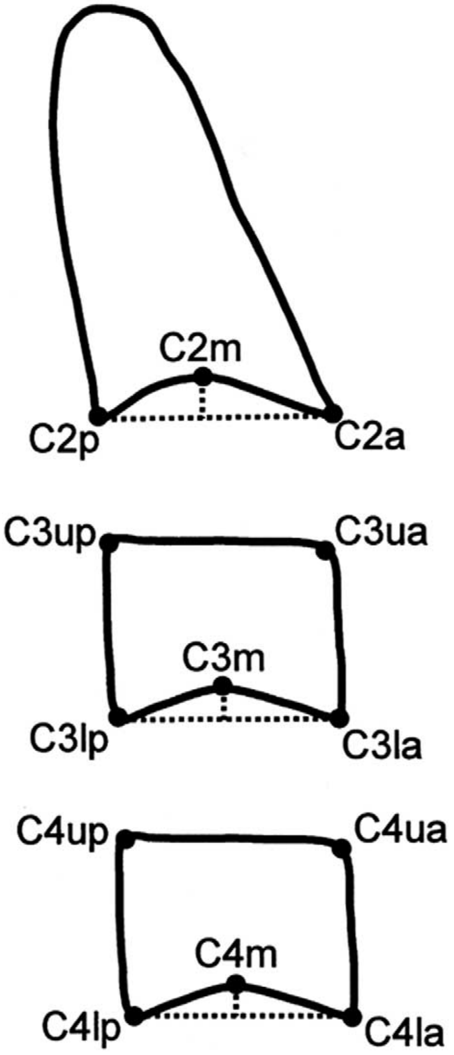

Figure 1 Cephalometric landmarks for the quantitative analysis of the morphologic characteristics of the vertebral bodies of C2, C3, and C4.

C3up, C3ua: the most superior points of the posterior and anterior borders of the body of C3.
C3lp, C3 m, C3la: the most posterior, the deepest, and the most anterior points on the lower border of the body of C3.
C4up, C4ua: the most superior points of the posterior and anterior borders of the body of C4.
C4lp, C4 m, C4la: the most posterior, the deepest, and the most anterior points on the lower border of the body of C4.

For the location of landmarks, the indications described by Hellsing were adopted partially.[24] With the aid of these landmarks, the following measurements were performed:

C2Conc: a measure of the concavity depth at the lower border of C2 (distance from the line connecting C2p and C2a to the deepest point on the lower border of the vertebra, C2 m).
C3Conc: a measure of the concavity depth at the lower border of C3 (distance from the line connecting C3lp and C3la to the deepest point on the lower border of the vertebra, C3 m).
C4Conc: a measure of the concavity depth at the lower border of C4 (distance from the line connecting C4lp and C4la to the deepest point on the lower border of the vertebra, C4 m).
C3BAR: ratio between the length of the base (distance C3lp-C3la) and the anterior height (distance C3ua-C3la) of the body of C3.
C3PAR: ratio between the posterior (distance C3up-C3lp) and anterior (distance C3ua-C3la) heights of the body of C3.
C4BAR: ratio between the length of the base (distance C4lp-C4la) and the anterior height (distance C4ua-C4la) of the body of C4.
C4PAR: ratio between the posterior (distance C4up-C4lp) and anterior (distance C4ua-C4la) heights of the body of C4.

Statistical analysis. The significance of the prevalence rates for the morphologic characteristics of the cervical vertebrae was evaluated at each observation time by means of the chi-squared test with Yates' correction ($P < 0.05$). Descriptive statistics were obtained for total mandibular length and for vertebral cephalometric measures at each of the six consecutive observations (T_1 through T_6). The differences between the mean values for all the computed variables at the six consecutive stages were tested for significance by means of ANOVA for repeated measurements with post hoc Scheffé's test ($P < 0.05$).

The cephalometric measurements of the bodies of the cervical vertebrae at each interval between consecutive cephalograms were analyzed by means of a multivariate statistical approach, discriminant analysis, to identify those vertebral morphologic variables mostly accounting for the differences between two consecutive observations. A stepwise variable selection (forward selection procedure) was performed with the goal of obtaining a model with the smallest set of significant cephalometric variables (F to enter and to remove = 4). Finally, the classifying power of selected cephalometric variables was tested. All statistical computations were performed by means of computer software (SPSS for Windows, version 10.0.0, SPSS, Inc., Chicago, IL).

Results

The findings of the visual analysis of the morphologic characteristics of cervical vertebrae (C2, C3, C4) are reported in Table 1. The features of the examined vertebrae at the six consecutive observations can be summarized as follows:

T_1. The lower border of C2 is flat in the vast majority of subjects at this stage; a concavity is evident at the lower border of C2 in only 7% of the individuals examined, a percentage that is not significant. The concavity is absent at the lower borders of both C3 and C4 in 100% of the subjects. The bodies of both C3 and C4 are trapezoid in shape.

