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# Correlation between skeletal maturation and developmental stages of canines and third molars among Saudi subjects

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**KEYWORDS**

Cervical vertebral maturation;
Nolla;
Demirjian;
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Cephalometric;
Canines;
Third molar

**Abstract** *Aims:* The present study was designed to evaluate the efficacy of using the developmental stages of the canines and third molars to predict the timing of skeletal maturity in the Saudi population.

*Material and methods:* The lateral cephalometric radiographs and orthopantograms of 239 Saudi patients, 106 males and 133 females, aged 9 to 21 years, were collected from several dental centers. Orthopantograms were used to assess the developmental stages of the upper and lower canine teeth and third molars using two popular methods: that of Nolla and that of Demirjian. Cervical vertebral maturation (CVM) stage was assessed on the lateral cephalometric images according to the method of Baccetti et al. Trained observers with no knowledge of patient age or gender performed assessments. Data were analyzed with Spearman's rank correlation coefficient at a significance level of $P \leq .05$.

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*Result:* Skeletal CVM stages III and IV had a stronger correlation with mandibular left canine developmental stage than with maxillary canine developmental stage in the two methods used (correlation with Nolla stage 10 and Demirjian stage H: root completely formed with apex closed), especially for male patients ($r = 0.700$, $P < .001$). In contrast, the maxillary third molars at Nolla stages 5 and 7 (crown completed to 1/3 of the root formed) showed an association with CVM stages III and IV ($r = 0.540$ for females and $r = 0.639$ for males, $P \leq .001$ for both) and with Demirjian stages D, E, and F. Males had slightly higher correlation values than females ($r = 0.578$ and 0.5010, respectively; $P \leq .001$) at CVM stages III and IV. Interestingly, canine teeth showed a stronger correlation than third molars with skeletal maturation in Saudi children.

*Conclusion:* Dental developmental stages were highly correlated with CVM stages III and IV among Saudi subjects.



## 1. Introduction

Many questions have been raised by researchers investigating whether dental age can be used to determine chronological age or if skeletal age estimation is a more reliable procedure. These questions include whether dental age can be used to plan the proper timing for orthodontic intervention and if dental age works as guidance in forensics.

Since the establishment of the strong correlation between tooth development and skeletal maturation, investigators have tried to determine whether dental age assessment is preferable to skeletal age assessment in estimating chronological age (Flores-Mir et al., 2005; Lamons and Gary, 1958; Sierra, 1987; Parbhakar et al., 2002; Gulati et al., 1990). Some researchers believe that the developmental stages of teeth are less affected than bone mineralization by variation in nutritional and endocrine status, as well as local factors. If tooth maturation can be considered a better indicator of chronological age than bone mineralization, then orthodontic intervention can be performed without further clinical investigation.

Orthodontists have suggested a strong relationship between pubertal growth and acceleration in the growth of the craniofacial skeleton. This relationship is very important in predicting future growth potential to have successful results when planning orthodontic treatment. Several indicators of skeletal maturation have been described in the literature to predict the pubertal growth spurt. The standard method for determining skeletal maturation is hand-wrist radiography. To avoid taking additional radiographs, Lamparski (1972) suggested using the cervical vertebrae as seen on routine lateral cephalometric radiographs. Later, many researchers, including Baccetti et al. (2005) and Hessel and Farman (1995) modified Lamparaski's method. Unfortunately, little is known about the correlation between the pubertal growth spurt and dental development. Some published studies (Anderson et al., 1975; Lewis and Garn, 1959) have found little relationship between tooth development and indicators of growth, while others (Lamons and Gary, 1958; Engstrom et al., 1983; Green, 1961; Krogman, 1967) have found positive correlations between third molar development and skeletal maturation. A stronger correlation has been found between skeletal maturation and the development of the mandibular canine than other teeth (Sierra, 1987; Engstrom et al., 1983; Khan and Ijaz, 2011; Coutinho et al., 1993; Chertkow, 1980).

Although dental eruption is considered an easy method to determine dental maturation, it has more variability in its timing than skeletal maturation (Moorrees et al., 1960). Multiple methods have been described for assessing dental age using different types of radiographs, such as oblique jaw radiography (Lewis and Garn, 1959), intraoral radiography (Nolla, 1960), and orthopantomography (Hegde and Sood, 2002).

Engstrom et al. (1983) used the stages of third molar development described by Bjork and Helm (1967) to clearly differentiate between its stages. However, the dental classification method of Nolla (1960) and the scoring system developed by Demirjian et al. (1973) are the easiest and most valid techniques used worldwide. The ease and validity of these techniques have been confirmed in many studies in various populations. Previous studies have found that third molar development and canine calcification stages are strongly correlated with skeletal maturity, which was investigated separately (Engstrom et al., 1983; Khan and Ijaz, 2011; Chertkow, 1980; Taher and Foda, 2001; Suma et al., 2011).

The present study was designed to evaluate the correlation between the maturational stage of the canine teeth and third molars and cervical vertebral maturity (CVM). If a strong association exists between dental and skeletal maturity, dental calcification stages may be used as a sole method to estimate the timing of the pubertal growth spurt in Saudi subjects.

