Dental Journal
Majalah Kedokteran Gigi

Dental Journal
(Majalah Kedokteran Gigi)
2025 March; 58(1): 60–65

Original article

Cervical vertebral maturation stage and Demirjian index for assessment of skeletal and dental maturation for children's growth stages

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ABSTRACT

Background: *Determining age is essential in various fields, particularly pediatric dentistry. A reliable method for assessing an individual's growth and development involves evaluating their chronological and biological age. Biological age can be determined by examining skeletal or dental maturation. Accurately assessing growth potential and timing of growth spurts is crucial for several clinical situations, especially in the planning and outcomes of treatments like orthodontic therapy.* ***Purpose:*** *This study uses common radiographic ortho-diagnosis techniques to analyze the accuracy of cervical vertebral maturation stages (CVMS) and the Demirjian index methods in evaluating children's growth and development stages.* ***Methods:*** *The CVMS assessment on cephalometric radiography was conducted using the Bacetti method, which includes six stages. In addition, the mandibular second molars' calcification stages were evaluated using the Demirjian index method, which encompasses stages A to H on panoramic radiography. Following this, skeletal and dental maturation accuracy was analyzed using the Statistical Package for Social Sciences application.* ***Results:*** *This study revealed differences in the chronological age corresponding to each stage of calcification of the mandibular second molars and the CVMS. Additionally, CVMS was found to be the most accurate method for assessing age in children. Furthermore, the right side was generally preferred over the left at the calcification stages of the mandibular second molars.* ***Conclusion:*** *Using CVMS to assess skeletal maturation provides a more accurate determination of growth and developmental stages in children than the Demirjian index.*

Keywords: *calcification of mandibular second molars; CVMS; dental maturation; growth; medicine; skeletal maturation*
Article history: *Received 1 November 2023; Revised 23 March 2024; Accepted 18 April 2024; Published 1 March 2025*

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INTRODUCTION

Determining a person's age using various methods is important in many fields, including pediatric dentistry. This process is closely related to understanding the complex stages of growth and development. Accurately assessing growth potential and the timing of growth spurts is essential for various clinical situations, especially when planning and evaluating treatments, such as orthodontic therapy.[1–3]

Evaluating a child's chronological and biological age is crucial for identifying their growth and development phases. However, biological age can also be determined by examining the skeletal and dental maturation stages.[4,5] Skeletal maturation can be assessed using the cervical vertebral maturation stages (CVMS) method, which involves observing the development stages of the cervical vertebrae.[6,7] Meanwhile, dental maturation is typically evaluated by assessing the degree of tooth calcification.

The CVMS method is often used to evaluate skeletal maturation, leveraging lateral cephalometric radiographs, an ortho-diagnostic radiographic technique.[8] The method has also been proven effective for estimating growth phases based on the morphological characteristics of the second, third, and fourth cervical vertebrae on lateral cephalometric radiographs.[9] Bacetti developed the CVMS assessment, which consists of six stages (CS1 – CS6) (Table 1). The first two stages are prepubertal, stages three and four are pubertal, and the remaining are postpubertal.[10] However,

DOI: 10.20473/j.djmkg.v58.i1.p60–65

during adult development, there is a transformation that does not result in consistency within the vertebral body.[11]

Assessing tooth calcification levels using panoramic radiography has proven to be an effective method for evaluating dental maturation. Numerous studies indicate that this approach is not affected by local factors like premature tooth loss, dental caries, or ankylosis, nor by environmental factors such as nutrition and hormone metabolism. The technique for assessing stages of tooth calcification, developed by Demirjian, is known as the Demirjian index. It consists of eight stages, ranging from stage A to stage H (as shown in Table 2). The Demirjian index is widely utilized for its simplicity, ease of inter-examiner agreement, standardization, and reproducibility.[5,12,13] The development of mandibular second molars typically occurs by age 16, making them a reliable indicator of growth and development stages.[14] However, various studies have highlighted that the Demirjian index has limitations: it tends to overestimate dental maturation in children under eight years old and underestimate it in older age groups.[5] Consequently, this study aims to analyze the accuracy of the CVMS method and the Demirjian index in evaluating children's growth and development stages. This analysis considers the strengths and weaknesses of both methods concerning mandibular second molars. Additionally, the study examines the accuracy of using the right or left second molars in assessing dental maturation.