Table 1 Results of Qualitative Analysis of Cervical Vertebral Characteristics at the Six Consecutive Observations

	T_1		T_2		T_3		T_4		T_5		T_6	
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Concavity at the lower border of C2	2 (6.7%)	28 (93.3%)	24 (80%)	6 (20%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)
Concavity at the lower border of C3	0 (0%)	30 (100%)	2 (6.7%)	28 (93.3%)	28 (93.3%)	2 (6.7%)	28 (93.3%)	2 (6.7%)	29 (96.7%)	1 (3.3%)	30 (100%)	0 (0%)
Concavity at the lower border of C4	0 (0%)	30 (100%)	0 (0%)	30 (100%)	3 (10%)	27 (90%)	26 (86.7%)	4 (13.3%)	29 (96.7%)	1 (3.3%)	30 (100%)	0 (0%)
C3 shape: trapezoid	30 (100%)	0 (0%)	29 (96.7%)	1 (3.3%)	23 (76.7%)	7 (23.3%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)
C4 shape: trapezoid	30 (100%)	0 (0%)	26 (86.7%)	4 (13.3%)	15 (50%)	15 (50%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)
C3 shape: rectangular horiz.	0 (0%)	30 (100%)	1 (3.3%)	29 (96.7%)	7 (23.3%)	23 (76.7%)	30 (100%)	0 (0%)	12 (40%)	18 (60%)	0 (0%)	30 (100%)
C4 shape: rectangular horiz.	0 (0%)	30 (100%)	4 (13.3%)	26 (86.7%)	15 (50%)	15 (50%)	30 (100%)	0 (0%)	14 (46.7%)	16 (53.3%)	0 (0%)	30 (100%)
C3 shape: squared	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	18 (60%)	12 (40%)	15 (50%)	15 (50%)
C4 shape: squared	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	16 (53.3%)	14 (46.7%)	16 (53.3%)	14 (46.7%)
C3 shape: rectangular vert.	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	15 (50%)	15 (50%)
C4 shape: rectangular Vert.	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	0 (0%)	30 (100%)	14 (46.7%)	16 (53.3%)

T_2. A concavity is present at the lower border of C2 in 80% of the subjects. The observation at T_2 is characterized also by the absence of a concavity at the lower borders of C3 (with the nonsignificant exception of 7% of the subjects) and of C4. Both C3 and C4 still are trapezoid in shape, with the nonsignificant exceptions of 3% and 13% of the subjects showing rectangular horizontal bodies for C3 and C4, respectively.

T_3. A concavity is present at the lower border of C2 (100% of the subjects) and of C3 (with the nonsignificant exception of 7% of the subjects). No concavity is present at the lower border of C4 (with the nonsignificant exception of 10% of the cases). The shape of both C3 and C4 may be either trapezoid or rectangular horizontal.

T_4. This observation is characterized by the presence of a concavity at the lower borders of C2, C3 (with the nonsignificant exception of 7% of the cases), and C4 (with the nonsignificant exception of 13% of the cases). The bodies of both C3 and C4 now are rectangular horizontal in shape (100% of the subjects).

T_5. A concavity is present at the lower borders of C2, C3 (with the nonsignificant exception of 3% of the cases), and C4 (with the nonsignificant exception of 3% of the cases). The body of C3 is rectangular horizontal in 40% of the cases and squared in the remaining subjects. The body of C4 is rectangular horizontal in 47% of the cases and squared in the remaining subjects.

T_6. A concavity is present at the lower borders of all the three examined cervical vertebrae. The body of C3 is squared in 50% of the cases and rectangular vertical in the remaining 50% of the cases. The body of C4 is squared in 53% of the cases and rectangular vertical in the remaining subjects.

Descriptive statistics for the cephalometric measurements of vertebral morphologic characteristics are reported in Table 2, together with the statistical comparisons between consecutive observations. No significant differences for any of the measurements were assessed between T_1 and T_2 with the exception of a significant increase in the depth of the concavity at the lower border of the second cervical vertebra (C2Conc). The depth of the concavities at the lower borders of both the second (C2Conc) and the third (C3Conc) cervical vertebra is significantly greater at T_3 when compared with T_2. In the transition from T_2 to T_3, the height of the anterior border of both C3 and C4 increases significantly, thus leading to significant decrements in the ratio between the heights of the posterior and anterior borders of the vertebral bodies (C3PAR and C4PAR).

At T_4, the depth of the concavity at the lower border of C4 (C4Conc) becomes significantly greater than at T_3. In the transition from T_3 to T_4, the height of the anterior borders of both C3 and C4 increases significantly again, thus leading to significant decreases both in the ratio between the heights of the posterior and anterior borders of the vertebral bodies (C3PAR and C4PAR) and in the ratio between the length of the base and the anterior height of the vertebral bodies (C3BAR and C4BAR). On average, C3PAR and C4PAR now

Table 2 Results of Quantitative Analysis: Descriptive Statistics and Statistical Comparisons (ANOVA for Repeated Measurements with Post Hoc Scheffe's test) on the Measurements at the Six Consecutive Cephalometric Observations.

