Original Article

Predicting the mandibular growth spurt:
The roles of chronological age, sex, and the cervical vertebral maturation method

Lorenzo Franchi[a]; Michele Nieri[b]; Irene Lomonaco[c]; James A. McNamara Jr.[d]; Veronica Giuntini[e]

ABSTRACT

Objectives: To develop a prediction model that combined information derived from chronological age, sex, and the cervical vertebral maturation (CVM) method to predict the pubertal spurt in mandibular growth.

Materials and Methods: A total of 50 subjects (29 females, 21 males) were selected from the American Association of Orthodontists Foundation Craniofacial Growth Legacy Collection, the University of Michigan Growth Study, and the Denver Child Growth study. A total of 456 lateral cephalograms were analyzed, and a multilevel logistic model was applied. The outcome variable was the presence or absence of the mandibular pubertal growth peak. The predictive variables were chronological age up to the third order, sex, presence or absence of CS 3 interactions between age and sex, age and CS 3, sex and CS 3.

Results: The mean age ± standard deviation (SD) at the first cephalogram was 8.2 ± 0.5 years, whereas the mean age at the last cephalogram was 16.5 ± 1.1 years. The mean interval ± SD between two consecutive cephalograms was 1.0 ± 0.1 years. The mean age ± SD at the lateral cephalogram obtained immediately before the mandibular pubertal growth peak was 12.1 ± 1.1 years for females and 13.2 ± 0.8 years for males. The greatest increase in mandibular length occurred after CS 3 in 78% of the subjects. The presence of CS 3, age, second-order age, sex, and the interaction between age and sex were all statistically significant predictors of the mandibular pubertal growth spurt.

Conclusions: CS 3, chronological age, and sex can be used jointly to predict the pubertal peak in mandibular growth. (*Angle Orthod.* 2021;91:307–312.)

KEY WORDS: Cephalometrics; CVM method; Mandibular growth spurt

INTRODUCTION

Several indicators of individual skeletal maturity have been proposed over the years to define treatment timing in orthodontics. The easiest indicator to record is the chronological age of the patient. Some investigators have reported that chronological age can be regarded as a reliable predictor for the adolescent growth spurt.[1,2] The estimation of the pubertal peak, however, should not be based solely on chronological age because the peak is also influenced by many factors such as secular trend, genetic factors (mediated by environmental factors), and weight (nutritional

[a] Associate Professor, Department of Experimental and Clinical Medicine, Orthodontics, The University of Florence, Florence, Italy; and Thomas M. Graber Visiting Scholar, Department of Orthodontics and Pediatric Dentistry, School of Dentistry, The University of Michigan, Ann Arbor, Mich, USA.

[b] Research Fellow, Department of Experimental and Clinical Medicine, Orthodontics, The University of Florence, Florence, Italy.

[c] Student, Annual Continuing Education Course, Department of Experimental and Clinical Medicine, Orthodontics, The University of Florence, Florence, Italy.

[d] Thomas M. and Doris Graber Endowed Professor of Dentistry Emeritus, Department of Orthodontics and Pediatric Dentistry, School of Dentistry; Professor Emeritus of Cell and Developmental Biology, School of Medicine; and Research Scientist Emeritus, Center for Human Growth and Development, The University of Michigan, Ann Arbor, Mich, USA; and Private Practice, Ann Arbor, Mich, USA.

[e] Assistant Professor, Department of Experimental and Clinical Medicine, Orthodontics, The University of Florence, Florence, Italy.

Corresponding author: Dr James A. McNamara Jr., Department of Orthodontics and Pediatric Dentistry, The University of Michigan, Ann Arbor, Michigan, USA
(e-mail: mcnamara@umich.edu)

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status).[2] The most commonly used indicators of individual skeletal maturity are increase in height,[1,3] skeletal maturation of the hand and wrist,[4,5] and the cervical vertebral maturation (CVM) method.[6–8]

Several studies have demonstrated that the CVM method can detect the pubertal peak in a reliable way,[9–14] whereas other investigations have found that the CVM method is not a reliable method to identify the adolescent growth spurt.[1,15–18] Only the studies by Morris and colleagues[18] and by Montasser[19] have investigated the role of chronological age, sex, and CVM in predicting the pubertal peak in mandibular growth by using a multilevel logistic regression analysis. The CVM method used in study of Morris et al.[18] was an older version that was based on five vertebrae as described by Franchi et al. in 2000.[10] Currently, the CVM method evaluating five vertebrae is not the most commonly used method in clinical practice.[8]

Thus, the aims of the present study were to evaluate the relationship between cervical stage and the peak in mandibular growth and to develop a predictive model that combines the information derived from chronological age, sex, and the CVM method evaluating three vertebrae[7–8] to predict the pubertal spurt in mandibular growth.