MATERIALS AND METHODS

This was an analytical retrospective study using secondary data. It was conducted from July to November 2022 using panoramic and lateral cephalometric radiographs of patients at the Pediatric Dentistry Clinic, Universitas Airlangga Dental and Oral Hospital, Surabaya, Indonesia, from 2017 to 2020. Furthermore, observations and assessments of maturation stages from radiographic photos were performed from August to October 2022. Observations and assessments were performed using three observers. In November, the data obtained were analyzed using the IBM Statistical Analysis for Social Science (SPSS) 26.0 application.

In this study, the independent variable was the child's circumpubertal phase, while the dependent variables included skeletal and dental maturation. The controlled variables were gender and chronological age. According to the theory, the adolescent growth spurt occurs in three phases: the pre-pubertal phase (characterized by a moderate increase in growth speed), the pubescent phase (the fastest growth phase), and the post-pubescent phase (where the growth rate slows down).[15] The pubertal growth spurt typically begins at ages 9 to 10 for girls and 11 to 12 for boys.[16] At age 10, girls experience their lowest growth velocity, while boys reach their lowest at 11.5 years. The maximum peak height velocity (PHV) occurs around 12 years for girls and 14 years for boys.[17] Therefore, gender and chronological age were controls in CVMS and Demirjian index assessment.

To illustrate the accuracy of CVMS and the Demirjian index method in assessing stages of development and growth in children, data analysis was carried out using SPSS 16.0 software on Windows XP, with a significant value of 0.05 (p=0.05). The accuracy of the two methods was compared based on the standard error value. Assessment of skeletal and dental maturation involved three observers, and the average result was calculated. The data used in this study comprised radiographs from patients with no history of systemic diseases that could interfere with normal growth and development and no occurrences of facial trauma, surgery on facial structures, congenital abnormalities, structural growth syndromes, and facial anomalies.

The data used to determine the CVMS were collected by examining the concavity of the inferior edge and observing the morphological changes in the cervical vertebrae (CS1 – CS6) on panoramic radiographs. Six CVMS stages can be identified based on the C2, C3, and C4 vertebrae morphology. The first step was to evaluate the lower edges of the three vertebral bodies, while the shape of C3 and C4 (Table 1) was assessed in the second step.[18] Data

Table 1. Six stages of CVMS using the Baccetti method[18]

CVMS (CS)	Description
CS1	The lower edges of all three vertebrae (C2 – C4) are flat. The bodies of C3 and C4 are trapezoidal (the superior edge of the vertebral body tapers from posterior to anterior). Peak mandibular growth occurs approximately 2 years after this stage.
CS2	There appears to be a concavity at the lower edge of C2. The bodies of the C3 and C4 are still trapezoidal. Peak mandibular growth occurs approximately 1 year after this stage.
CS3	There is a concavity at the lower edge of C2 and C3. The bodies of C3 and C4 can be trapezoidal or horizontally rectangular. Peak mandibular growth occurs throughout the year at this stage.
CS4	A concavity exists at the lower edge of C2, C3, and C4. The bodies of the C3 and C4 are horizontally rectangular. Peak growth of the mandible has occurred 1–2 years before this stage.
CS5	The concavities at the lower edges of C2, C3, and C4 are still visible. There is at least one body from C3 and C4, which is square. If it is not square, one of the other bodies is still a horizontal rectangle. Peak growth of the mandible has been completed approximately 1 year before this stage.
CS6	The concavities at the lower edges of C2, C3, and C4 are still visible. There is at least one body from C3 and C4, which is square. If it is not square, one of the other bodies is still a horizontal rectangle. Peak growth of the mandible has been completed approximately 2 years before this stage.

DOI: 10.20473/j.djmkg.v58.i1.p60–65

were gathered by assessing the degree of tooth formation on cephalometric lateral radiographs to determine the Demirjian index of the left and right mandibular second molars. This method classifies the process into eight stages, ranging from A to H, based on the level of tooth development. In assessing stages of tooth development, according to Demirjian et al.,[19] a score of 0 was given when there were no signs of calcification (Table 2).