	T_1			T_2			T_3			T_4			T_5			T_6		
	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE	Mean	SD	SE
Age (months)	104.67	15.12	2.76	116.40	14.84	2.71	128.73	14.99	2.74	141.17	14.42	2.63	153.30	14.41	2.63	166.00	13.83	2.53
Co-Gn (mm)	107.85	5.33	0.97	110.32	5.68	1.04	112.63	5.78	1.06	118.05*	5.83	1.06	119.63	5.91	1.08	121.77	5.93	1.08
C2Conc (mm)	0.44	0.46	0.08	0.76*	0.49	0.09	1.15*	0.44	0.08	1.58*	0.37	0.07	1.91	0.40	0.07	2.23	0.48	0.09
C3Conc (mm)	0.01	0.41	0.07	0.36	0.49	0.09	0.95*	0.53	0.10	1.36	0.64	0.12	1.85	0.60	0.11	2.40*	0.68	0.12
C4Conc (mm)	0.03	0.31	0.06	0.12	0.29	0.05	0.31	0.39	0.07	1.07*	0.53	0.10	1.77*	0.60	0.11	2.28*	0.63	0.11
C3PAR (ratio)	1.35	0.15	0.03	1.26	0.16	0.03	1.16*	0.12	0.02	0.98*	0.08	0.01	0.98	0.06	0.01	0.99	0.06	0.01
C3BAR (ratio)	1.85	0.24	0.04	1.77	0.23	0.04	1.61*	0.15	0.03	1.39*	0.14	0.02	1.20*	0.15	0.03	1.03*	0.13	0.02
C4PAR (ratio)	1.34	0.13	0.02	1.25	0.14	0.03	1.15*	0.17	0.03	1.01*	0.06	0.01	1.00	0.07	0.01	0.97	0.05	0.01
C4BAR (ratio)	1.83	0.25	0.05	0.71	0.22	0.04	1.59	0.21	0.04	1.36*	0.12	0.02	1.19*	0.18	0.03	1.04	0.12	0.02

*Indicates statistical significance with respect to the preceding observation.

have a ratio of approximately 1:1, an indication that both C3 and C4 vertebral bodies are rectangular horizontal in shape.

T_5 and T_6 are characterized by decrements of the ratio between the length of the base and the anterior height of the vertebral bodies (C3BAR and C4BAR). The mean values for these measurements indicate that the vertebral bodies become progressively more squared in shape. At T_6, one third of the cases show a rectangular vertical shape of one or both C3 and C4 vertebral bodies.

Discriminant analysis revealed that the forming concavity at the lower border of C2 can account for 80% of the differences between T_1 and T_2. The depth of C3Conc becomes the discriminant variable between T_2 and T_3 with a classifying power of 75%. The difference in the posteroanterior ratio of C3 (C3PAR) together with the depth of the concavity at the lower border of C4 (C4Conc) are the discriminant factors between T_3 and T_4 (classifying power equal to 85%). C3PAR in association with both the ratio between the length of the base and the anterior height of C3 (C3BAR) and C4Conc are able to discriminate between T_4 and T_5 in 88% of the cases. The ratios for C3 (C3BAR and C3PAR) together with the depth of the concavity at the lower border of C2 (C2Conc) are the discriminant variables between T_5 and T_6 in 80% of the cases.

Discussion

The modifications in the size and shape of the cervical vertebrae in growing subjects have gained increasing interest during the past few decades as a biological indicator of individual skeletal maturity. One of the main reasons for the increasing popularity of the method is that the analysis of cervical vertebral maturation is performed on the lateral cephalogram, a type of film used routinely in orthodontic diagnosis. The objective of the present investigation was to provide a refinement of the method through the definition of six stages (cervical stages 1 to 6) for a more practical application in dentofacial orthopedics, and more specifically:

a direct appraisal of the skeletal maturity of the mandible in relation to the morphological features of the cervical vertebrae;

an evaluation of the morphological features of the cervical vertebral bodies restricted to those that are visible on the lateral cephalogram even when a protective collar is worn, as originally proposed by Hassel and Farman[20];

a definition of the cervical vertebral morphology at each developmental stage that allows the clinician to apply the CVM method on the basis of the information derived from a single cephalogram. The assessment of individual stages in cervical vertebral maturation through the comparative analysis of between-stage changes should be avoided.

The anatomical features of the second (odontoid process), third, and fourth cervical vertebrae were evaluated here as visualized on lateral cephalograms in a time interval ranging on average from 2 years before to 2 years after the peak in mandibular growth. The description of the consecutive

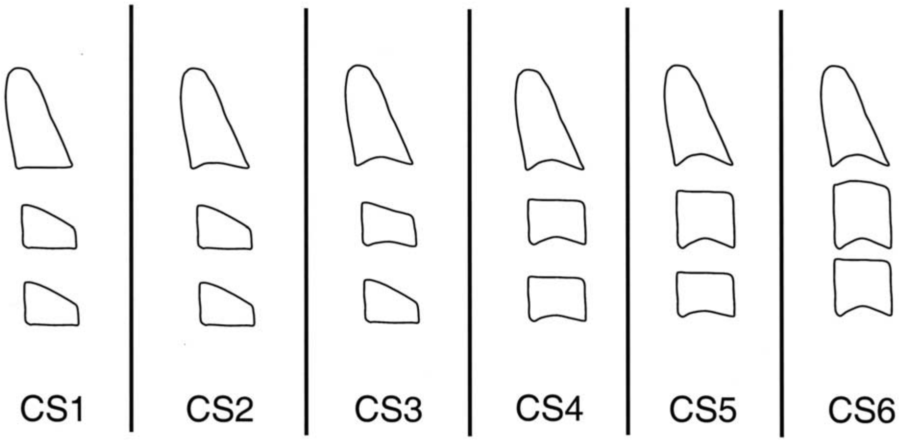

Figure 2 Schematic representation of the stages of cervical vertebrae according to the newly modified method.

stages in vertebral development consisted of a noncomparative definition of morphological characteristics at each observation.

The findings of both the visual (qualitative) and cephalometric (quantitative) analyses revealed that a statistically significant discrimination can be made between the initial two stages in cervical vertebral maturation only according to the difference in depth of the concavity at the lower border of the second cervical vertebra. A definite concavity at the lower border of C2 is present in 80% of the subjects at cervical stage 2.

