# Craniofacial growth spurt in Class I subjects

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**Introduction:** The objective was to study the growth spurt of Class I subjects, focusing on the ability to predict the peak of the growth spurt of the maxillary (Co-A) and mandibular (Co-Pog) lengths from the maturational changes of the cervical vertebrae. **Methods:** The longitudinal lateral cephalographs of 14 males (ages, 10-15 years) and 12 females (ages, 9-14 years) were selected from the Craniofacial Growth Studies Legacy Collection of the American Association of Orthodontists Foundation. The cephalographs were taken at regular 1-year intervals. A cervical vertebral maturation (CVM) method that divided skeletal maturation into 6 stages was used for growth prediction. Growth increments calculated for the annual age intervals were used to examine the diagnostic performance of the CVM method. **Results:** In males, the most peaks for Co-Pog were detected in the CVM3-CVM4 interval in 7 males (50%); for Co-A, the most peaks were found in the CVM2-CVM3 interval in 7 males (50%). In females, the most peaks for both Co-Pog and Co-A were seen in the CVM2-CVM3 interval in 7 females (58%) and in 6 females (50%), respectively. The fewest peaks were detected in CVM4-CVM5 for both males and females. **Conclusions:** In Class I subjects with balanced anteroposterior jaw relationships, presence of CVM3 would indicate the peak of the growth spurt, and CVM2 would mean that the peak has not yet arrived. During CVM2, the shapes of cervical vertebrae 3 and 4, whether trapezoid or horizontal rectangular, would indicate whether the subject is in the early CVM2 or is about to be in CVM3. (Am J Orthod Dentofacial Orthop 2019;155:473-81)

Orthodontics has every reason for a long history of attempts to study growth of the craniofacial complex.[1] Treatment of skeletal problems with growth modification, the first phase of 2-phase orthodontics, was a main motive for researchers and clinicians to vet the craniofacial growth. Orthodontists elucidated that they can use growth expressed during the adolescent growth period to correct skeletal jaw malrelationships. Therefore, timing of orthodontic treatment has special importance.[2-4]

Authors studying craniofacial growth used various tools,[5-8] including lateral cephalometric radiographs.[9] The value of lateral cephalometric radiographs in orthodontic clinics is undeniable in diagnosis, setting treatment objectives, and evaluation and prediction of treatment results.[10] To make the most benefit of the already-taken radiographs, both qualitative and quantitative methods of skeletal growth assessment were introduced by researchers to the orthodontic community.[11-14] Because of the eagerness to find a practical, valid, and reliable method to predict craniofacial growth, the use of the cervical vertebral maturation (CVM) method extended from evaluation of skeletal maturation to prediction of the pubertal growth spurt. Several cross-sectional and longitudinal studies have examined the use of this method in evaluating and predicting craniofacial growth.[15,16] Longitudinal studies have used records taken successively at frequent intervals for repeated measurements for the same subject over time. This allows calculation of the actual amount of growth over a specified time interval; special efforts have been used to predict the mandibular growth potential.[17-22]

Previous conclusions about the diagnostic validity and reliability of the CVM method in the identification of the peak of mandibular growth were on the 2 extremes. The method was highly recommended by some researchers,[17,23] but it was considered unreliable by others.[24,25] One weakness repeatedly seen in previous studies was including different classes of malocclusion in the same group.[25-27] The malocclusion was not considered as a variable during sample selection,

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assignment of groups in the sample, or the statistical analyses, although differences had been found when studying craniofacial growth. Mandibular growth in Class II Division 1 subjects was found to be smaller compared with Class I subjects.[28] Those in Class III were suggested to show greater mandibular growth and longer pubertal peaks than those with Class I and Class II malocclusions.[29-32]

In one of the few exceptions to what is prevalent, Engel et al[32] evaluated the predictability of the peak of the maxillary and mandibular lengths in females with Class II malocclusion using the CVM method. However, studies with similar designs are rare and did not investigate the prediction of craniofacial growth changes in Class II or Class III subjects sufficiently. It is of equal importance to study the skeletal growth and its predictability in Class I subjects with balanced craniofacial skeleton; this will complete the picture and improve the interpretation of the findings. To overcome this limitation, only Class I subjects were included in this study.

This study used lateral cephalographs from the American Association of Orthodontists Foundation's Craniofacial Growth Legacy Collection Web site (http://www.aaoflegacycollection.org). It provides records from 9 of the famous longitudinal craniofacial growth studies in the United States and Canada. The records include x-rays, facial photographs, and dental study models for untreated children and adolescents of different ethnicities. A primary purpose of the Web site is to make collaborative studies using records from various collections feasible. The longitudinal cephalographs used here were selected from Michigan and Mathews growth studies because those lateral cephalographs were collected in a close period of time from subjects of the same ethnicity.

