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Cervical Vertebral Maturation Method for Comparing the Onset and Duration of Pubertal Growth Spurt Between Class I and II Subjects

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Objectives The present study aimed at evaluating the onset and duration of the pubertal growth spurt in skeletal class I and II individuals, utilizing the cervical vertebral maturation (CVM) method.
Methods A total of 132 Iranian individuals (class I=68, class II=64) were evaluated retrospectively in this cross-sectional study. The subjects were between 9 and 16 years old and had never undergone orthodontic treatment. The lateral cephalograms of the subjects were independently traced by two examiners to determine their skeletal class, employing Steiner and Wits analyses. Baccetti's CVM method was employed to assess skeletal maturation. The onset and duration of the pubertal growth spurt (CS3-CS4 interval) was analyzed among the two classes and genders using the independent samples t-Test. P-values less than 0.05 were considered statistically significant.
Results The duration of the pubertal growth spurt equaled 1.62 (±1.33) years in skeletal class I subjects and 1.34 (±1.21) years in skeletal class II subjects. The difference in duration between the two classes, with an average of 0.28 years (3.36 months), was statistically significant ($p<0.001$). The average onset age of growth spurt was estimated to be 11.91 (±1.32) years in class I subjects and 11.41 (±1.19) years in class II subjects, but this difference was insignificant ($p=0.110$). The onset and termination of the pubertal growth spurt occurred later by 1.49 years ($p<0.001$) and 1.27 years ($p<0.001$), respectively, in male subjects.
Conclusion Class I and II subjects had similar growth spurt onset ages, but class II spurt duration was shorter by 3.36 months. Females experienced longer and earlier growth spurts compared to males.
Keywords Age of Onset; Cephalometry; Cervical Vertebrae; Growth and Development; Puberty

Introduction

A critical factor for achieving the intended result in orthodontic treatment is the patient's remaining potential for growth. [1] Given the variability in the pace and quantity of human growth during distinct maturation stages, selecting an appropriate orthodontic treatment strategy at the right moment requires substantial expertise and knowledge. [2] Besides the two factors of pace and quantity, variations in the commencement age of growth spurt make the treatment planning more baffling since multiple factors, such as sex, ethnicity, etc., can affect this age. [3]

The patients' growth potential can be determined by analyzing several biological indicators, including their height, weight, characteristics of sexual maturation, dental development, and skeletal development. These markers have been extensively studied and utilized in clinical practice for years. [4-6] The stage of skeletal development is typically determined using two established methods: hand-wrist radiographs and the cervical vertebral maturation (CVM) method. Since its inception, hand-wrist radiography has proven to be an accurate and reliable diagnostic tool. However, additional radiographs other than the routine radiographs employed in orthodontics (e.g., panoramic and lateral cephalogram) must be taken for this purpose. The preliminary version of the CVM method, introduced by Lamparski in 1972, relied on the morphology of the second to sixth cervical vertebrae when viewed on a lateral cephalogram. [7] About three decades later, Baccetti presented an updated version of the CVM method, which estimated the skeletal maturation based on the morphology of the second, third, and fourth cervical vertebrae. Patients are divided into six groups, ranging from cervical stage 1 (CS1) to cervical stage 6 (CS6), based on this methodology. [8] As a result of the fact that the most significant amount of mandibular growth takes place between CS3 and CS4, this period is typically referred to as the pubertal growth spurt. [8]

Based on existing research, the beginning and length of the pubertal growth spurt differ among patients belonging to distinct skeletal classes. [9, 10] Consequently, the clinician must bear skeletal classification in mind throughout orthodontic and orthopedic treatment planning. According to Jeelany et al. [9], class II individuals undergo a briefer period of pubertal growth spurt compared to class I, although the onset age is comparable between them. In contrast, Ghaleb et al. [11] observed a longer duration of the growth spurt in class II subjects when compared to class I, yet the starting age remained similar.