The appearance of a visible concavity at the lower border of the third cervical vertebra is the anatomic characteristic that mostly accounts for the identification of the stage immediately preceding the peak in mandibular growth (cervical stage 3). The distinction among Cvs 4, Cvs 5, and Cvs 6 as defined in the former CVM method is possible only by using the shape of the bodies of C3 and/or C4 as a discriminant factor.[18]

Stages of Cervical Vertebral Maturation

The stages of cervical vertebral maturation in the modified version of the method presented here are illustrated diagrammatically in Fig 2. The six stages are defined as follows:

Cervical stage 1 (CS1, Fig 3). The lower borders of all the three vertebrae (C2-C4) are flat. The bodies of both C3 and C4 are trapezoid in shape (the superior border of the vertebral body is tapered from posterior to anterior). The peak in mandibular growth will occur on average 2 years after this stage.

Cervical stage 2 (CS2, Fig 4). A concavity is present at the lower border of C2 (in four of five cases, with the remaining subjects still showing a cervical stage 1). The bodies of both C3 and C4 are still trapezoid in shape. The peak in mandibular growth will occur on average 1 year after this stage.

Cervical stage 3 (CS3, Fig 5). Concavities at the lower borders of both C2 and C3 are present. The bodies of C3 and C4 may be either trapezoid or rectangular horizontal in shape. The peak in mandibular growth will occur during the year after this stage.

Cervical stage 4 (CS4, Fig 6). Concavities at the lower borders of C2, C3, and C4 now are present. The bodies of both C3 and C4 are rectangular horizontal in shape. The peak in mandibular growth has occurred within 1 or 2 years before this stage.

Cervical stage 5 (CS5, Fig 7). The concavities at the lower borders of C2, C3, and C4 still are present. At least one of the bodies of C3 and C4 is squared in shape. If not squared, the body of the other cervical vertebra still is rectangular horizontal. The peak in mandibular growth has ended at least 1 year before this stage.

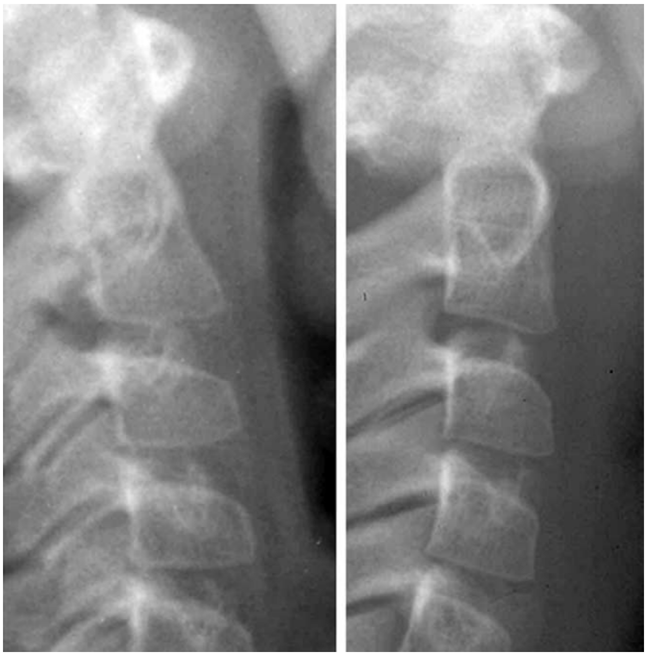

Figure 3 Cervical stage 1 (CS1): two clinical examples.

Figure 4 Cervical stage 2 (CS2): two clinical examples.

Cervical stage 6 (CS6, Fig 8). The concavities at the lower borders of C2, C3, and C4 still are evident. At least one of the bodies of C3 and C4 is rectangular vertical in shape. If not rectangular vertical, the body of the other cervical vertebra is squared. The peak in mandibular growth has ended at least 2 years before this stage.

Figure 5 Cervical stage 3 (CS3): two clinical examples.

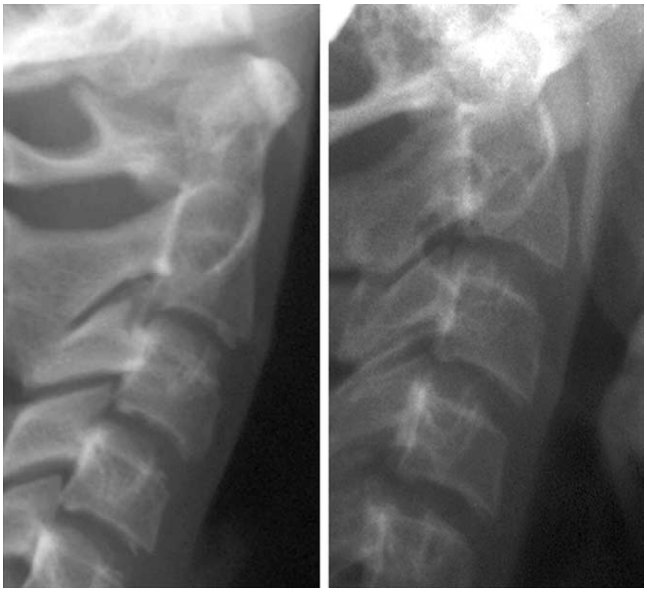

Figure 6 Cervical stage 4 (CS4): two clinical examples.