## 2. Materials and methods

Ethical approval was obtained from the College of Dentistry Research Centre of King Saud University (CDRC NO. IR0055) prior to conducting this study. This retrospective study was performed on a sample selected with purposive sampling technique, and collected from the Department of Orthodontics at King Saud University College of Dentistry, King Khaled Hospital, King Abdulaziz Hospital, and the orthodontic clinic at Asir Central Hospital. Patients' ages ranged from 9 to 21 years for both genders. This range was intentionally selected because it corresponds with the period of developmental formation of the canine teeth and third molars. The entire study sample was taken from the files of patients with no history of previous orthodontic treatment, no missing teeth (in particular, maxillary and mandibular right and left canines and third molars), and no history of trauma or injury to the head and neck region. Poor-quality radiographs and non-Saudi patients were excluded. Radiographs were collected with oral parental consent.

Orthopantograms were used to assess the developmental stages of the upper and lower canine teeth and third molars. The developmental stages were estimated with Nolla's method, which divides tooth development into ten stages from 0 to 10 (Fig. 1).

In addition, the developmental stage of the lower left canine tooth and third molar was estimated with Demirjian's method, which divides tooth development into eight stages from A to H. Stages from C to H were considered because their period of formation corresponds with CVM stages II, III, IV, V, and VI (Fig. 2). The lateral cephalometric radiograph was used to assess the maturational stage of the cervical vertebrae based on the presence or absence of concavity at the inferior border, as described by Baccetti et al. (2005) (Fig. 3).

Orthopantomograph® OP 100 and Orthoceph® OC 100 (Model # 100-1-1-2), are Manufactured by Instrumentarium Corporation Imaging Division 1996, Tuusula FINLAND, Code# 63409-4A and serial # 72290. The panoramic exposure

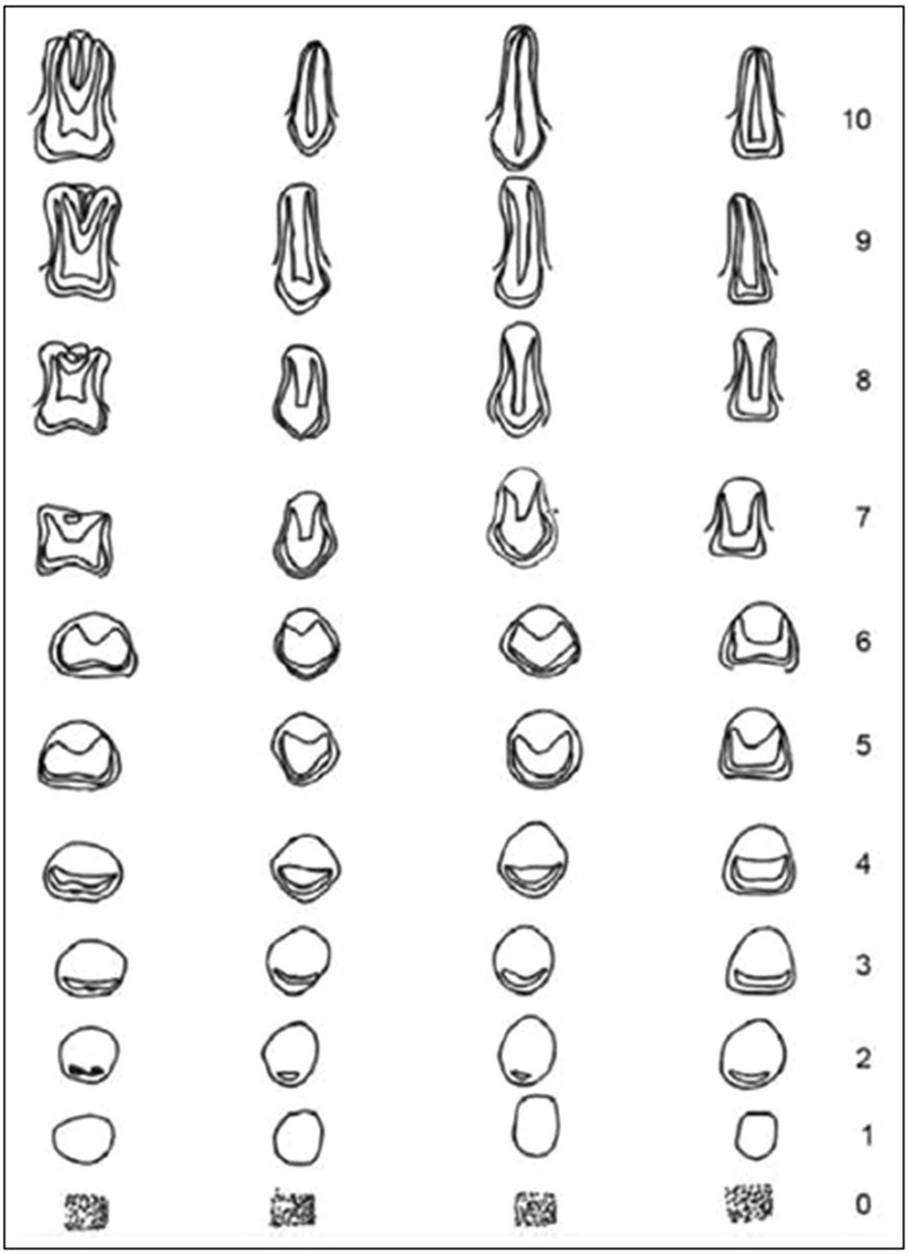


**Fig. 1** Schematic representation of stages of tooth calcification according to Nolla method. Stage 0: Absence of crypt, Stage 1: Presence of crypt, Stage 2: Initial calcification, Stage 3: One-third of crown completed, Stage 4: Two-third of crown completed, Stage 5: Crown almost completed, Stage 6: Crown completed, Stage 7: One-third of root completed, Stage 8: Two-third of root completed, Stage 9: Root almost complete; open apex, Stage10: Apical foramen of root closed. Figure Caption is credited from: Nolla CM. Development of the permanent teeth. J Dent Child. (1960);27: 254–263.