Depending on the patient's growth stage, there are various treatment options for class II subjects, ranging from fixed to removable appliances. However, selecting the appropriate treatment modality becomes perplexing on the grounds that the growth potential of a person cannot be

exactly forecasted until after a considerable period of pubertal growth spurt has elapsed. As a consequence, recognizing the current growth stage of a subject and estimating the remaining portion of the growth spurt would assist clinicians in selecting the right treatment plan for class II patients. In other words, the class II patient's growth pattern can be altered if the treatment is initiated at the right time. [12, 13]

Due to the higher prevalence of skeletal classes I and II globally, analogous to the Iranian population, it is crucial to increase the knowledge and conduct more research on these two classes to achieve better results in practice. [14] Owing to the limited amount of research comparing pubertal growth spurt and skeletal classes with a focus on the Iranian population, this study explored the onset age and duration of the pubertal growth spurt in patients of skeletal classes I and II employing the CVM method in Iranian adolescents.

Methods and Materials

This retrospective observational study was conducted in 2021-2022 under the Helsinki Deceleration of Human Rights and the "Strengthening the Reporting of Observational Studies in Epidemiology" (STROBE) guidelines. The sample was selected by examining 897 digital lateral cephalograms available in the Department of Orthodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran. The present study received approval from the Ethics Committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.DRC.REC.1400.061), and all subjects' parents or caregivers signed a consent form permitting examiners to use their radiographs in the research. The confidence level and power of the study were set at 95% and 80%, respectively. These values were used in Equation 1 to determine the sample size. The study by Jeelani et al. [9] served as the source of the statistical parameters, including the mean and standard deviation, utilized in the present study to calculate the minimum required sample size of each study group. The computations yielded 68 subjects for class I (34 females and 34 males) and 64 for class II (32 females and 32 males).

$$n = \frac{(\delta_1^2 + \delta_2^2).(Z_{1-\alpha/2} + Z_{1-\beta})^2}{(M_1 - M_2)^2}$$

The subjects were included according to these criteria:

- High-resolution lateral cephalograms where the C2, C3, and C4 vertebrae could be distinctly traced.
- Iranian ethnicity
- Age within the range of 9 to 16 years old
- Without previous orthodontic treatment
- No history of congenital tooth missing or extractions
- Without any systemic diseases affecting the body development
- Normal vertical relation of the jaws (Jarabak's ratio of 62% to 65% and sum of posterior angles equal to 396°). [15]
- Within the CVM stage of CS3 or CS4

The exclusion criteria were:

- Presence of craniofacial anomalies
- Presence of cleft lip/palate

Two expert examiners (one pediatric dentistry resident and one general dentist) manually assessed each subject's CVM stage and skeletal classification. Baccetti's method was used for the CVM staging [8], while Steiner and Wits analyses were used for the skeletal classification. [16] A subject's ANB angle classification as either class I or class II depended on the measurement falling within a range of 2 ± 2°. If the ANB angle was greater than 4°, it was categorized as class II. If Steiner's analysis had a high probability of erroneous judgment, the Wits analysis came into play. Points A and B were used as starting points to draw two perpendicular lines that intersected with the occlusal plane at points A' and B', respectively. A class I relationship was indicated when the A'-B' distance fell within the range of 1±1 mm. On the other hand, a class II relationship was identified when the distance exceeded 2 mm. [17] Each examiner double-assessed the lateral cephalograms in random order with a one-week interval. In each cephalogram, the dentition and age were hidden, requiring examiners to rely merely on cervical vertebrae to probe skeletal maturation. In the event of any disagreement, resolutions were reached through discussions between examiners or by seeking advice from an orthodontist. If the lower borders of the C2 and C3 vertebrae exhibit a concave shape, while the C3 and C4 vertebrae appear trapezoidal or as horizontal rectangles, the individual is categorized as being in the CS3 stage, which marks the beginning of the pubertal growth spurt. Similarly, if the concavity is visible on the lower border of all three vertebrae, along with the C3 and C4 vertebrae appearing as horizontal rectangles, the individual is classified as being in the CS4 stage, which represents the termination of the spurt. [8] (Figure 1)

A total of 132 subjects, belonging to classes I and II, fulfilled the specified inclusion and exclusion criteria. The subjects were evenly distributed with regard to CVM stages (CS3 and CS4) and genders simultaneously (Table 1).