Application to Dentofacial Orthopedics

The clinical application of the method to dentofacial orthopedics becomes relevant for those treatment protocols that benefit from the inclusion of the period of accelerated mandibular growth. CVM method can be useful as a maturational index to detect the optimal time to start treatment of mandibular deficiencies by means of functional jaw orthopedics.[25,26] It has been demonstrated that the effectiveness of functional treatment of Class II skeletal disharmony depends strongly on the biological responsiveness of the condylar cartilage, which in turn is related to the growth rate of the mandible.[27]

Figure 7 Cervical stage 5 (CS5): two clinical examples.

Figure 8 Cervical stage 6 (CS6): two clinical examples.

When CS1 or CS2 are diagnosed in the individual patient with mandibular deficiency, the clinician can wait at least one additional year for a radiographic reevaluation aimed to start treatment with a functional appliance. The appearance of a definite concavity at the lower border of C2 indicates that the growth spurt is approaching, that is, that the year of the peak will start approximately 1 year after this stage. CS3 represents the ideal stage to begin functional jaw orthopedics, as the peak in mandibular growth will occur within the year after this observation. In the sample examined here, total mandibular length exhibited an average increase of 5.4 mm in the year following CS3, a significantly greater increment when compared with the growth interval from CS1 to CS2 (about 2.5 mm), from CS2 to CS3 (again about 2.5 mm), and to the postpeak between-stage intervals (1.6 mm and 2.1 mm for the intervals from CS4 to CS5 and from CS5 to CS6, respectively).

Treatment Timing for Class II Malocclusion

An emerging fundamental concept underlying Class II correction is that this type of intervention should be undertaken when the likelihood for a maximum growth response is high, that is, during the circumpubertal growth period. A series of short-term studies has demonstrated statistically and clinically significant correction of the Class II dentoskeletal relationships when either functional appliances or fixed appliances in combination with Class II elastics are used during the circumpubertal period (Table 3). When Class II malocclusion is treated too early (therapy starting at CS1 and completed before the interval of peak velocity in mandibular growth, ie, before CS3), the net difference in supplementary growth of the mandible (expressed cephalometrically by the measurement Co-Pg or Co-Gn) in the treated samples versus untreated controls ranges between 0.4 mm and 1.8 mm (Table 3). On the contrary, when intervention in a Class II pa-

Table 3 Analysis of the Literature Regarding Treatment Timing for Class II Malocclusion*

The Effect of Treatment Timing on Supplementary Elongation of the Mandible in Class II Treatment					
Pre-Pubertal Class II Treatment (treatment ends before the pubertal peak in mandibular growth)			**Pubertal Class II Treatment (treatment includes the pubertal peak in mandibular growth)**		
Study	**Appliance**	**Net increase in mandibular length over untreated controls**	**Study**	**Appliance**	**Net increase in mandibular length over untreated controls**
McNamara et al., 1985[28]	FR-2	+1.2 mm	McNamara et al., 1985[28]	FR-2	+3.6 mm
Petrovic et al., 1994[29]	Class II elastics	+1.0 mm	Petrovic et al., 1994[29]	Class II elastics	+3.0 mm
Tulloch et al., 1997[30]	Bionator	+1.4 mm	Lund and Sandler, 1998[36]	Twin-block	+2.4 mm
Keeling et al., 1998[31]	Bionator	+0.4 mm	Franchi et al., 1999[37]	Acrylic Herbst	+2.7 mm
Baccetti et al., 2000[25]	Twin-block	+1.8 mm	Baccetti et al., 2000[25]	Twin-block	+4.7 mm
Baccetti and Franchi, 2001[26]	FR-2	+1.0 mm	Baccetti and Franchi, 2001[26]	FR-2	+3.9 mm
De Almeida et al., 2002[32]	FR-2	+0.9 mm	Faltin et al., 2003[35]	Bionator	+4.3 mm
Janson et al., 2003[33]	FR-2	+0.5 mm			
O'Brien et al., 2003[34]	Twin-block	+1.6 mm			
Faltin et al., 2003[35]	Bionator	+0.8 mm			

*The appraisal of treatment timing in individual studies was based upon chronologic age, hand and wrist, or CVM method. All data are short-term and refer to controlled studies.

tient includes the CS3-CS4 interval (growth spurt), the net supplementary growth of the mandible in treated samples versus untreated controls ranges from 2.4 mm to 4.7 mm (Table 3). The data reported in Table 3 suggest also that in Class II patients, the timing of therapeutic intervention has a greater impact on supplementary elongation of the mandible than does the type of appliance used.

The only long-term study that deals with the evaluation of the role of treatment timing in Class II correction[35] revealed that the use of a Bionator followed by fixed appliances in contrast with untreated Class II controls is able to induce a supplementary elongation of the mandible of less than 2 mm when the functional appliance is used before the peak in mandibular growth, and of about 5 mm when the growth spurt is included in the treatment interval. These results possess significance not only at the statistical level, but also at the clinical level, as the correction of a full cusp Class II molar relationship to Class I represents a 5 to 6 mm sagittal correction at the level of the occlusal plane.