The aim of this study was to investigate the maxillary and mandibular pubertal growth changes of Class I subjects and relate the maximum increases in their body lengths to the CVM stages.

## MATERIAL AND METHODS

The longitudinal lateral cephalographs of 26 Class I subjects, 14 males and 12 females, were selected from Michigan and Mathews longitudinal growth studies to form the sample for this study. Angle classification was among the data in the American Association of Orthodontists Foundation's Craniofacial Growth Legacy Collection Web site. The mean ANB angles were 1.9° ± 1.2° for males and 2.6° ± 0.8° for females at 10 years old, indicating skeletal anteroposterior facial balance.

The sample size calculations used comparison of specificity proportions (p1 and p2) according the following equation[33]:

$$n = \frac{[p1(1-p1)+p2(1-p2)]}{(p1-p2)^2} \times cp,\ power$$

where $n$ is the number of subjects required in each group and $cp, power$ is 7.9 for $P = 0.05$ and power of 80%. The result showed that 12 subjects would be required in each group. Thus, a sample size of 26 subjects was adequate for the objectives of this study including the comparison between the female and male groups.

Homogeneity of the sample was considered in the design of this study because it would contribute positively to the statistical analyses, since it decreases variations. Therefore, the selected Class I subjects were from the same ethnicity and in the common chronologic age range of the pubertal growth spurt. The subjects were males from 10 to 15 years and females from 9 to 14 years of age of northern European ethnicity. Also, lateral cephalographs in the Michigan and Mathews growth studies were taken in close time frames (1953-1970 and 1967-1979, respectively).

From the records of these growth studies, lateral cephalographs taken at regular 1-year intervals were selected for the study. This meant that for each sex group, 6 cephalographs were evaluated for every subject in the study. The age span was chosen to encompass the prepeak, peak, and immediately postpeak stages of the adolescent facial growth spurt in both sexes; however, it did not definitely extend to complete maturation.

The skeletal maturation was assessed using a qualitative method. This method described the changes in the morphology of cervical vertebrae (CV) 2, 3, and 4 on a lateral cephalograph and divided the skeletal maturation into 6 stages according to consistently observed shape changes.[11] The method divided skeletal maturation into 6 stages from CVM1 to CVM6. Accordingly, good quality and contrast of radiographs that showed at least CV2, CV3, and CV4 was necessary to include the radiograph in the study.

### Statistical analysis

To enhance the reliability of the results, casual and systematic errors of the cephalometric measurements and intraevaluator agreement level for the repeated assessments of CVM stages were tested. Reliability tests were done before proceeding to assessment of the whole sample of cephalographs by randomly selecting 30 cephalographs for repeated measurements. Dahlberg's formula[34] ($Se^2 = \sum d^2/2n$), where $Se^2$ is the error variance, and $d$ is the difference between 2

**Table I.** Two × 2 representation for calculations of sensitivity, specificity, positive and negative predictive values (PPV and NPV), and accuracy for the peak of the pubertal growth spurt

| | *Subjects in the peak of growth spurt* | *Subjects not in the peak of growth spurt* | |
|---|---|---|---|
| Positive subjects | True positives (TP) | False positives (FP) | $PPV = \frac{TP}{TP+FP}$ |
| Negative subjects | False negatives (FN) | True negatives (TN) | $NPV = \frac{TN}{TN+FN}$ |
| | $Sensitivity = \frac{TP}{TP+FN}$ | $Specificity = \frac{TN}{TN+FP}$ | |

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN}$$

determinations of the same variable, tested casual errors. Dependent *t* tests tested systematic errors. Intraexaminer agreement between repeated evaluations of the CVM stages was evaluated with Cohen kappa statistics.

Because it was not possible to blind the chronologic age and sex of the subject, the skeletal age assessment was done randomly using the case numbers given to the subjects. All cephalographs of each subject were assessed at 1 time but randomly without chronologic order. After assessment of the CVM stages for the whole sample, the data were arranged by separating them according to sex into male and female groups. In each group, the data of each subject were arranged according to the chronologic age. Following the same steps for CVM stage assessment, skeletal measurements were taken. The condylion (Co) to pogonion (Pog) linear distance for total mandibular length and the Co to point A (A) linear distance for total maxillary length were used.

Annual growth increments were calculated for each subject according to the annual age intervals (9-10 years to 13-14 years in females and 10-11 years to 14-15 years in males). This resulted in 5 annual age intervals for both sexes. The CVM stage was recorded for each of the 6 annual cephalographs for each subject. The CVM stages at the beginning and end of the annual age interval corresponding to the largest increments of maxillary and mandibular growth were taken as the CVM interval corresponding to the peak of the pubertal growth spurt.