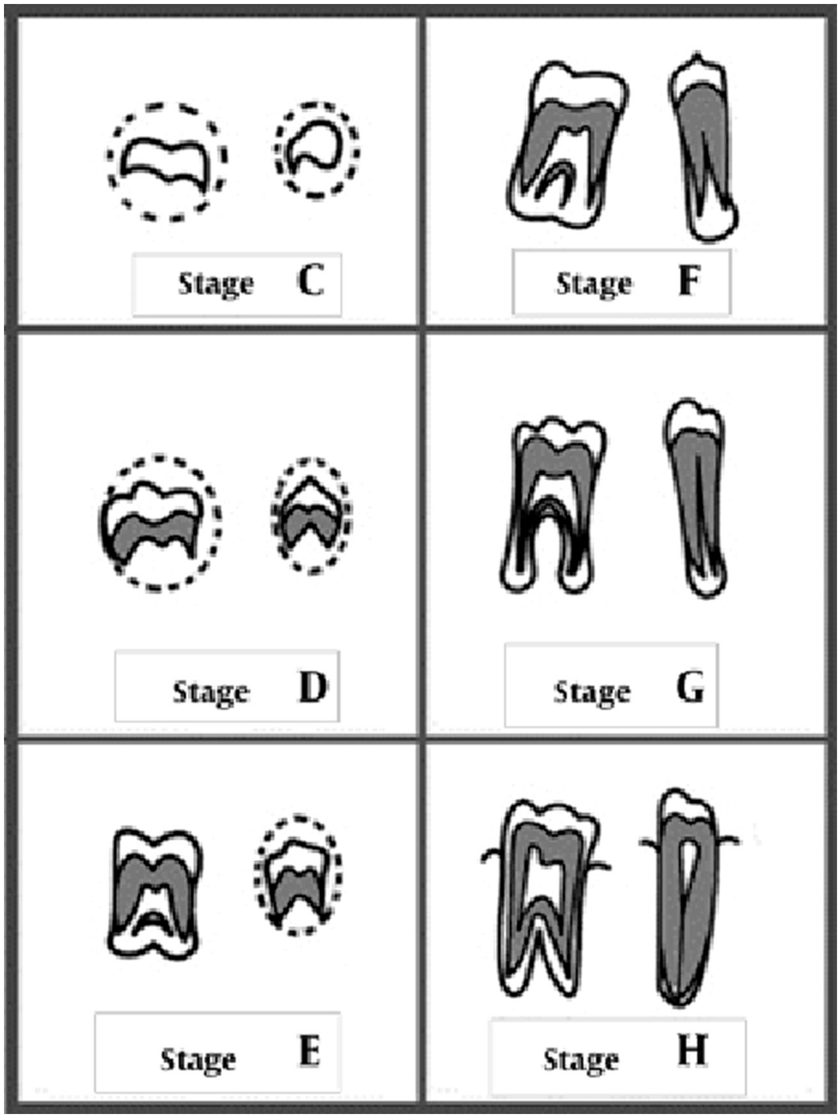


**Fig. 2** Schematic representation of stages of tooth calcification according to Demirijian et al. C. Enamel formation is complete at the occlusal surface. D. Crown formation is complete to the level of the cementoenamel junction. Root formation has commenced. The pulp horns are beginning to differentiate. E. The root length remains shorter than the crown height. The walls of the pulp chamber are straight, and the pulp horns are more differentiated than in the stage. In molars radicular bifurcation has to calcify. F. The walls of the pulp chamber form an isosceles triangle, and the root length is equal to or greater than the crown height. In molars, the bifurcation has developed sufficiently to give the roots a distinct form. G. The walls of the root canal are parallel, but the apical end is partially open. In molars, only the distal root is rated. Figure Caption is credited from: Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol. (1973);45: 211–227.

time was 16 s, with 13 mA, and 68 KVP, while the lateral cephalometric radiograph exposure time was 6.79 s with 10 mA, and 68 KVP.

Radiographs were interpreted by two trained and calibrated examiners. The inter- and intra-examiner reliability were 0.81 and 0.86, respectively. These values were established by reviewing 30 randomly selected radiographs twice, with a 1-month interval. These radiographs used for calibration of the examiners and reliability were not included in the main sample of the study. Statistical tests were performed at a 95% confidence level with the SPSS software package (Version 17.0, SPSS Inc., Chicago, IL, USA). Descriptive statistics were obtained by calculating the mean and standard deviation of all variables for both genders. The Spearman rank order correlation coefficient was used to assess the strength of the relationships between CVM stages III and IV and canine tooth and third molar calcification stages. P-values equal to or less than .05 were considered statistically significant.