Treatment Timing for Class III Malocclusions

Early treatment of Class III disharmony has been advocated for a long time.[38] The clinical understanding that Class III malocclusion is established early in life and that it is not a self-correcting disharmony has led to the recommendation of intervention as early as in the deciduous dentition. Cephalometric and morphometric investigations using Class III untreated controls have demonstrated that treatment of Class III malocclusion by means of efficient protocols (eg, maxillary expansion and protraction) is more effective in the early than in the late mixed dentition.[39-41]

Until recently, however, information about the possible role of treatment timing on long-term changes after active therapy for Class III malocclusion was not available in the literature.[42] At a postpubertal observation (CS5 or CS6), when active growth of the craniofacial skeleton is completed for the most part, Class III subjects treated with a rapid maxillary expander and a facial mask well before the growth spurt (CS1) present with different long-term changes with respect to Class III subjects treated at a later stage, that is, at the peak in mandibular growth (CS3). Prepubertal orthopedic treatment of Class III malocclusion is effective both in the maxilla (which shows a supplementary growth of about 2 mm over Class III untreated controls) and in the mandible (restriction in growth of about 3.5 mm over controls), whereas treatment of Class III malocclusion at puberty is effective at the mandibular level only (restriction in growth of about 4.5 mm over controls).[42]

The findings in the maxilla have a biological explanation in the physiology of the circummaxillary sutures, which are more amenable to orthopedic intervention during the early stages, whereas they become more heavily interdigitated around puberty.[43] On the other hand, the possibility of restricting mandibular growth both before and during puberty gives the clinician the chance of resuming facemask therapy at a later time when correction of Class III relationships is only partial after the prepubertal intervention.

Treatment Timing for Transverse Maxillary Deficiency

The issue of treatment timing for maxillary expansion aimed to correct transverse maxillary deficiency has been addressed in the past by Melsen[44] and by Wertz and Dreskin.[45] Melsen used autopsy material to examine histologically the maturation of the midpalatal suture at different developmental stages.[44] In the infantile stage (up to 10 years of age), the suture was broad and smooth, whereas in the juvenile stage (from 10 to 13 years) it had developed in a more typical squamous suture with overlapping sections. Finally, during the adolescent stage (13 and 14 years of age) the suture was wavier with increased interdigitation. From these histological data, the inference is that patients who show an advanced stage of skeletal maturation at the midpalatal suture may have difficulty in undergoing orthopedic maxillary expansion. Clinical support for the histologic findings by Melsen[44] is derived from the results of a study by Wertz and Dreskin[45] who noted greater and more stable orthopedic changes in young patients (under the age of 12 years). Either group of researchers, however, did not use any biological indicator of skeletal maturity to define “early” versus “late” treatment.

The use of the CVM method has been applied recently to the estimate of the effects of different treatment timing on the correction of transverse maxillary deficiency.[46] A sample of 42 patients was compared with a control sample of 20 subjects. Posteroanterior cephalograms were analyzed for each of the treated subjects at T_1 (pretreatment), T_2 (immediate postexpansion), and T_3 (long-term observation); films were available at T_1 and at T_3 for the controls. The mean age at T_1 was 11 years and 10 months for both the treated and the control groups. The mean ages at T_3 also were comparable (20 years 6 months for the treated group, and 17 years 8 months for the control group). Following rapid maxillary expansion and retention (2 months on average), fixed standard edgewise appliances were placed. The study included transverse measurements on dentoalveolar structures, maxillary and mandibular bases, and other craniofacial regions (nasal, zygomatic, orbital, and cranial).

Treated and control samples were divided into two groups according to individual skeletal maturation as evaluated by the CVM method. The early treated and early control groups consisted of subjects who had not reached the pubertal peak in skeletal growth velocity at T_1 (CS1 through CS3), whereas the late-treated and late control groups were comprised of subjects during or slightly after the peak at T_1 (CS4 through CS6). The group treated before the pubertal peak showed significantly greater short-term increases in the width of the nasal cavities. In the long-term, increments in maxillary skeletal width, maxillary intermolar width, lateronasal width, and latero-orbitale width were significantly greater in the early-treated group when compared with the corresponding control group. The late-treated group exhibited significant increases in lateronasal width and in maxillary and mandibular intermolar widths. The use of the CVM method demonstrated that rapid maxillary expansion before the peak in skeletal growth velocity is able to induce more pronounced transverse craniofacial changes at the skeletal level. Treatment changes are more dentoalveolar in nature when expansion is performed during or after the peak.

Treatment Timing for Increased Vertical Dimension

The CVM method also has been applied to the appraisal of ideal treatment timing for a specific therapeutic protocol for the correction of vertical excess of the face by means of a bonded rapid maxillary expander in association with a vertical-pull chincup. One of the goals of orthopedic treatment in subjects with increased vertical dimension is the control of the vertical growth of the mandibular ramus (expressed cephalometrically by the measure Co-Go). Available short-term data from our research group show that a significantly more favorable effect can be obtained when treatment is performed at CS3, that is, at the peak in mandibular growth, when compared with treatment performed at an earlier maturational stage (CS1). No significant increase in ramal height is observed in hyperdivergent subjects treated at CS1, whereas a significant increase of about 2 mm more than in untreated controls is recorded in hyperdivergent subjects who receive orthopedic treatment at CS3.

Final Remarks

The CVM method is comprised of six maturational stages (cervical stage 1 through cervical stage 6, CS1-CS6), with the peak in mandibular growth occurring between CS3 and CS4. The pubertal peak has not been reached without the attainment of both CS1 and CS2. In particular, the detection of CS2 indicates that the growth spurt is approaching, and it will start at CS3, which is approximately 1 year after CS2. Active growth is virtually completed when the CS6 is attained.

The method is particularly useful when skeletal maturity has to be appraised on a single cephalogram and only the cervical vertebrae from the second one through the fourth one are visible. The CVM method has the further advantage to be assessed on the lateral cephalogram, which is the radiographic record used routinely for orthodontic diagnosis and treatment planning.