Growth increments calculated for the annual age intervals were used to examine the diagnostic performance of the method. The analysis included sensitivity, specificity, positive predictive values, negative predictive values, and accuracy. These proportions measured the extent to which the CVM stages could indicate the peak of the growth spurt. A representation of how these proportions are calculated is given in Table I. True positives mean subjects who are in the growth peak identified by CVM stages as in the growth peak, true negatives mean subjects who are not in the growth peak that are identified by CVM stages as not in the growth peak, false positives mean subjects who are not in the growth peak but are identified by CVM stages as in the growth peak, and false negatives mean subjects who are in the growth peak but are identified by CVM stages as not in the growth peak. Sensitivity is the probability that the interval between certain CVM stages is present at the time of the growth spurt (true-positive rate), specificity is the probability that the interval between certain CVM stages is absent when the growth spurt is absent (true-negative rate), the positive predictive value is the proportion of true positive to total positive results, the negative predictive value is the proportion of true negative to total negative results, and accuracy is the overall probability that a subject will be correctly assessed as measured by the proportion of true (both true positives and true negatives) to total results (true positives and negatives, and false positives and negatives).

A multilevel logistic regression for prediction of presence or absence of the peak of the pubertal growth spurt in either Co-Pog or Co-A was also calculated. In applying the multilevel logistic regression, the peak of the pubertal growth spurt was investigated with the predictors CVM stages, age, and sex. This was done for each of the 3 cervical-stage intervals in this study: CVM2-CVM3, CVM3-CVM4, and CVM4-CVM5.

For all calculations, $P \leq 0.05$ was set as the level of statistical significance, and statistical tests were carried out using SPSS Statistics for Windows (version 22.0; IBM, Armonk, NY).

## RESULTS

The results showed no systematic errors. Casual errors were 0.5 mm or less. High reliability of CVM staging was indicated by the 0.90 kappa value that was found.

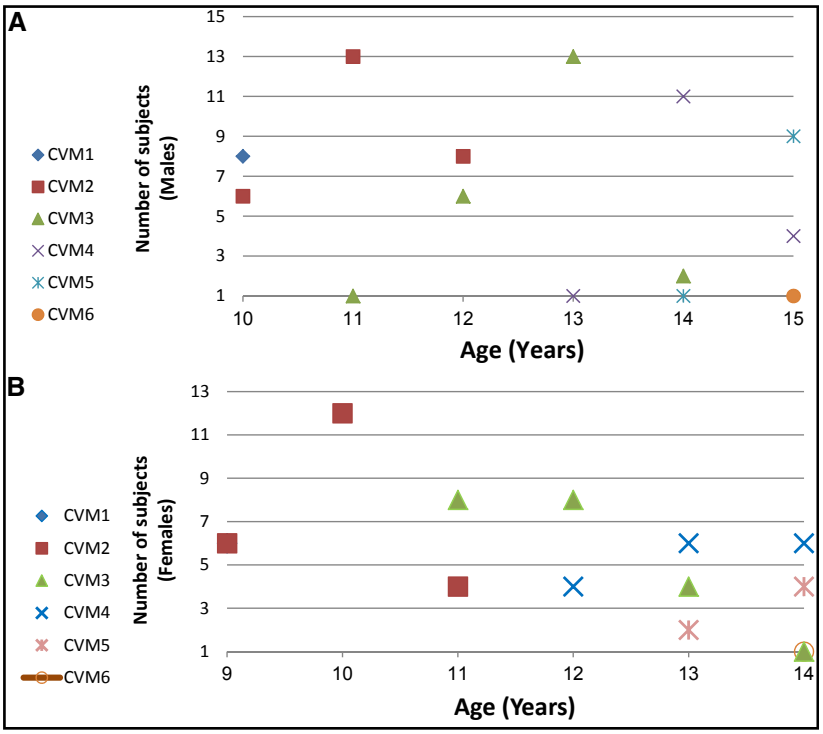


**Fig 1. A,** Distribution of CVM stages for males by chronologic age; **B,** distribution of CVM stages for females by chronologic age.