## 3. Results

Two hundred thirty-nine patients, comprising 106 males and 133 females, with a mean age of 13.77 ± 0.992 and 13.07 ± 1.439 years, respectively, were included in this study. Patient age ranged from 9 to 21 years (Fig. 4). The target group of the present study was patients within the growth spurt period

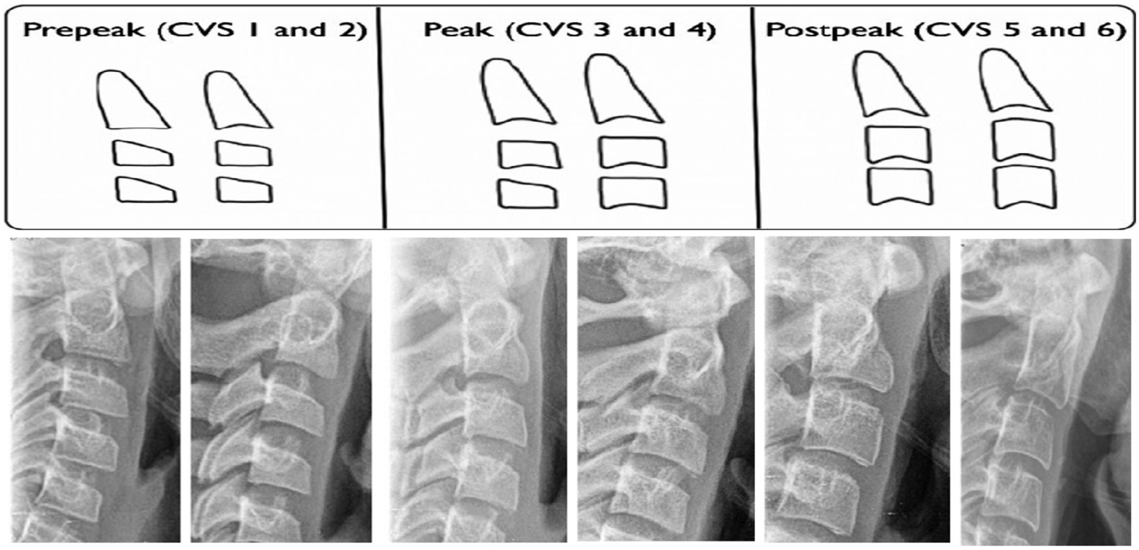


**Fig. 3** Schematic representation of cervical vertebral maturation stages according to Baccetti et al. CVS 1: C2,C2,and C4 inferior border are flat and the vertebrae are trapezoidal in shape. CVS 2: Concavities at lower border of C2 and C3 and Bodies of C3 and C4 are or rectangular horizontal in shape. CVS 3: Concavity at the lower border of C2, C3, C4 and bodies of C3, C4 are rectangular horizontal in shape. CVS 4: Distinct concavity at the lower border of C2, C3, C4. at least one of C3 and C4 is nearly square in shape. CVS 5: Accentuated Concavities of the lower border of C2, C3, C4. C3 and C4 are square in shape. CVS 6: Deep concavity at the lower border of C2, C3, C4. C3 and C4 is rectangular vertical (heights are greater than widths). Figure Caption is credited from: Baccetti T, Franchi L, McNamara JA Jr. The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. Semin Orthod. (2005);11: 119–129.

(CVM stages III and IV), because of the importance of this period for orthodontic treatment success. The mean age for both genders was almost the same (13.1 years for males and 13.8 years for females at CVM III; 16.1 years for males and 14.2 for females at CVM IV) (Fig. 5).

### *3.1. Distribution of patients according to CVM stage*

Among the 239 subjects, 107 (45%) fulfilled our target group requirement of CVM stage III or stage IV. Fifty-three patients (22%) were within CVM stage III (26 males and 27 females), and 54 (22.6%) were in stage IV (18 males and 36 females).

### *3.2. Distribution of patients according to canine tooth and third molar dental classification stage (DCS)*

#### *3.2.1. Canine tooth DCS distribution*

The skeletal maturity stages CVM III and IV were consistent with the canine tooth classification stages 8, 9, and 10 according to the Nolla method, and stages F, G, and H according to the Demirjian method. Among the 107 (45%) patients that were included in the skeletal maturity group and the above canine tooth developmental stages, 44 (18%) were males and 63 (25%) were females.