The use of a reliable biological indicator of skeletal maturity such as the CVM method is highly recommended for a wide variety of research and clinical applications. In both prospective and retrospective controlled studies, CVM stages enable the researcher to categorize treated/untreated subjects for a biologically appropriate matching between experimental and control samples. Further, the appraisal of the CVM stage in the individual subject allows for a more precise definition of early and late samples in studies aimed to determine the role of treatment timing in the effectiveness of different treatment protocols for the correction of malocclusions. To date, the application of the method in investigations on treatment timing in orthodontics and dentofacial orthopedics has revealed that:

1. Class II treatment is most effective when it includes the peak in mandibular growth;
2. Class III treatment with maxillary expansion and protraction is effective in the maxilla only when it is performed before the peak (CS1 or CS2), whereas it is effective in the mandible during both prepubertal and pubertal stages;
3. skeletal effects of rapid maxillary expansion for the correction of transverse maxillary deficiency are greater at prepubertal stages, while pubertal or postpubertal use of the rapid maxillary expander entails more dentoalveolar effects; and
4. deficiency of mandibular ramus height can be enhanced significantly in subjects with increased vertical facial dimension when orthopedic treatment is performed at the peak in mandibular growth (CS3).

To summarize, effects of therapies aimed to enhance/restrict mandibular growth appear to be of greater magnitude at the circumpubertal period during which the growth spurt occurs in comparison to earlier intervention, while effects of therapies aimed to alter the maxilla orthopedically (maxillary protraction/maxillary expansion) are greater at prepubertal stages.

The CVM method can be helpful for the assessment of completion of active growth in studies dealing with the long-term effects of orthodontic/orthopedic treatment strategies. Similarly, the method can be used to identify clinically the adequate time for intervention in subjects who need surgery for the late correction of facial disharmonies.

Due to its practical applications, the CVM method appears to be a powerful diagnostic tool. The implementation of the method in orthodontic decision making allows for an improvement of treatment outcomes by combining effective and efficient protocols with optimal treatment timing.

References

1. Nanda RS: The rates of growth of several facial components measured from serial cephalometric roentgenograms. Am J Orthod 41:658-673, 1955
2. Björk A: Variations in the growth pattern of the human mandible: longitudinal radiographic study by the implant method. J Dent Res 42:400-411, 1963
3. Hunter CJ: The correlation of facial growth with body height and skeletal maturation at adolescence. Angle Orthod 36:44-54, 1966
4. Ekström C: Facial growth rate and its relation to somatic maturation in healthy children. Swed Dent J (Suppl) 11:1-99, 1982
5. Lewis A, Roche AF, Wagner B: Pubertal spurts in cranial base and mandible: comparisons within individuals. Angle Orthod 55:17-30, 1985
6. Hägg U, Pancherz H, Taranger J: Pubertal growth and orthodontic treatment, in Carlson DS, Ribbens KA (eds): Craniofacial Growth During Adolescence. Craniofacial Growth Series, Vol 20. Ann Arbor, MI, Center for Human Growth and Development, University of Michigan, 1987, pp 87-115
7. Greulich WW, Pyle SI: Radiographic Atlas of Skeletal Development of the Hand and Wrist. Stanford, Stanford University Press, 1959
8. Björk A, Helm S: Prediction of the age of maximum puberal growth in body height. Angle Orthod 37:134-143, 1967
9. Tofani M: Mandibular growth at puberty. Am J Orthod 62:176-194, 1972
10. Hägg U, Taranger J: Skeletal stages of the hand and wrist as indicators of the pubertal growth spurt. Acta Odontol Scand 38:187-200, 1980
11. Hellman M: The process of dentition and its effects on occlusion. Dent Cosmos 65:1329-1344, 1923
12. Lewis AB, Garn SM: The relationship between tooth formation and other maturation factors. Angle Orthod 30:70-77, 1960