Descriptive data of the study sample are presented in Figures 1 through 3. Detailed distributions of CVM stages for both sexes by chronologic age are represented in Figure 1. Distributions of the peak of the growth spurt in maxillary and mandibular body lengths relative to the corresponding annual age intervals are shown in Figure 2 and also relative to the CVM stage intervals in Figure 3. For the chronologic age at which each of the 6 CVM stages was detected in the male group (Fig 1, *A*), 13 subjects were in CVM2 at age 11 and 6 moved to CVM3 at age 12. By age 13, 13 subjects were in CVM3. In the female group (Fig 1, *B*), at age 10, all 12 subjects were in CVM2; only 4 were still in CVM2 at age 11, and the remaining 8 moved to CVM3. By age 12, 8 females were in CVM3, and 4 were in CVM4.

The diagnostic proportions of the CVM stage intervals CVM2-CVM3 and CVM3-CVM4 in locating the peak of the growth spurt in mandibular (Co-Pog) and maxillary (Co-A) lengths according to each annual age interval are summarized in Tables II and III, respectively. Excluding the interval between 9 and 10 years in females in which no peaks were seen, accuracy values of CVM2-CVM3 ranged from 0.07 to 0.86 for Co-Pog and from 0.07 to 0.93 for Co-A in males; in females, accuracy values ranged from 0.25 to 0.92 for Co-Pog and from 0.25 to 0.75 for Co-A. Accuracy values of CVM3-CVM4 in identifying the growth spurt in males ranged from 0.36 to 1.0 for Co-Pog and from 0.29 to 1.0 for Co-A. In females, accuracy values ranged from 0.33 to 1.0 for both Co-Pog and Co-A. Accuracy values of CVM4-CVM5 ranged from 0.21 to 0.93 for Co-Pog and from 0.14-0.93 for Co-A in males; in females, accuracy values ranged from 0.17 to 1.0 for Co-Pog and from 0.33 to 1.0 for Co-A (Table IV).

The multilevel logistic regression for prediction of the presence or absence of the peak of the pubertal growth spurt in Co-Pog yielded odds ratios of 19.59 and 0.054 and *P* values of 0.006 and 0.10 for CVM2-CVM3 and CVM4-CVM5, respectively. For Co-A, the odds ratio was 5.034, and the *P* value was 0.019 for CVM2-CVM3. *P* values for the other predictors, whether for Co-Pog or Co-A, were greater than 0.05.

## DISCUSSION

The difference in the age range between the sexes in the sample in this study was based on the known time variability in their growth patterns. Advanced skeletal maturation in females compared with males, especially at the beginning and peak of the pubertal growth spurt,

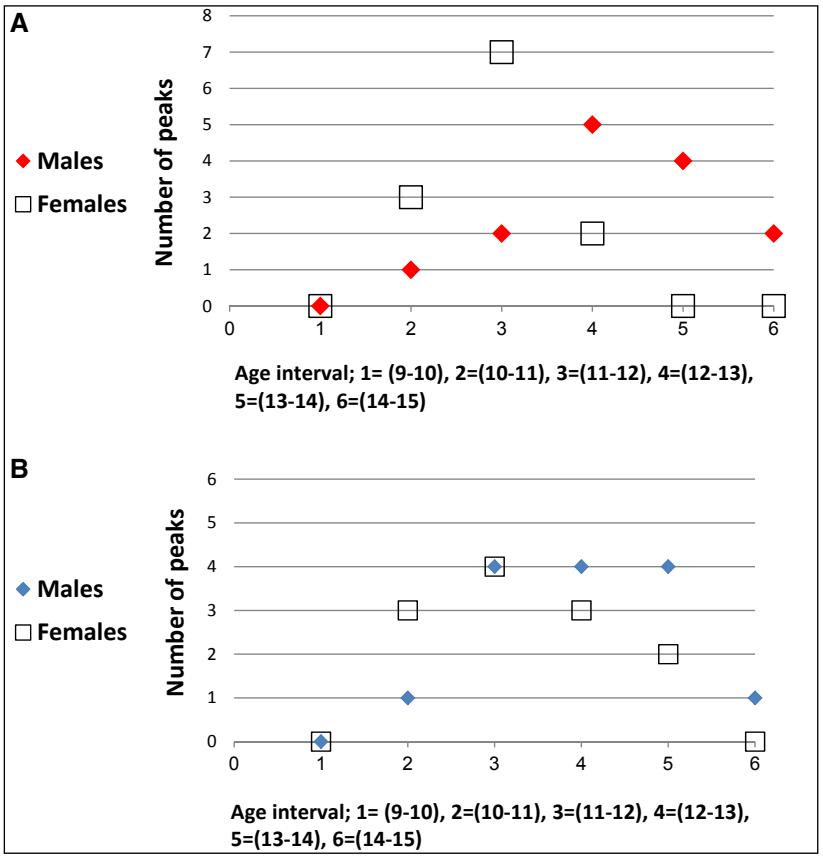


**Fig 2. A,** Distribution of the peak of the growth spurt for Co-Pog according to the annual intervals; **B,** distribution of the peak of the growth spurt for Co-A according to the annual intervals.

has been proven.[35,36] The selected age ranges were wide enough to ensure including the growth peak in the range. However, the results showed that each CVM stage was seen in the cephalographs at different chronologic ages (Fig 1). Also, the peaks of the Co-Pog and Co-A growth spurts were distributed over a wide range of chronologic age intervals (Fig 2). This makes it unreliable to depend on chronologic age to assess a patient's skeletal growth situation as suggested by Gray et al,[25] who preferred chronologic age as the indicator of the peak of mandibular growth over the CVM method.