Statistical Analysis

The intra- and inter-examiner reliability were assessed using Cohen's kappa coefficient and raw agreement. The one-sample Kolmogorov-Smirnov test was employed to determine whether the data followed a normal distribution. Levene's test was conducted to examine the equality of variances. A confidence interval of 95% was applied, and a P-value of less than 0.05 was considered to indicate statistical significance. Once it was confirmed that the data exhibited a normal distribution, the independent samples t-

Test was selected to compare the pubertal growth spurt length (CS3-CS4 interval) and the average ages of participants at stages CS3 and CS4. The inter-gender comparison was made through the same test. The SPSS version 21 (IBM Corp., Armonk, NY) was used for the analyses.

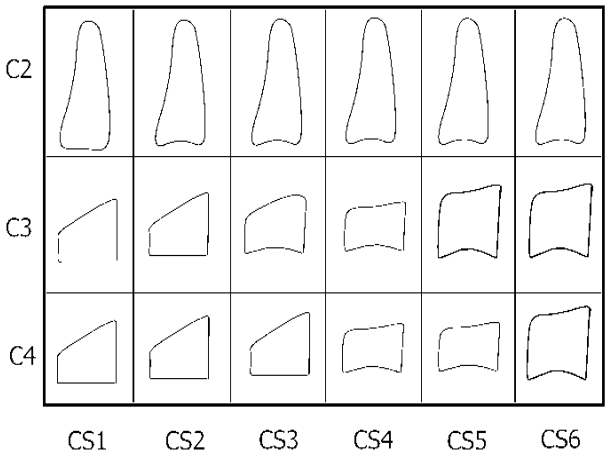

Figure 1: Baccetti's cervical vertebral maturation (CVM) staging. CS1: The lower borders of all three vertebrae appear flat. C3 and C4 are trapezoidal. CS2: C2 shows a concave lower border. C3 and C4 remain trapezoidal. CS3: C2 and C3 both exhibit concave lower borders. C3 and C4 can be either trapezoidal or resemble horizontal rectangles. CS4: Concavities are seen in the lower borders of the three vertebrae. C3 and C4 are shaped as horizontal rectangles. CS5: The lower borders of the three vertebrae display concavity. C3 and C4 could be either square or horizontal rectangle. CS6: Concavity is present in the lower borders of three vertebrae. The shape of C3 and C4 can be square or vertical rectangle.

Table 1- Descriptive information of sample population (N=132)

Malocclusion Classification (N)	Cervical Vertebral Stage	Chronological Age (years)		Gender		Total (N)
		Min.	Max.	Female (N=66)	Male (N=66)	
Class I (68)	CS3	9	15	17	17	34
	CS4	11	16	17	17	34
Class II (64)	CS3	10	14	16	16	32
	CS4	10	15	16	16	32

CS=cervical stage based on Baccetti's classification

Results

The level of raw agreement for intra- and inter-examiner assessments equaled 95% and 82%, respectively, for CVM staging, while the corresponding values were 95% and 88% for skeletal class evaluation. The Cohen's kappa coefficient reached 90% and 80% for intra- and inter-examiner agreement during CVM staging. In addition, the corresponding values for skeletal classification were 90% and 85%. The outcomes of the independent samples t-Test revealed that the duration of the pubertal growth spurt was approximately 0.28 years (3.36 months) shorter compared to class I ($p<0.001$) (Table 2). As mentioned before, CS3 is the onset stage of the pubertal growth spurt. Comparing the chronological age of subjects at CS3 showed that the spurt initiated at a similar age, and there was no significant difference observed ($p=0.110$).

Table 2- Comparison of the mean duration of pubertal growth spurt between two skeletal classes (independent samples t-Test)

Malocclusion Classification	Mean Chronological Age (years ± SD)		Duration of Pubertal Growth Spurt (years ± SD)	Inter-Class Difference (years)	Cohen's d	P value
	CS3	CS4				
Class I	11.91 ± 1.32	13.53 ± 1.33	1.62 ± 1.33	0.28	0.22	<0.001*
Class II	11.41 ± 1.19	12.75 ± 1.22	1.34 ± 1.21			

CS=cervical stage based on Baccetti's classification
* P-values less than 0.05 are considered statistically significant

In terms of comparing genders, the independent samples t-Test depicted that the length of the pubertal growth spurt was 1.82 ± 1.16 years for females and 1.60 ± 1.08 years for males. There was a statistically significant difference of 0.22 years (2.64 months) between the two genders (p< 0.001), as indicated in Table 3. Additionally, male subjects experienced the beginning of the growth spurt approximately 1.49 years later (p< 0.001), and the spurt ended approximately 1.27 years later (p< 0.001) compared to females (Table 4).