MATERIALS AND METHODS

The Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis statement[20] was followed.

Subjects were selected from the records of the Fels, Iowa, Mathews, and Oregon Growth Studies that were available through the American Association of Orthodontists Foundation (AAOF) Craniofacial Growth Legacy Collection Project (www.aaoflegacycollection.org). In addition, the complete records of the University of Michigan Growth Study (after having removed the 30 subjects that were used in the previous study by Baccetti et al.[7]) and of the Denver Child Growth study were screened.

Inclusion criteria were availability of a series of at least six consecutive annual lateral cephalograms from the age of 7 years to 18 years; the bodies of the second, third, and fourth vertebrae had to be visible in all films; the interval between two consecutive cephalograms had to range from a minimum of 6 months to a maximum of 18 months; the first cephalogram of the series had to show CVM stages 1 or 2;[7,8] and the last cephalogram of the series had to show at least CVM stage 5.[7,8] Exclusion criteria were incomplete records, radiographs of poor quality, anomalies in vertebral morphology, and evident orthodontic treatment (with the exception of space maintainers).

Total mandibular length (the linear distance from Condylion to anatomical Gnathion [Co-Gn]) was measured on all cephalograms by the same examiner on the digital cephalograms using cephalometric software (Viewbox 4.0, dHal Software, Kifissia, Athens, Greece). The value of Co-Gn was standardized to 0% enlargement (life size) after adjustment of the magnification factor of the different growth studies.

The increases in Co-Gn between consecutive cephalograms taken annually were calculated for the entire series of cephalograms for each subject. Because the intervals between consecutive cephalograms were not always 12 months in duration, the increases in Co-Gn were annualized. “Mandibular pubertal growth peak” was defined as the greatest increase in the annualized value of Co-Gn between consecutive cephalograms.

The CVM method used in the present study was the one described by McNamara and Franchi.[8] The intermediate or in-between stages (when the characteristics of two consecutive stages were present in a single image)[8] were included in the more immature stage, that is, the intermediate CS 3–4 was classified as CS 3. All cephalograms were staged according to the CVM method by a single expert examiner. All subjects from the growth studies who met all inclusion/exclusion criteria were included in this study.

Statistical Analysis

Intraexaminer reproducibility for the CVM stages and for the Co-Gn measurement was calculated on 30 randomly selected cephalograms after a 2-week washout period with the weighted κ coefficient for ordinal data and with the intraclass correlation coefficient, respectively (MedCalc, version 19.0.3, MedCalc Software bvba, Ostend, Belgium). Random error for the Co-Gn measurement was assessed with Dahlberg’s formula.

As for inferential statistics, a multilevel logistic model with two levels (“subject” and “cephalogram”) was applied. The outcome variable was the presence or absence of the pubertal peak in mandibular growth. The predictive variables were chronological age up to the third order (or cubic term, indicating the presence of inflection point in the curve; in general, the higher the order, the more complex the curve), sex, presence or absence of CS 3, interactions between age and sex, age and CS 3, sex and CS 3. The interactions and age from second order were included in the model only if they were statistically significant (MLwiN, version 2.26, University of Bristol, Bristol, UK).

Sensitivity, specificity, and accuracy were calculated considering the highest probability of obtaining the mandibular growth peak in each subject as derived from the multilevel logistic model (JMP version 13.0.0, SAS Institute Inc, Cary, N.C., USA).

RESULTS

From a parent sample of 1151 subjects, a final sample of 50 subjects (29 females and 21 males) was selected. Six cases (5 females and 1 male) were derived from the Fels Growth Study, 2 (1 female and 1 male) from the Iowa Growth Study, 3 (1 female and 2 males) from the Mathews Growth Study, 24 (15 females and 9 males) from the Oregon Growth Study, 3 (1 female and 2 males) from the Denver Growth Study, and 12 (6 females and 6 males) from the University of Michigan Growth Study.

The intraobserver reproducibility for the CVM method and for the Co-Gn measurement was "almost perfect"[21] (CVM method: 0.87 [95% confidence interval, CI, 0.77–0.96]; Co-Gn: 0.99 [95% CI. 0.99–1.00]). The random error for the Co-Gn measurement was 0.57 mm.