Studying the normal is a logical first step before studying the variations or the deviations from normal. Many previous studies have pooled the different classes of malocclusion and the 2 sexes in the statistical analyses.[23,26,27] Perinetti et al[23] criticized the design of the study of Engel et al[32] to evaluate the predictability of the maximum rate of the maxillary and mandibular lengths in females with Class II malocclusion. Although Engel et al attributed their results to the poor reproducibility of the CVM method, Perinetti et al attributed the results to 2 factors; one was selecting Class II females whose minimal mandibular growth was expected. These different opinions support the proposed need to study the growth spurt in each class of malocclusion separately. Selecting only Class I subjects for this study made a homogenous sample that was advantageous compared with including different classes of malocclusion in 1 sample. Also, statistical analyses were done separately for each sex group.

The subjects in this study were not evaluated regarding growth type. A study on the effect of different growth types in Class I subjects on the timing and rate of the peak mandibular growth found that the timing and rate of peak mandibular growth did not differ between vertical, average, and horizontal types of growth.[37] The growth spurts of mandibular length has been documented in several studies that were done on Class II, Class III, and pooled subjects without certain malocclusion classifications, but similar spurts in the maxillary growth were controversial.[18,38,39] Others challenged

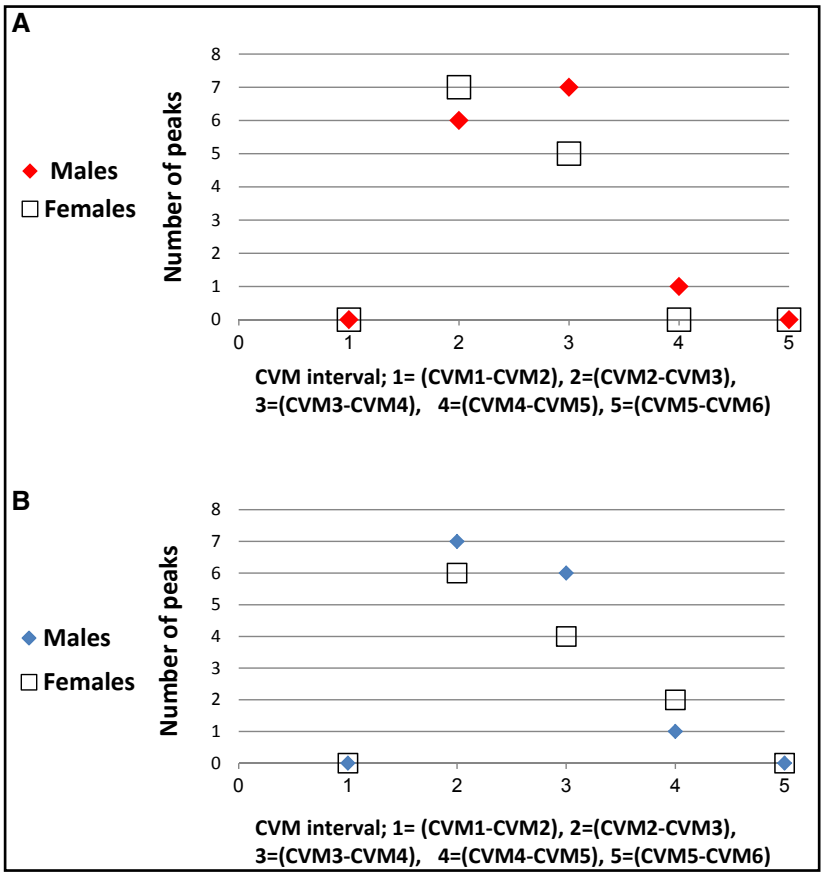


**Fig 3. A,** Distribution of the peak of the growth spurt for Co-Pog according to the CVM intervals; **B,** distribution of the peak of the growth spurt for Co-A according to the CVM intervals.

the hypothesis of the anteroposterior growth spurt whether in the maxilla or the mandible.[40] In this study, we found a high coincidence in the occurrence of the peaks of mandibular (Co-Pog) and maxillary (Co-A) lengths; this means that the peaks occurred during the same growth interval in all subjects, except for 1 subject in the male group and 2 subjects in the female group. The largest annual increase in the maxillary or mandibular length was at the peak of the growth spurt for the corresponding jaw.