Table 3- Comparison of the mean duration of pubertal growth spurt between the two genders (independent samples t-Test)

Gender	Chronological Age (Mean ± SD)		Duration of Pubertal Growth Spurt (Mean ± SD)	Inter-Gender Difference (years)	Cohen's d	P value
	CS3	CS4				
Female	10.84 ± 0.97	12.66 ± 1.36	1.82 ± 1.16	0.22	0.20	<0.001*
Male	12.33 ± 1.08	13.93 ± 1.08	1.60 ± 1.08			

CS=cervical stage based on Baccetti's classification
* P-values less than 0.05 are considered statistically significant

Table 4- Comparison of the onset and termination age of pubertal growth spurt between the two genders (independent samples t-Test)

Cervical Vertebral Stage	Chronological Age (Mean ± SD)		Mean Difference (years)	Cohen's d	P value
	Female	Male			
CS3	10.84 ± 0.97	12.33 ± 1.08	1.49	1.45	<0.001*
CS4	12.66 ± 1.36	13.93 ± 1.08	1.27	1.03	<0.001*

CS=cervical stage based on Baccetti's classification
* P-values less than 0.05 are considered statistically significant

Discussion

The assessment of skeletal maturation involves multiple methods, and among them, the CVM method is extensively utilized. This approach relies on the morphology of three cervical vertebrae. [8] Based on previous research, the maximum mandibular growth falls within the pubertal growth spurt, which is the interval of CS3 and CS4. [8] However, it is important to note that the beginning and length of the growth spurt can differ among individuals of different skeletal classes, posing challenges to selecting appropriate orthodontic treatment plans. [9, 10] The present study aimed to compare the onset age and duration of the pubertal growth spurt between subjects of class I and II. In this regard, 132 lateral cephalograms were analyzed using Baccetti's CVM method, and comparisons were made between different skeletal classes and genders. In brief, it was found that pubertal growth spurt commenced at a comparable age in both classes, while the duration was shorter in class II subjects. In addition, the spurt started earlier and persisted longer in female subjects.

The reliability of the CVM method for evaluating skeletal maturation is a much-debated argument among scholars. While some studies confirm this method as a reliable way of estimating growth spurt [18, 19], pieces of evidence have raised questions about the correlation between CVM and skeletal maturity. [20, 21] For instance, Demirturk Kocasarac et al. [22] recorded a very strong correlation between the stage of CVM and spheno-occipital synchondrosis fusion in male patients and a strong correlation in females. In addition, Lucchese et al. [23] acknowledged the CVM method as a dependable tool capable of substituting the hand-wrist method. Conversely, Perinetti et al. [20] do not recommend the CVM method for assessing mandibular growth spurt. In spite of the contentions surrounding the CVM method, Basheer et al. [24] argue that cone-beam computed tomography (CBCT) provides a more comprehensive assessment of a patient's growth status compared to traditional cephalometric radiographs.

As stated previously, our findings indicated that class I and class II subjects experienced the onset of pubertal growth spurt at a comparable age. In line with this notion, Jeelani et al. [9] also showed that the spurt starts at a similar age in the two classes. More studies also endorsed the simultaneous spurt commencement of class I and II subjects. [11, 25] Regarding the length of the pubertal growth spurt, our findings showed that class I and class II subjects had a spurt that lasted 1.62 ± 1.33 years and 1.34 ± 1.21 years, respectively. Consistent with our assertion, Jeelani et al. [9] concluded that the spurt is shorter in class II subjects. They reported a duration of 0.95 ± 0.20 years for class I and 0.60 ± 0.15 for class II, exhibiting a statistically significant difference. In line with the abovementioned results, Salazar-Lazo et al. [25] discovered the spurt duration of pubertal growth to be 10 months in class I and 6 months in class II. The four months difference was statistically significant. In contrast to mentioned studies, Ghaleb et al. [11] depicted that the pubertal growth spurt duration was approximately 13 months in class I and 19 months in class II, and their difference was significant. It is important to

note that the accuracy of CS visual evaluation may vary depending on the specific stage being assessed. While measurements are generally precise and reproducible, the highest level of disagreements and, consequently, the lowest accuracy have been observed in CS4. [26] Hence, the clinicians' judgment may not be utterly reliable when the patient proceeds toward the latter phases of the pubertal growth spurt.