A total of 456 lateral cephalograms were analyzed. All quantitative data are expressed as mean ± standard deviation. The mean number of cephalograms per subject was 9.1 ± 1.2 (minimum 6 and maximum 12 cephalograms). In Table 1, the frequencies of the different CVM stages and the corresponding percentages are reported. The mean age at the first cephalogram was 8.2 ± 0.5 years (minimum 7.5, maximum 9.9 years), whereas the mean age at the last cephalogram was 16.5 ± 1.1 years (minimum 14.0, maximum 20.2 years). The mean interval between two consecutive cephalograms was 1.0 ± 0.1 years (minimum 0.75, maximum 1.49).

The annualized mandibular pubertal growth peak of Co-Gn was 4.5 ± 1.2 mm for females and 5.7 ± 1.3 mm for males. The mean age at the lateral cephalogram immediately before the mandibular pubertal growth peak was 12.1 ± 1.1 years for females and 13.2 ± 0.8 years for males. Table 2 reports the frequencies and percentages of the CVM stages on the lateral cephalogram immediately before the mandibular pubertal growth peak. Interestingly, the greatest increase in mandibular length occurred after CS 3 in 78% of the cases.

As for inferential statistics (Table 3), the presence of CS 3, age, second-order age, and sex were all statistically significant. Only the interaction between age and sex was statistically significant. All other interactions were not significant, and therefore they were not included in the final model. The third-order age also was not included in the model because it was not statistically significant.

The logistic model is reported in both Table 3 and Figure 1.

Table 1. Frequencies and Percentages of the CVM Stages

CVM Stage	Frequency	Percentage
CS 1	140	31
CS 2	62	14
CS 3	86	19
CS 4	57	12
CS 5	72	16
CS 6	39	8
Total	456	100

The predictive equation for male subjects at CS 3 was the following:

$$P = \frac{1}{1 + e^{-(-66.575+2.253+10.609age-0.435age\text{^}2-11.151+0.885age)}}*100$$

The predictive equation for male subjects presenting with a CVM stage different from CS 3 was the following:

$$P = \frac{1}{1 + e^{-(-66.575+10.609age-0.435age\text{^}2-11.151+0.885age)}}*100$$

The predictive equation for female subjects at CS 3 was the following:

$$P = \frac{1}{1 + e^{-(-66.575+2.253+10.609age-0.435age\text{^}2)}}*100$$

The predictive equation for female subjects presenting with a CVM stage different from CS 3 was the following:

$$P = \frac{1}{1 + e^{-(-66.575+10.609age-0.435age\text{^}2)}}*100$$

From Figure 1 and the previous equations, it can be derived that the highest probability of having the mandibular growth peak was reached for female subjects with CS 3 at 12.2 years, and it was equal to 59%. For male subjects with CS 3 the highest probability of having the mandibular growth peak was 61% at 13.2 years. In addition, the probability of having the mandibular growth peak was greater than 50% in female subjects with CS 3 between 11.3 and 13.1 years and in male subjects with CS 3 between 12.2 and 14.2 years.

The sensitivity (62%) of the model was calculated as the number of mandibular growth peaks predicted correctly by the logistic multilevel regression (31) out of the number of actual mandibular growth peaks (50). The specificity (95%) was calculated as the number of observations in which the model did not identify the mandibular growth peak (337) out of the total number of observations without the mandibular growth peak (356). The accuracy (91%) was calculated as the observations predicted correctly by the model (368) out of the total number of observations (406).

Table 2. Frequencies and Percentages of the CVM Stages on the Lateral Cephalogram Immediately Before the Mandibular Pubertal Growth Peak

CVM Stage	Frequency	Percentage
CS 1	4	8
CS 2	3	6
CS 3	39	78
CS 4	4	8
CS 5	0	0
CS 6	0	0
Total	50	100

DISCUSSION

The results of the present study showed that the pubertal peak in mandibular length occurred after CS 3 in 78% of the cases. This meant that, in more than 3/4 of the subjects, the mandibular pubertal growth spurt could be expected in the year after CS 3.