Authors of a previous study found the greatest increment of mandibular growth during the CVM3-CVM4 interval.[23] Not only that, but another study reported a significant decline in the growth rate during the interval of CVM4-CVM5.[18] From the proportions calculated in this study, the positive predictive value measuring the proportion of the true positive to total positive results gives especially valuable information because it indicates the possibility that a subject showing the growth peak is really in this stage.[23] In this study, we studied the growth spurt according to 3 CVM intervals: CVM2-CVM3, CVM3-CVM4, and CVM4-CVM5. The distribution of the overall positive predictive value showed that, in males, the most peaks for Co-Pog were detected in the CVM3-CVM4 interval in 7 subjects of the 14 (50%). In females, the most peaks were found in the CVM2-CVM3 interval in 7 subjects of the 12 (58%). For both sexes, the most peaks for Co-A were seen in the CVM2-CVM3 interval in 7 males of the 14 (50%) and in 6 females of the 12 (50%). On total, CVM3 was present during the peak of Co-Pog growth spurt in all 12 females and in 10 females during the Co-A growth peak, whereas it was found in 13 males during the peak of Co-Pog and also the Co-A growth spurt. This distribution showed that CVM3 almost always was involved in the peak of the growth spurt at either the CVM2-CVM3 or the CVM3-CVM4 interval. One male had the peaks of Co-Po and Co-A during CVM4-CVM5, and 2 females had the peak of Co-A during CVM4-CVM5.

Although different methods of CVM assessment have divided the skeletal maturation spurt into a number of stages, there are no sharp or abrupt changes in the

**Table II.** Diagnostic reliability of CVM2-CVM3 in predicting mandibular and maxillary growth peaks according to annual age intervals from 10-15 years in males and 9-14 year in females

| *Age interval* | *(10-11)* | *(11-12)* | *(12-13)* | *(13-14)* | *(14-15)* |
|---|---|---|---|---|---|
| Males (CVM2-CVM3) | | | | | |
| Co-Pog | | | | | |
| Sensitivity | 1.0 | 1.0 | 0.80 | 0.0 | 0.0 |
| Specificity | 0.0 | 0.0 | 0.0 | 0.80 | 1.0 |
| PPV | 0.07 | 0.14 | 0.31 | 0.0 | - |
| NPV | - | - | 0.0 | 0.67 | 0.86 |
| Accuracy | 0.07 | 0.14 | 0.29 | 0.57 | 0.86 |
| Peaks (n) | 1 | 2 | 5 | 4 | 2 |
| Co-A | | | | | |
| Sensitivity | 1.0 | 1.0 | 0.75 | 0.0 | 0.0 |
| Specificity | 0.0 | 0.0 | 0.0 | 0.80 | 1.0 |
| PPV | 0.07 | 0.29 | 0.23 | 0.0 | - |
| NPV | - | - | 0.0 | 0.67 | 0.93 |
| Accuracy | 0.07 | 0.29 | 0.21 | 0.57 | 0.93 |
| Peaks (n) | 1 | 4 | 4 | 4 | 1 |
| Age interval | (9-10) | (10-11) | (11-12) | (12-13) | (13-14) |
| Females (CVM2-CVM3) | | | | | |
| Co-Pog | | | | | |
| Sensitivity | - | 1.00 | 0.71 | 0.0 | - |
| Specificity | 0.0 | 0.0 | 0.40 | 0.60 | 0.92 |
| PPV | 0.0 | 0.25 | 0.63 | 0.0 | 0.0 |
| NPV | - | - | 0.50 | 0.75 | 1.00 |
| Accuracy | 0.0 | 0.25 | 0.58 | 0.50 | 0.92 |
| Peaks (n) | 0 | 3 | 7 | 2 | 0 |
| Co-A | | | | | |
| Sensitivity | - | 1.0 | 1.0 | 0.0 | 0.0 |
| Specificity | 0.0 | 0.0 | 0.50 | 0.56 | 0.90 |
| PPV | 0.0 | 0.25 | 0.50 | 0.0 | 0.0 |
| NPV | - | - | 1.0 | 0.63 | 0.82 |
| Accuracy | 0.0 | 0.25 | 0.67 | 0.42 | 0.75 |
| Peaks (n) | 0 | 3 | 4 | 3 | 2 |

*PPV*, Positive predictive value; *NPV*, negative predictive value.