This study used the total sampling method to determine the number of samples. Given the limited availability of data meeting the study's criteria, an evaluation of all available samples that met these criteria was performed. Furthermore, the total number of radiographs used was 230. The data obtained were analyzed statistically to determine the accuracy of CVMS and Demirjian index assessments of mandibular second molars on stages of growth and development in children.

After collecting the data, a consensus test was conducted to evaluate the agreement among the three observers regarding the maturity assessment results. Following this, a normality test was performed to analyze the sample distribution using the Kolmogorov–Smirnov method. Once the normality test was completed, the CVMS and Demirjian index methods were compared using the Kruskal–Wallis test. The accuracy of each method was determined based on the standard error derived from the statistical analysis. A smaller standard error value indicates a higher precision of the method, while a larger standard error suggests lower precision.

RESULTS

This study used 115 panoramic and 115 lateral cephalometric radiographs as the sample size. The sample consisted of males aged 6–14 and females aged 6–17. This uneven distribution of data led to the presence of information that was not accounted for in this study.

Table 2. Eight stages of tooth calcification using the Demirjian index[19]

Stages	Description
A	Calcification at the occlusal point without fusion of the different calcified parts.
B	Fusion of calcified points. The contours of the occlusal surface begin to become recognizable.
C	Enamel formation on the occlusal surface is complete, and dentin formation begins. The pulp chamber appears curved, and there is no visible pulp horn.
D	The crown formation has been completed up to the cementoenamel junction. Root formation begins to occur. The pulp horn begins to differentiate, but the walls of the pulp chamber still appear curved.
E	Root length still appears shorter than crown height. The walls of the pulp chamber appear straight, and the pulp horns are more differentiated compared to previous stages. In molars, the bifurcation begins to calcify.
F	The walls of the pulp chamber are shaped like an isosceles triangle. Root length is proportional to or greater than crown height. Bifurcation has developed enough in molars to shape the roots differently.
G	The walls of the root canal appear parallel, but the apical end of the root is still partially opened. In molars, only the distal root is assessed.
H	The apical end of the root is closed (what is assessed is the distal root of the molar tooth). The periodontal membrane surrounding the root and apex has the same width.

Table 3. Distribution of skeletal maturation, second molar calcification, and chronological age by gender

Gender	CVMS				Right Second Molar Calcification				Left Second Molar Calcification			
	Stages	Min. Age	Max. Age	Mean	Stages	Min. Age	Max. Age	Mean	Stages	Min. Age	Max. Age	Mean
Male	CS1	6	9	7.80	C	6	10	7.50	C	6	7	6.67
	CS2	7	10	8.63	D	7	11	8.88	D	7	11	8.88
	CS3	8	13	10.35	E	8	13	10.06	E	8	13	10.06
	CS4	11	14	12.56	F	10	14	11.22	F	10	14	11.14
	CS5	14	14	14.00	G	11	14	12.53	G	11	14	12.42
	Total	6	14	10.65	H	11	14	12.50				
					Total	6	14	10.65	Total	6	14	10.65
Female	CS1	6	8	7.33	C	6	9	8.00	C	6	9	8.00
	CS2	8	10	8.60	D	8	10	8.43	D	8	10	8.43
	CS3	8	13	9.59	E	8	11	9.50	E	8	11	9.45
	CS4	10	15	12.18	F	9	13	11.08	F	9	13	10.85
	CS5	12	16	14.17	G	10	17	13.50	G	10	17	13.58
	CS6	17	17	17.00	H	16	16	16.00				
	Total	6	17	11.17	Total	6	17	11.17	Total	6	17	11.17
Total	CS1	6	9	7.63	C	6	10	7.78	C	6	9	7.50
	CS2	7	10	8.62	D	7	11	8.67	D	7	11	8.67
	CS3	8	13	9.98	E	8	13	9.83	E	8	13	9.83
	CS4	10	15	12.37	F	9	14	11.14	F	9	14	10.95
	CS5	12	16	14.15	G	10	17	13.11	G	10	17	13.07
	CS6	17	17	17.00	H	11	16	13.67				
	Total	6	17	10.92	H	11	16	13.67	Total	6	17	10.92