As a peculiar feature of this study, chronological age was entered in the predictive model as a curvilinear variable (polynomial curve up to the third order or degree). This feature was a very important aspect when analyzing the peak in mandibular growth as a function of age. As a matter of fact, if age was entered as a linear variable, the probability of having the mandibular growth peak would increase or decrease linearly along with age. However, mandibular growth was not linear along with age but rather followed a curvilinear (nonlinear) trend that was characterized, particularly during adolescence, by an acceleration that reached a peak that was followed by a deceleration until the end of active growth.[22,23]

The results of the present study were not comparable with those by Engel et al.[15] and Gray et al.,[16] who applied a linear mixed model analysis to identify mandibular length. In the present study, a logistic regression model to detect the presence or absence of the mandibular growth peak was applied. The regression equations found by Engel et al.[15] and Gray et al,[16] therefore, allowed calculation of either mandibular length or the change in mandibular length, which has limited clinical value. The regression equation that was found in the present study allows calculating the probability of having the mandibular pubertal growth peak in the subsequent year, which can be useful clinically. In addition, these previous investigations[15,16] were characterized by relatively small sample sizes (29[15] and 25[16] subjects).

The most appropriate statistical approach that appears to answer this question is a multilevel logistic regression model in which the outcome variable is the presence or absence of the pubertal growth spurt (measured as the greatest annual increase in the length Co-Gn), and the predictive variables were presence or absence of CS 3, sex, chronological age at each film, and interactions among these variables. Only the studies of Morris et al.[18] and Montasser[19] applied this statistical approach. The CVM method that was used by Morris et al.,[18] however, was the version based on the evaluation method of the older five vertebrae.[10] Montasser used the CVM method proposed by Hassel and Farman.[6] In addition, these studies[18,19] used chronological age only as a linear predictive variable without considering that, after a given age, the probability of finding the pubertal peak should decrease.

The present study, therefore, was the first to apply a multilevel logistic model to investigate the role of chronological age (up to third order), sex, and CVM method on three cervical vertebrae for the prediction of the pubertal peak in mandibular growth. The limitations of the present study were the lack of validation of the prediction model and the fact that the same examiner evaluated both the increments in Co-Gn and the CVM stages. Unfortunately, it was not possible to validate the prediction model on a different sample because all eligible subjects available through the AAOF Craniofacial Growth Legacy Collection Project, the University of Michigan Growth Study, and of the Denver Child Growth study were included in this study. No other growth study was available.

Another limitation was the secular trend of the chronological age at which the pubertal growth spurt occurs. In general, the secular trend is toward the earlier onset of puberty with an earlier maturation of the mandible.[24,25] Therefore the results of the present study should be analyzed with caution because they were based on radiographs collected about 40 to 50 years

Table 3. Multilevel Logistic Model for the Prediction of the Mandibular Pubertal Growth Peak

Variable	Estimate	Standard Error	Odds Ratio	95% CI Odds Ratio	*P* Value
Constant (intercept)	−66.575	17.153			
CS 3	2.253	0.395	9.52	4.39–20.64	<.0001
Age	10.609	2.840			.0002
Age^2	−0.435	0.117			.0002
Sex	−11.151	5.533			.0439
Age × sex	0.885	0.434			.0414
σ_u^2	0.000	0.000			

σ_u^2 indicates variance.