Comparing the two genders, Magalhães et al. [27] concluded that females exhibited an earlier skeletal maturation in contrast to males. According to the findings of Jeelani et al. [9], the initiation of the pubertal growth spurt occurred significantly earlier in female subjects, with a difference of approximately 4 months. Confirming that, Ghaleb et al. [11] and Naderi et al. [28] also demonstrated an approximately 12 and 17 months earlier onset of the growth spurt in females, respectively. As mentioned, our results also approved the earlier onset of the growth spurt in female patients. In contrast, our findings about the growth spurt's duration in the two genders contradicted previous research. Our study delineated a 0.22-year decrease in the duration of the growth spurt among boys, which closely aligns with the reported reduction of 0.20 years in the study of Naderi et al. [28]. On the contrary, this parameter was significantly longer in the boys explored in the studies of Jeelani et al. [9] and Ghaleb et al. [11]. In distinction to most previous similar studies [9-11], our approach aimed to enhance the reliability of inter-gender comparisons by ensuring an equal number of samples from both genders in each study group. In light of the findings from this present research, when a female subject is compared with a male subject at the same chronological age, the former would probably show a higher level of skeletal maturation and, therefore, would need an earlier orthodontic examination in order to achieve desired outcomes. In line with this concept, a study on the German population found that boys and girls receive orthodontic treatments at similar ages. However, the majority of girls have already progressed to the later stages of puberty by this point, whereas the majority of boys have not yet reached puberty when they undergo treatment. [29] Therefore, taking inter-gender differences for granted can undermine treatment outcomes.

Orthodontists often delay treatment until all permanent teeth have erupted, aiming to minimize the overall treatment duration. However, this approach misses a significant portion of facial growth. For instance, facial growth diminishes considerably after age 15, limiting orthodontic corrections primarily to tooth movement rather than growth modulation. [30] Servello et al. [31] state that patients of class II relationship would show a better response when receiving the orthodontic treatment within the interval of CS3-CS4. Furthermore, Flieger et al. [32] reported that accelerated growth occurs at 11.2 years old in class II subjects, which is the optimal time for their treatment. In Kochar et al. [33] study, treating class II patients within their pubertal growth spurt resulted in significant skeletal changes and maxillary retrusion. Functional appliances like Frankel and Bionator are commonly used to treat class II subjects, taking advantage of the remaining growth potential. [30] As a result, it is pivotal for clinicians to be knowledgeable about the patient's current level of skeletal maturation and the remaining growth potential to synchronize with the patient's growth and achieve optimal outcomes. Nevertheless, Perinetti et al. [34] asserted that mere dependence on the CVM method could lead to biases in treatment planning. As a matter of fact, even though the CS4 stage represents a relatively small proportion of the adult population, it is still significant in terms of clinical decision-making.

In terms of future horizons, advancements in artificial intelligence have ushered in a new era for determining patients' CVM stage and growth spurts. Several models have been developed as promising adjunct tools to aid clinicians in the process of maturation staging. [35, 36] A review study examining six deep-learning models constructed for CVM staging demonstrated a minimum accuracy of 90% across all models. [36] However, some might contend that further improvements are necessary for artificial intelligence to match the accuracy of human measurements. [35]

Cross-sectional studies are limited in their ability to accurately capture longitudinal phenomena like human growth compared to longitudinal studies that involve repeated clinical and radiographic assessments. However, conducting serial radiographs on patients can raise ethical concerns. Due to limited sources of subjects, the sample size in the current study was not enough to compare the subjects of the two genders within their skeletal classifications. Moreover, skeletal maturation patterns significantly differ between the subjects of different continents with different ethnicities. [27] Therefore, comparing the results of studies conducted in different nationalities may not be accurate, so intra-population comparisons may be more practical and result in more valuable judgments for that specific population

Conclusion

Although class I and class II subjects exhibited a similar onset age for the pubertal growth spurt, the spurt duration was found to be 0.28 years (3.36 months) shorter in class II subjects. Furthermore, female subjects experienced an earlier and more prolonged pubertal growth spurt compared to males.

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