DOI: 10.20473/j.djmkg.v58.i1.p60–65

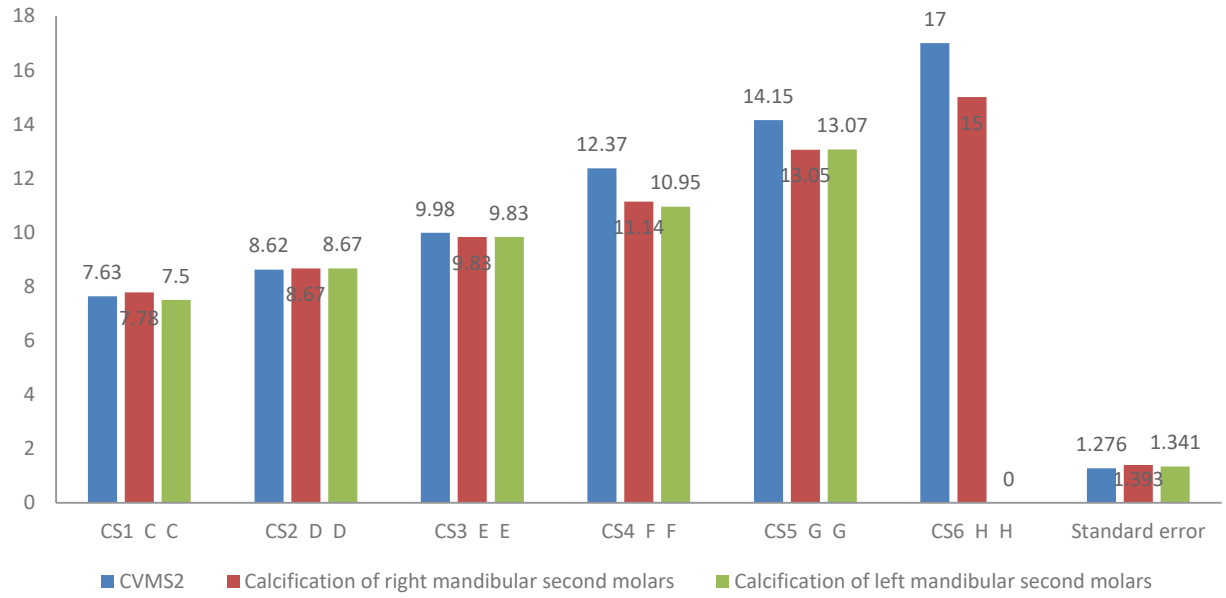

Figure 1. Difference test results between CVMS and calcification of the second molar against chronological age.

The results indicated that CS6 was not detected in the male CVMS group. However, CS6 was identified in the female age group of 17 years. In the Demirjian index group concerning the left mandibular second molars, the stages of dental maturation were only found in stages C to G for both males and females. In contrast, dental maturation was more extensively distributed in the right mandibular second molars sample, ranging from stage C to H. The CVMS and Demirjian index samples yielded different test results (Table 3).

In the test of the three observers' agreement, a strong agreement was found for both CVMS and the Demirjian index assessment of the left and right mandibular second molars (Kappa value >0.8). Based on the Kolmogorov–Smirnov normality test, it was found that the data used was not normally distributed ($p<0.05$). Consequently, a Kruskal–Wallis test was conducted, which compared the Demirjian index of the right and left second molars and CVMS against chronological age. The results of the difference tests found that CVMS had the smallest standard error compared to the Demirjian index for the second mandibular molars, both right and left, as shown in Figure 1.