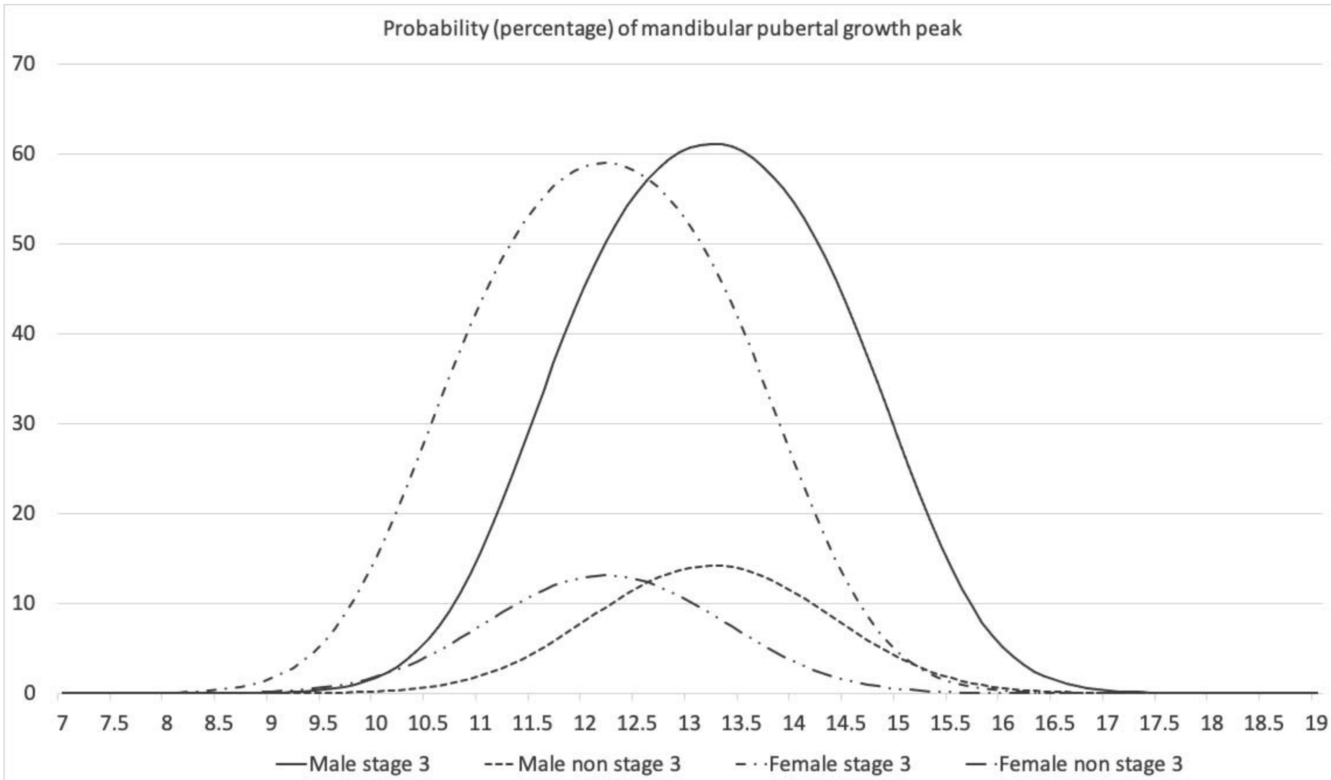

Figure 1. Graphic representation of the logistic model. This model depicts the probability of having the mandibular pubertal growth peak in the year following the lateral cephalogram (y-axis) as a function of chronological age (x-axis), sex, and CS 3. The dashed curve with single dots describes the mandibular peak probability for female subjects at CS 3. The dashed curve with double dots describes the mandibular peak probability for female subjects at a CVM stage different from CS 3. The continuous curve describes the mandibular peak probability for male subjects at CS 3. The dashed curve describes the mandibular peak probability for male subjects at a CVM stage different from CS 3.

ago. For ethical reasons it is impossible to collect a contemporary sample of untreated subjects with lateral cephalograms taken annually.

Interestingly, CS 3, chronological age, second-order age, sex, and the age × sex interaction were all significant predictors for the presence of the pubertal peak in mandibular growth. This result disagreed with that of Morris et al.,[18] who found that only chronological age was a significant predictor. This difference in results could be explained by the fact that Morris et al.[18] restricted their analysis only to the age groups from 10 through 14 years. In addition, as emphasized previously, they staged the vertebrae by using the CVM method on five vertebrae,[10] whereas the CVM method on three vertebrae was used in the current study.[7,8] On the contrary, Montasser[19] reported that presence of CS 3 would indicate the peak of the growth spurt.

Figure 1 can be used to assess the probability of having the mandibular pubertal growth peak in the year following the lateral cephalogram (y-axis) as a function of chronological age (x-axis), sex, and CS 3. The maximum probability of having the mandibular pubertal growth peak in the year following the lateral cephalogram for subjects at CS 3 was 12.2 years (59%) for females and 13.2 years (61%) for males. At the same age for non-CS 3 subjects, the probabilities of having the mandibular pubertal growth peak were only 13% and 14% for females and males, respectively. Therefore, it was confirmed that CS 3 can be a useful predictor for the mandibular growth peak. From a practical standpoint, if a female subject is between 11 and 13 years of age (considering the secular trend in the onset of the pubertal growth spurt)[24,25] and shows a CS 3 on the lateral cephalogram, she has a probability greater than 50% of having the mandibular pubertal peak during the following year. Similarly, a male subject between 12 and 14 years at CS 3 has a probability greater than 50% of showing the mandibular pubertal peak during the following year. During the same age interval, if the subject does not show a CS 3 stage, the probability of the mandibular pubertal peak occurring during the following year is only between 10% and 15%.

In the future, the addition of other predictors, such as the presence of secondary sexual characteristics or the age at menarche in females, could help in improving the predictive capabilities of the mandibular growth peak of CS 3 in CVM.

CONCLUSIONS

The present study showed the following:

- The greatest increase in mandibular length occurred after CS 3 in 78% of the subjects.
- CS 3, chronological age, and sex were significant predictors for the presence of the pubertal peak in mandibular growth.

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