**Table III.** Diagnostic reliability of CVM3-CVM4 in predicting mandibular and maxillary growth peaks according to annual age intervals from 10-15 years in males and 9-14 years in females

| *Age interval* | *(10-11)* | *(11-12)* | *(12-13)* | *(13-14)* | *(14-15)* |
|---|---|---|---|---|---|
| Males (CVM3-CVM4) | | | | | |
| Co-Pog | | | | | |
| Sensitivity | 1.0 | 1.0 | 1.0 | 1.0 | 0.50 |
| Specificity | 1.0 | 0.67 | 0.0 | 0.10 | 0.75 |
| PPV | 1.0 | 0.33 | 0.36 | 0.31 | 0.25 |
| NPV | 1.0 | 1.0 | - | 1.0 | 0.90 |
| Accuracy | 1.0 | 0.71 | 0.36 | 0.36 | 0.71 |
| Peaks (n) | 1 | 2 | 5 | 4 | 2 |
| Co-A | | | | | |
| Sensitivity | 1.0 | 0.75 | 1.0 | 1.0 | 0.0 |
| Specificity | 1.0 | 0.70 | 0.0 | 0.10 | 0.69 |
| PPV | 1.0 | 0.50 | 0.29 | 0.31 | 0.0 |
| NPV | 1.0 | 0.88 | - | 1.0 | 0.90 |
| Accuracy | 1.0 | 0.71 | 0.29 | 0.36 | 0.64 |
| Peaks (n) | 1 | 4 | 4 | 4 | 1 |
| Age interval | (9-10) | (10-11) | (11-12) | (12-13) | (13-14) |
| Females (CVM3-CVM4) | | | | | |
| Co-Pog | | | | | |
| Sensitivity | - | 1.0 | 1.0 | 1.0 | - |
| Specificity | 1.0 | 0.44 | 0.0 | 0.20 | 0.42 |
| PPV | - | 0.38 | 0.58 | 0.20 | 0.0 |
| NPV | 1.0 | 1.0 | - | 1.0 | 1.0 |
| Accuracy | 1.0 | 0.58 | 0.58 | 0.33 | 0.42 |
| Peaks (n) | 0 | 3 | 7 | 2 | 0 |
| Co-A | | | | | |
| Sensitivity | - | 1.0 | 1.0 | 1.0 | 0.50 |
| Specificity | 1.0 | 0.44 | 0.0 | 0.22 | 0.40 |
| PPV | - | 0.38 | 0.33 | 0.30 | 0.14 |
| NPV | 1.0 | 1.0 | - | 1.0 | 0.80 |
| Accuracy | 1.0 | 0.58 | 0.33 | 0.42 | 0.42 |
| Peaks (n) | 0 | 3 | 4 | 3 | 2 |

*PPV*, Positive predictive value; *NPV*, negative predictive value.

continuum of the morphologic and dimensional stages. For example, Baccetti et al[26,27] specifically marked the appearance of a visible concavity at the lower border of CV3 as an important change. The appearance of the concavity was considered as the 1 anatomic characteristic that could be used as a marker of the stage immediately preceding the peak in mandibular growth. Gray et al[25] suggested that the CVM method could identify patients who had passed the growth peak, but not those who had not entered it yet. They made suggestions, although they found the difference between the shapes of the cervical vertebrae detectable during and after the mandibular growth peak. After the peak, the vertebrae showed a distinct concavity of the lower border and were clearly square in shape.

In this study, the general trends for both sexes showed that the sensitivity of CVM2-CVM3 was higher in identifying the growth peak of mandibular (Co-Pog) and maxillary (Co-A) lengths in the younger ages, whereas the sensitivity of CVM4-CVM5 was higher in the older ages. The sensitivity of CVM3-CVM4 was high in all intervals in both sexes except the interval between 14 and 15 years. On the other hand, the specificity of CVM2-CVM3 was higher for the older ages. The specificity of CVM4-CVM5 was higher for the younger ages in both sexes. The specificity of CVM3-CVM4 was higher for the younger and older age intervals in both males and females. These trends show the validity of the CVM method in predicting the pubertal growth spurt.