13. Tanner JM: Growth at Adolescence. 2nd ed. Oxford, Blackwell Scientific Publications, 1962
14. Hägg U, Taranger J: Menarche and voice changes as indicators of the pubertal growth spurt. Acta Odontol Scand 38:179-186, 1980
15. Lamparski DG: Skeletal age assessment utilizing cervical vertebrae. Unpublished master's thesis. Pittsburgh, PA, Department of Orthodontics, University of Pittsburgh, 1972
16. O'Reilly M, Yanniello GJ: Mandibular growth changes and maturation of cervical vertebrae—a longitudinal cephalometric study. Angle Orthod 58:179-184, 1988
17. Franchi L, Baccetti T: The use of maturational indices for the identification of optimal treatment timing in dentofacial orthopedics, in McNamara JA Jr, Kelly KA (eds): Treatment Timing: Orthodontics in Four Dimensions. Craniofacial Growth Series, Vol 39. Ann Arbor, MI, Center for Human Growth and Development, University of Michigan, 2002, pp 151-170
18. Franchi L, Baccetti T, McNamara JA Jr: Mandibular growth as related to cervical vertebral maturation and body height. Am J Orthod Dentofacial Orthop 118:335-340, 2000
19. Baccetti T, Franchi L, McNamara JA Jr: An improved version of the cervical vertebral maturation (CVM) method for the assessment of mandibular growth. Angle Orthod 72:316-323, 2002
20. Hassel B, Farman A: Skeletal maturation evaluation using cervical vertebrae. Am J Orthod Dentofacial Orthop 107:58-66, 1995
21. Pancherz H, Szyska M: Analyse der Halswirbelkörper statt der Handknochen zur Bestimmung der skelettalen und somatischen Reife. IOK 32:151-161, 2000
22. Grave K, Townsend G: Cervical vertebral maturation as a predictor of the adolescent growth spurt. Aust Orthod J 19:25-32, 2003
23. Riolo ML, Moyers RE, McNamara JA Jr, et al: An Atlas of Craniofacial Growth: Cephalometric Standards from The University School Growth Study, The University of Michigan. Monograph 2, Craniofacial Growth Series. Ann Arbor, MI, Center for Human Growth and Development, University of Michigan, 1974
24. Hellsing E: Cervical vertebral dimensions in 8-, 11-, and 15-year-old children. Acta Odontol Scand 49:207-213, 1991
25. Baccetti T, Franchi L, Toth LR, et al: Treatment timing for twin block therapy. Am J Orthod Dentofacial Orthop 118:159-170, 2000
26. Baccetti T, Franchi L: Maximizing esthetic and functional changes in Class II treatment by means of appropriate treatment timing, in McNamara JA Jr, Kelly KA (eds): New Frontiers in Facial Esthetics. Craniofacial Growth Series, Vol 38. Ann Arbor, MI, Center for Human Growth and Development, University of Michigan, 2001, pp 237-251
27. Petrovic A, Stutzmann J, Lavergne J: Mechanism of craniofacial growth and modus operandi of functional appliances: a cell-level and cybernetic approach to orthodontic decision making, in Carlson DS (ed): Craniofacial growth theory and orthodontic treatment. Craniofacial Growth Series, Vol 23. Ann Arbor, MI, Center for Human Growth and Development, University of Michigan, 1990, pp 13-74
28. McNamara JA Jr, Bookstein FL, Shaughnessy TG: Skeletal and dental changes following functional regulator therapy on Class II patients. Am J Orthod 88:91-110, 1985
29. Petrovic A, Stutzmann J: Crescita sagittale della mandibola mediante edgewise ed elastici di II Classe. Ortognatod It 3:93-108, 1994
30. Tulloch JFC, Phillips C, Koch G, et al: The effect of early intervention on skeletal pattern in Class II malocclusion: a randomized clinical trial. Am J Orthod Dentofacial Orthop 111:391-400, 1997
31. Keeling SD, Wheeler TT, King GJ, et al: Anteroposterior skeletal and dental changes after early Class II treatment with bionators and headgear. Am J Orthod Dentofacial Orthop 113:40-50, 1998
32. De Almeida MR, Henriques JF, Ursi W: Comparative study of the Fränkel (FR-2) and bionator appliances in the treatment of Class II malocclusion. Am J Orthod Dentofacial Orthop 121:458-466, 2002
33. Janson GR, Toruno JL, Martins DR, et al: Class II treatment effects of the Frankel appliance. Eur J Orthod 25:301-309, 2003
34. O'Brien K, Wright J, Conboy F, et al: Effectiveness of early orthodontic treatment with the twin-block appliance: a multicenter, randomized, controlled trial. Part 1: Dental and skeletal effects. Am J Orthod Dentofacial Orthop 124:234-243, 2003
35. Faltin K, Faltin RM, Baccetti T, et al: Long-term effectiveness and treatment timing for Bionator therapy. Angle Orthod 73:221-230, 2003
36. Lund DI, Sandler PJ: The effects of twin blocks: a prospective controlled study. Am J Orthod Dentofacial Orthop 113:104-110, 1998
37. Franchi L, Baccetti T, McNamara JA Jr: Treatment and posttreatment effects of acrylic splint Herbst appliance therapy. Am J Orthod Dentofacial Orthop 115:429-438, 1999
38. Graber TM: Orthodontics: principles and practice. Philadelphia, WB Saunders, 1972, pp 705-708
39. Baccetti T, McGill JS, Franchi L, et al: Skeletal effects of early treatment of Class III malocclusion with maxillary expansion and face-mask therapy. Am J Orthod Dentofacial Orthop 113:333-343, 1998
40. Franchi L, Baccetti T, McNamara JA Jr: Shape-coordinate analysis induced by rapid maxillary expansion and facial mask therapy. Am J Orthod Dentofacial Orthop 114:418-426, 1998
41. Baccetti T, Franchi L: Updating cephalometrics through morphometrics: thin-plate spline analysis of craniofacial growth/treatment changes, in McNamara JA Jr (ed): Growth Modification: What Works, What Doesn't, and Why. Monograph No. 35, Craniofacial Growth Series. Ann Arbor, MI, Center for Human Growth and Development, University of Michigan, 1999, pp 257-273
42. Franchi L, Baccetti T, McNamara JA Jr: Post-pubertal assessment of treatment timing for maxillary expansion and protraction therapy followed by fixed appliances. Am J Orthod Dentofacial Orthop 126:555-568, 2004
43. Melsen B, Melsen F: The postnatal development of the palatomaxillary region studied on human autopsy material. Am J Orthod 82:329-342, 1982
44. Melsen B: Palatal growth studied on human autopsy material: a histologic microradiographic study. Am J Orthod 68:42-54, 1975
45. Wertz R, Dreskin M: Midpalatal suture opening: a normative study. Am J Orthod 71:367-381, 1977
46. Baccetti T, Franchi L, Cameron CG, et al: Treatment timing for rapid maxillary expansion. Angle Orthod 71:343-350, 2001