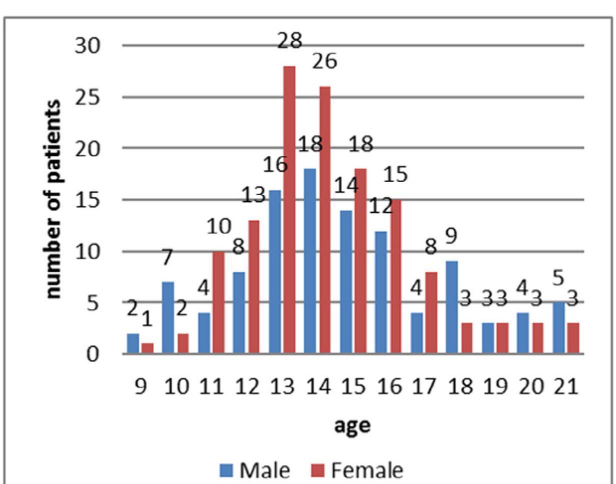


**Fig. 4** Distribution of male and female patients according to chronological age.

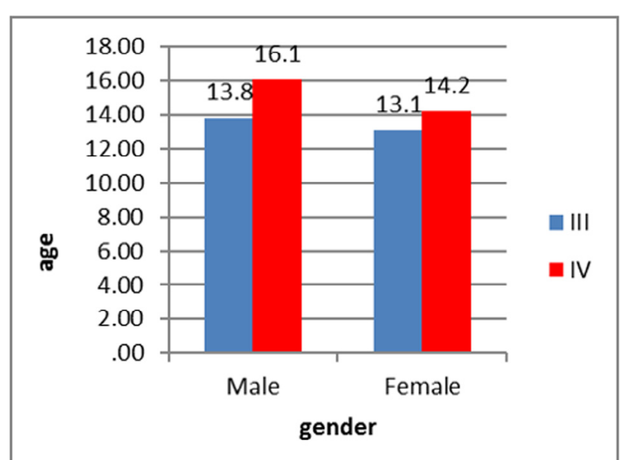


**Fig. 5** Mean age of male and female patients at cervical vertebral maturation stages III and IV.

According to the canine tooth calcification description of the Nolla method, the majority of our patients were under stage 10. Among male patients there was a strong correlation between CVM stages III and IV and the developmental stages of the upper right and left and lower right and left canine teeth (r = 0.686, 0.692, 0.682, and 0.700, respectively; $P \leq .001$) (Table 1). Among female patients there was a weak correlation between CVM stage and developmental stage of the right and left maxillary canines (r = 0.370 and 0.378, respectively; $P \leq .001$). For the mandibular right and left canines in females, the correlation coefficients were slightly higher but still considered weak (r = 0.436 and 0.419, respectively; $P \leq .001$) (Table 1).

With the Demirjian method we found that the lower left canine stage H (closed apex) was more prevalent than the other developmental stages in both genders in our targeted group of CVM stages III and IV. Among male subjects there was a strong correlation between CVM stages III and IV and mandibular left canine developmental stage H (r = 0.700, $P \leq .001$) (Table 3). Likewise, true stage H was more prevalent than all other dental developmental stages among females. However, there was a lower correlation coefficient for females than for males (r = 0.443, $P \leq .001$) (Table 3).

#### 3.2.2. Third molar DCS distribution

The skeletal maturity stages CVM III and IV were consistent with third molar DCS 5, 6, 7, 8, 9, and 10 according to the Nolla method. CVM stages III and IV were consistent with third molar stages D, E, F, G, and H according to the Demirjian method. Among 103 (41.2%) male patients, 25 (10%) patients with a third molar according to the Nolla method were in CVM stage III and 18 (7.2%) were in CVM stage IV. The same previously mentioned dental and skeletal maturational stages were applied for both maxillary and mandibular third molars using the Nolla and Demirjian methods.

Table 2 shows the skeletal maturity and maxillary and mandibular right and left third molar maturity for both genders according to the Nolla method. Among the male subjects, the right and left maxillary third molar maturity correlated strongly with CVM stage III at Nolla stage 5 and with CVM stage IV at Nolla stage 7 (r = 0.610 and 0.639, respectively; $P \leq .001$). The mandibular right third molars showed a moderate correlation at the same stages (r = 0.497, $P \leq .001$). Surprisingly, the mandibular left third molar had a weaker correlation coefficient than the right (r = 0.396, $P \leq .001$). In contrast, in female patients at CVM stage III the highest percentage of maxillary and mandibular right and left third molars were at Nolla stage 6. However, in females at CVM stage IV, the highest percentage of right and left maxillary and right mandibular third molars were at stage 7, while the highest percentage of left mandibular third molars were at stage 5. The correlation between skeletal maturity stage and right and left maxillary and mandibular third molar maturity varied from good to weak (r = 0.541, 0.519, 0.480, and 0.472, respectively; $P \leq .001$).

Table 4 shows the skeletal and left mandibular third molar maturity for both genders according to the Demirjian method. The highest percentage of male patients at CVM stage III had third molar maturity at stage D. The highest percentage of male patients at CVM stage IV had third molar maturity at stages E and F equally. For the female patients, the highest percentage of patients at CVM stages III and IV had third molar maturity at stage D. Among male patients there were somewhat strong correlations between Demirjian stage D and CVM stage III and between Demirjian stages E and F and CVM stage IV (r = 0.578). For female patients correlations were found between Demirjian stage D and both CVM stages III and IV (r = 0.501; $P \leq .001$).