DISCUSSION

Understanding craniofacial growth and development is essential for accurate diagnosis and effective treatment planning, particularly in orthodontics. Various methods can be used to identify children's growth and development, including the chronological and biological age assessment. Biological age assessment involves evaluating the stages of skeletal and dental maturation. Wrist radiography can determine skeletal maturation; however, this method requires additional X-ray exposure for the dental patient. As a result, the CVMS assessment is widely accepted since it utilizes lateral cephalometric photographs, commonly used in ortho-diagnosis. Additionally, the primary method for assessing dental maturation is the evaluation of calcification stages of the mandibular second molars, typically conducted using panoramic photographs, which also serve as valuable tools for ortho-diagnosis.[20]

In the test of the three observers' agreement, a strong agreement was found for both CVMS and the Demirjian index assessment of the left and right mandibular second molars, but the data were not distributed normally. Using Kruskal–Wallis, a difference test was conducted to compare the Demirjian index of the right and left second molars and CVMS against chronological age. The results indicated significant differences in chronological age at each stage of calcification, which aligned with findings from previous studies.

Pubertal growth spurt often occurred around 9–10 years and 11–12 years in girls and boys, respectively (CS3-CS4).[16,21] These results were inconsistent with this study, where CS3 in girl samples was achieved at an average age of 9.59, while CS4 was achieved at an average age of 12.18. For boy samples, CS3 and CS4 were attained at an average age of 10.35 and 12.56, respectively. Based on these results, girls tended to mature earlier than boys, as reported by Howell in 2015.[22]

One limitation of the CVMS assessment method is that, as individuals transition into adulthood, the vertebral bodies develop concavity in their inferior portions without an equivalent increase in height. Consequently, the transformation from a rectangular horizontal to a rectangular vertical shape in all vertebral bodies is inconsistent, resulting in inaccurate growth information.[11] In this study, biological age was evaluated through dental

DOI: 10.20473/j.djmkg.v58.i1.p60–65

age assessment, specifically by examining the calcification stages of the mandibular second molars.

Some differences were noted between the findings of this study and those of previous reports. The right mandibular second molars reached calcification stage E at an average age of 9.83 years, followed by stage F at 11.14 years and stage G at 13.11 years. In contrast, the left mandibular molars reached calcification stage E at the same average age of 9.83 years, but they progressed to stage F earlier, at 10.95 years, and reached stage G at 13.07 years. These results suggest that the left mandibular molars undergo calcification slightly earlier than their right counterparts.

These results were consistent with those of Dadgar et al.,[14] where it appeared that stage E calcification in mandibular second molars was achieved at the CS2 stages (pre-growth maturation stages), indicating the onset of PHV. Furthermore, stages F and G calcification were attained at CS3 and CS4 (development maturation stages), showing growth spurt stages. The H calcification stage was reached at CS5 and CS6 (the end of the pubertal growth mutation), indicating little or no residual puberty growth.[14]

Based on the results of difference tests using the SPSS application, it was found that CVMS had the smallest standard error compared to calcification stages of mandibular second molars, both right and left. These results showed that CVMS had the highest accuracy in assessing age in children. Meanwhile, at the calcification stages, the right side of the molars was considered more appropriate compared to the left side.

The findings align with previous studies that demonstrated the high accuracy of CVMS assessments. The study reported that nearly 95% of individuals exhibited a correlation between the interval of spinal stages 3 to 4 and the onset of pubertal acceleration in mandibular and peak height growth. Additionally, the CVM analysis showed a reproducibility rate of 98.6%. Other studies have indicated that dental maturation has good potential for predicting growth phases and could be an alternative to CVMS.[4,14]

Previous studies' other results also explained that CVMS and Demirjian's method were accurate for determining mandibular length. Research on children with Down syndrome stated that dental age was more correlated with chronological age than skeletal age.[20,23] Based on previous research and this study's results, CVMS methods can assess craniofacial growth in children, leading to accurate diagnoses and optimal treatment outcomes. Additionally, dental age can be specifically employed for individuals with skeletal growth disorders. However, the limited number of samples that met the specified criteria restricts the study's ability to comprehensively and accurately describe the various stages of growth and development. Therefore, the findings should be interpreted cautiously, and further research is necessary.

In conclusion, the evaluation of skeletal maturation using the CVMS method was more accurate in determining the stages of growth and development in children compared to the Demirjian index for mandibular second molars. It is highly recommended that future research involve a more diverse sample and be conducted in a clinical setting. This will ensure that assessments are carried out more rigorously, ultimately improving the accuracy of evaluating children's growth and development stages.

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