The multilevel logistic regression analysis results aligned with those from the diagnostic reliability analysis. Multilevel logistic regression analysis showed CVM2-CVM3 as an independent predictor for the peak of the growth spurt for both Co-Pog and Co-A. For

**Table IV.** Diagnostic reliability of CVM4-CVM5 in predicting mandibular and maxillary growth peaks according to annual age intervals from 10-15 year in males and 9-14 years in females

| *Age interval* | *(10-11)* | *(11-12)* | *(12-13)* | *(13-14)* | *(14-15)* |
|---|---|---|---|---|---|
| Males (CVM4-CVM5) | | | | | |
| Co-Pog | | | | | |
| Sensitivity | 0.0 | 0.0 | 0.20 | 1.0 | 1.0 |
| Specificity | 1.0 | 1.0 | 1.0 | 0.20 | 0.08 |
| PPV | - | - | 1.0 | 0.33 | 0.15 |
| NPV | 0.93 | 0.86 | 0.69 | 1.0 | 1.0 |
| Accuracy | 0.93 | 0.86 | 0.71 | 0.43 | 0.21 |
| Peaks (n) | 1 | 2 | 5 | 4 | 2 |
| Co-A | | | | | |
| Sensitivity | 0 | 0 | 0.25 | 1.0 | 1.0 |
| Specificity | 1.0 | 1.0 | 1.0 | 0.20 | 0.08 |
| PPV | - | - | 1.0 | 0.33 | 0.08 |
| NPV | 0.93 | 0.71 | 0.77 | 1.0 | 1.0 |
| Accuracy | 0.93 | 0.71 | 0.79 | 0.43 | 0.14 |
| Peaks (n) | 1 | 4 | 4 | 4 | 1 |
| Age interval | (9-10) | (10-11) | (11-12) | (12-13) | (13-14) |
| Females (CVM4-CVM5) | | | | | |
| Co-Pog | | | | | |
| Sensitivity | - | 0.0 | 0.29 | 1.0 | - |
| Specificity | 1.0 | 1.0 | 0.60 | 0.40 | 0.17 |
| PPV | - | - | 0.50 | 0.25 | 0.0 |
| NPV | 1.0 | 0.75 | 0.38 | 1.0 | 1.0 |
| Accuracy | 1.0 | 0.75 | 0.42 | 0.50 | 0.17 |
| Peaks (n) | 0 | 3 | 7 | 2 | 0 |
| Co-A | | | | | |
| Sensitivity | - | 0.0 | 0.0 | 1.0 | 1.0 |
| Specificity | 1.0 | 1.0 | 0.50 | 0.44 | 0.20 |
| PPV | - | - | 0.0 | 0.38 | 0.20 |
| NPV | 1.0 | 0.75 | 0.50 | 1.0 | 1.0 |
| Accuracy | 1.0 | 0.75 | 0.33 | 0.58 | 0.33 |
| Peaks (n) | 0 | 3 | 4 | 3 | 2 |

*PPV*, Positive predictive value; *NPV*, negative predictive value.

Co-A, CVM4-CVM5 could be a predictor for absence of the peak of growth spurt.

Based on the CVM method used in this study, CVM2 showed developing concavity in the lower border of CV3, and CVM3 showed marked concavity in the lower border of CV3 and a developing concavity in the lower border of CV4.[11] From these results, a suggested standardized method to assess the growth status from a lateral cephalometric image would be to start by spotting CVM3; if present. this would mean that the subject is in the peak of the growth spurt. If the subject is still in CVM2, this would mean that he or she is not in the peak yet; then it would be reasonable to also assess the shapes of CV3 and CV4, since as the shapes change from trapezoid to horizontal rectangular with the transition from CVM2 to CVM3. The shapes of CV3 and CV4, whether trapezoid or rectangular, would indicate whether the subject is in the early CVM2 or is about to be in CVM3.

Since this was a longitudinal study, it has an element of strength that cannot be ignored. The homogeneity of the sample added to the strength element; homogeneity decreases variations found in heterogeneous samples. Therefore, because the sample was not large, homogeneity made this not as critical as it would have been if the sample was not homogeneous. These results contribute to the understanding of skeletal growth maturation and the craniofacial growth spurt. These results are also be useful for comparison with results of other studies of Class II and Class III subjects with deviated skeletal growth when the sample is also derived from historical growth studies. These applications are important for orthodontic clinicians and researchers. However, applying these results to children seeking orthodontic treatment now should be done carefully for severa; reasons, among them the secular trends in the skeletal maturation pattern. There is some evidence of secular trends in the skeletal maturation pattern.[41,42]

## CONCLUSIONS

In Class I subjects with a balanced anteroposterior jaw relationship, the high inclusion of CVM3 in the peak of Co-Pog and Co-A pubertal growth spurts suggests that CVM3 would indicate the peak of the growth spurt. CVM2 would mean that the peak is not yet present. In this case, it would be reasonable to also assess the shapes of the CV3 and CV4; the shapes, whether trapezoid or horizontal rectangular, would indicate whether the subject is in the early CVM2 or is about to be in CVM3.

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