### 3.3. Percentage distribution of canine and third molar dental calcification stages within CVM III and IV skeletal maturity stages

#### 3.3.1. Nolla method: (Table 5)

For the maxillary right and left canine calcification stages in males at CVM stage III, the highest percentage fell in stages

**Table 1** Distribution of cervical vertebral maturation (CVM) stages III & IV, according to maturity of maxillary and mandibular right and left canine teeth for both genders (Nolla method).

| Tooth | | Max Rt *Canine* | | Max Lt *Canine* | | Mand Rt *Canine* | | Mand Lt *Canine* | |
|---|---|---|---|---|---|---|---|---|---|
| CVS | | III | IV | III | IV | III | IV | III | IV |
| Nolla Stages | | No (%) | No (%) | No (%) | No (%) | No (%) | No (%) | No (%) | No (%) |
| Males | 8 | 1(3.8) | 0 | 1(3.8) | | 1(3.8) | | 1(8.3) | |
| | 9 | 9(34.6) | | 10(38.5) | 1(5.6) | 8(30.8) | 1(5.9) | 7(30.8) | 2(11.1) |
| | 10 | 16(61.5) | 18(100) | 15(57.7) | 17(94.9) | 17(65.4) | 17(94.4) | 17(65.4) | 16(88.9) |
| | **Total**[a] | **26(100)** | **18(100)** | **26(100)** | **18(100)** | **26(100)** | **18(100)** | **26(100)** | **18(100)** |
| | r-value | 0.686 | | 0.692 | | 0.682 | | 0.700 | |
| | P-value | .000 | | .000 | | .000 | | .000 | |
| Females | 8 | 1(3.7) | 1(2.8) | 1(3.7) | 1(2.8) | | 1(2.8) | | 1(2.8) |
| | 9 | 8(29.6) | 4(11.1) | 7(25.9) | 4(4.1) | 7(25.9) | 4(11.1) | 7(25.9) | 3(8.3) |
| | 10 | 18(66.7) | 31(86.1) | 19(70.4) | 31(86.1) | 20(74.1) | 31(86.1) | 20(74.1) | 32(88.9) |
| | **Total**[a] | **27(100)** | **36(100)** | **27(100)** | **36(100)** | **27(100)** | **36(100)** | **27(100)** | **36(100)** |
| | r-value | 0.370 | | 0.378 | | 0.436 | | 0.418 | |
| | P-value | .000 | | .000 | | .000 | | .000 | |

r = Spearman rank order correlation coefficient, $P \leq .05$ were considered statistically significant.

[a] Total represents the number of patients in all dental and skeletal maturational stages.

**Table 2** Distribution of cervical vertebral maturation (CVM) stages III & IV, according to maturity of maxillary and mandibular right and left third molars for both genders (Nolla method).

| Tooth | | Max Rt *Third Molar* | | Max Lt *Third Molar* | | Mand Rt *Third Molar* | | Mand Lt *Third Molar* | |
|---|---|---|---|---|---|---|---|---|---|
| CVS | | III | IV | III | IV | III | IV | III | IV |
| Nolla stages | | No (%) | No (%) | No (%) | No (%) | No (%) | No (%) | No (%) | No (%) |
| Males | 5 | 5(20) | | 6(24) | | 8(30.8) | | 8(30.8) | |
| | 6 | 5(20) | 3(16.7) | 5(20) | 2(11.1) | 3(11.5) | | 3(11.5) | |
| | 7 | 3(12) | 5(27.8) | 3(12) | 6(33.3) | 3(11.5) | 8(44.4) | 3(11.5) | 8(44.4) |
| | 8 | 3(3.8) | 7(38.9) | 3(3.8) | 7(38.9) | 4(3.8) | 6(0) | 4(8.3) | 6(0) |
| | 9 | | 2(11.1) | 1(4) | 2(11.1) | | 2(11.1) | | 2(11.1) |
| | **Total**[a] | **25(100)** | **18(100)** | **25(100)** | **18(100)** | **26(100)** | **18(100)** | **26(100)** | **18(100)** |
| | r-value | 0.610 | | 0.639 | | 0.497 | | 0.396 | |
| | P-value | .000 | | .000 | | .000 | | .000 | |
| Females | 5 | 4(14.8) | 5(13.90) | 3(11.10 | 6(16.70 | 5(18.50 | 6(16.7) | 5(18.5) | 8(22.2) |
| | 6 | 8(29.6) | 11(30.6) | 9(33.3) | 8(22.2) | 8(29.6) | 5(13.9) | 8(29.6) | 6(16.7) |
| | 7 | 6(22.2) | 12(33.3) | 6(22.2) | 13(36.1) | 5(18.5) | 9(25) | 5(18.5) | 7(19.4) |
| | 8 | 1(3.7) | 1(2.8) | 1(3.7) | 1(2.8) | | 3(8.3) | | 3(8.3) |
| | **Total**[a] | **27(100)** | **36(100)** | **27(100)** | **36(100)** | **27(100)** | **36(100)** | **27(100)** | **36(100)** |
| | r-value | 0.540 | | 0.519 | | 0.480 | | 0.472 | |
| | P-value | .000 | | .000 | | .000 | | .000 | |

r = Spearman rank order correlation coefficient, P ≤ .05 were considered statistically significant.
[a] Total represents the number of patients in all dental and skeletal maturational stages.

**Table 3** Distribution of cervical vertebral maturation (CVM) stages III and IV according to mandibular left canine tooth maturity for both genders (Demirjian method).

| Tooth | | Mand *Lt Canine* | |
|---|---|---|---|
| CVS | | III | IV |
| *Demerjian maturational stages* | | *No (%)* | *No (%)* |
| Males | *F* | 1(3.8) | |
| | *G* | 8(30.8) | 2(11.1) |
| | *H* | 17(65.4) | 16(88.9) |
| | **Total**[a] | **26(100)** | **18(100)** |
| | *r-value* | 0.700 | |
| | *P-value* | .000 | |
| Females | *F* | | 1 (2.8) |
| | *G* | 7(25.9) | 3(8.3) |
| | *H* | 20(74.1) | 32(88.9) |
| | **Total**[a] | **27(100)** | **36(100)** |
| | *r-value* | 0.443 | |
| | *P-value* | .000 | |

r = Spearman rank order correlation coefficient, P ≤ .05 were considered statistically significant.
[a] Total represents the number of patients in all dental and skeletal maturational stages.

**Table 4** Distribution of cervical vertebral maturation (CVM) stages III & IV according to mandibular third molar maturity for both genders (Demirjian method).

| Tooth | | Mand *Third Molar* | |
|---|---|---|---|
| CVS | | III | IV |
| *Demerjian maturational stages* | | *No (%)* | *No (%)* |
| Males | *D* | 12(48) | |
| | *E* | 4(16) | 7(38.9) |
| | *F* | 3(12) | 7(38.9) |
| | *G* | | 2(11.1) |
| | *H* | | |
| | **Total**[a] | **25(100)** | **18(100)** |
| | *r-value* | 0.578 | |
| | *P-value* | .000 | |
| Females | *D* | 13(50) | 17(51.5) |
| | *E* | 6(23.1) | 8(24.2) |
| | *F* | | 2(6.1) |
| | *G* | | |
| | *H* | | |
| | **Total**[a] | **27(100)** | **33(100)** |
| | *r-value* | 0.501 | |
| | *P-value* | .000 | |

r = Spearman rank order correlation coefficient, P ≤ .05 were considered statistically significant.
[a] Total represents the number of patients in all dental and skeletal maturational stages.

9 (34.6% and 38.5%, respectively) and 10 (61.5% and 57.7%, respectively); the highest percentage approached stage 10. Similarly, females at CVM stage III largely had maxillary right and left canines in developmental stage 10, at a slightly higher percentage than males (66.7% and 70.4%, respectively). Mandibular right and left canines were at stage 10 among both males and females, with a percentage ranging from 65.4% to 74.1%.

Moreover, the maxillary and mandibular right and left third molars among males in CVM stage III were most often at developmental stage 5, with a percentage ranging from 20% to 30.8%. At CVM IV the percentage of mandibular right and left third molars at stage 7 was higher (44.4%) than that of maxillary right and left third molars at stage 8 (38.9%).

**Table 5** Percentage distribution of dental calcification stages of canine teeth and third molars according to skeletal maturity stages in males and females by the Nolla method.

| Teeth included | Males CVM III | Stage | Males CVM IV | Stage | Females CVM III | Stage | Females CVM IV | Stage |
|---|---|---|---|---|---|---|---|---|
| URC | 61.50% | 10 | 100% | 10 | 66.70% | 10 | 86.10% | 10 |
| ULC | 57.70% | 10 | 94.40% | 10 | 70.40% | 10 | 86.10% | 10 |
| LRC | 65.40% | 10 | 94.40% | 10 | 74.10% | 10 | 86.10% | 10 |
| LLC | 65.40% | 10 | 88.90% | 10 | 74.1 | 10 | 88.90% | 10 |
| URM | 20% | 5 & 6 | 38.90% | 8 | 29.60% | 6 | 30.6 | 6 |
| ULM | 24% | 5 | 38.90% | 8 | 33.30% | 6 | 22.20% | 6 |
| LRM | 30.80% | 5 | 44.40% | 7 | 29.60% | 6 | 16.70% | 5 |
| LLM | 30.8 | 5 | 44.40% | 7 | 29.60% | 6 | 22.20% | 5 |

U: upper, L: lower, R: right, L: left, C: canine, M: third molar.

**Table 6** Percentage distribution of dental calcification stages of canine teeth and third molars according to skeletal maturity stages in males and females by the Demirjian Method.

| Teeth included | Males CVM III | Stage | Males CVM IV | Stage | Females CVM III | Stage | Females CVM IV | Stage |
|---|---|---|---|---|---|---|---|---|
| LLC | 65.40% | H | 89% | H | 74.10% | H | 88.90% | H |
| LLM | 48.00% | D | 38.90% | E&F | 50.00% | D | 51.50% | D |

LLC: lower left canine, LLM: lower left third molar.

In contrast, among females at CVM stage III, maxillary right, mandibular right, and mandibular left third molars had the same percentage (29.6%) at stage 6, while the left maxillary third molar had a slightly higher percentage at stage 6 (33.3%). At CVM IV females had different percentages for right and left maxillary and right mandibular third molars at stage 7 (33.3%, 36.1%, and 25%, respectively). Surprisingly, 22.2% of mandibular left third molars were at stage 5.

*3.3.2. Demirjian method: (Table 6)*

In males and females at CVM stage III the highest percentage of mandibular left canine teeth were at Demirjian developmental stage H (65.4% in males and 74.1% in females); 88.9% of teeth were at stage H in female patients at CVM IV. In addition, a higher percentage of mandibular left third molars were at stage D in both males and females at CVM stage III (48% and 50%, respectively). However, at CVM stage IV females had a higher percentage of teeth at stage D (51.5%) compared with males (38.9%) and at E and F stages.

## 4. Discussion

The correlation between skeletal and dental age has been debated in orthodontics. Some studies have supported the correlation between skeletal maturation and dental development (Demisch and Wartmann, 1956; Lilliequist and Lundberg, 1971), while others have found only a weak correlation (Lewis and Garn, 1959; Acheson and Dupertuis, 1957; Falkner et al., 1962). In addition, racial differences in these correlations have been suggested (Engstrom et al., 1983; Chertkow, 1980; Taher and Foda, 2001; Al-Emran, 2008; Baccetti et al., 2005). This controversy may result from the different methodologies used to assess dental and skeletal ages. Also some studies that reported a weak correlation used dental eruption as a measurement of dental age, which is an unreliable method because dental eruption is highly variable.

Several studies have found a high correlation between CVM stage and the hand-wrist method (HWM) in indicating skeletal maturity (Alkhal et al., 2008; Sachan et al., 2011; Uysal et al., 2006; Kucukkeles et al., 1999). However, a study by Alkhal et al. (2008) found low correlations between CVM and HWM and chronological age among the southern Chinese population, indicating that chronological age is an unreliable method of assessing skeletal maturity.

The present study revealed an association between canine tooth developmental stages and skeletal CVM stages III and IV, with the mandibular left canine having a stronger correlation coefficient than the maxillary canine in the two methods used (Nolla at stage 10 and Demirjian at stage H), especially for male patients. This finding agrees with that of Taher and Foda (2001), who found a significant relationship between canine tooth development (at stage G) and CVM stages III and IV. Likewise, Khan and Ijaz (2011) found a strong correlation between canine tooth developmental stages F and G and the skeletal growth spurt, using HWM instead of CVM. Those stages were closely related to the calcification of the adductor sesamoid and capping of the third middle phalanx; calcification of the adductor sesamoid and capping of the third middle phalanx on hand-wrist radiographs indicate peak growth stages among Caucasian children, and correspond to CVM stages III and IV. Additionally, Rozylo-Kalinowska et al. (2010) reported the same significant results in the Polish population for males at stage G (57.38%) and females at canine stage H (74.14%). Hasan and Abuafan (2016) established a similar high correlation in the Sudanese population, ranging from 0.586 in females to 0.759 in males and with 50% of canine teeth at stage G and 46.1% at stage F. We found higher percentages in our male Saudi patients at CVM stages III and IV (65.4% and 89%, respectively) (Table 5) than those reported for Egyptians (50% and 57%, respectively) (Taher and Foda, 2001). However, very similar values were reported for Pakistani children at CVM stages III and IV (Solmaz et al., 2013) (65.3% and 87.5% of canine teeth at stage G and H, respectively) and Iranian females (Goyal et al., 2014) (64.8% and 93.8% of canine teeth at stage H, respectively). This finding indicates that Saudi children reach the growth spurt peak later than Egyptian, Sudanese, Polish, and Pakistani children, but that growth-spurt timing is similar to that of Iranian and Polish females.

The results of Coutinho et al. (1993) in the US population (r = 0.53–0.85), Rasool et al. (2014) in the Pakistani population (r = 0, 0.871), and Goyal et al. (2014) in the Rwandan African population (r = 0.599 for males and 0.719 for females) are similar to our results, with a higher correlation between the mandibular canine and skeletal maturity indicators. In addition, Sachan et al. (2011) reported a good correlation between canine tooth development at stage 9 and skeletal maturity for both males and females (r = 0.635 and 0.891, respectively). In addition, Srkoc et al. (2015) found a high correlation between canine tooth development and skeletal maturity in both males and females in the Croatian population (r = 0.6 and 0.567, respectively). Among male subjects at CVM stage III in that study, 57.1% had canine teeth at stage F; among females, 35.7% had canine teeth at stages E and F. That study also reported that among males and females at CVM stage IV, 62% and 72.1%, respectively, had canine teeth at stage H. Our results showed that the mandibular left canine tooth development had a stronger correlation with skeletal maturation (r = 0.7) than the right canine tooth (r = 0.692), at stage 10 according to the Nolla method and stage H according to the Demirjian method, especially in males. Surprisingly, females showed weaker correlation in both methods (r = 0.418 and 0.443, respectively), a finding that disagrees with that of Sachan et al. (2011) who reported a higher correlation among the Indian population than our study for males and females (r = 0.891 and 0.635, respectively), but using the HWM. Likewise, Rasool et al. (2014) and Solmaz et al. (2013) both found higher correlations among female subjects than our study (r = 0.871 and 0.702–0.75, respectively).

Our findings disagree with those of Sachan et al. (2011), who reported a lower correlation between canine tooth development and skeletal maturity in males (r = 0.49) and higher correlation in females (r = 0.53) in the Greek population. Listas and Lucchese (2016) also found that the percentages of canine teeth at developmental stage H among patients at CVM stages III and IV were higher than our findings in both males (80.4% and 85.2%, respectively) and females, (92.3% and 97.1%, respectively). In addition, an association between third molar developmental stage and skeletal CVM stages III and IV was detected, but canine tooth development showed a stronger correlation than third molar development with skeletal maturation. Suma et al. (2011) reported strong correlations between third molar development at stages D (complete crown formation) and E (one-third of the root formed) and skeletal maturity in both males and females (r = 0.88 for maxillary and mandibular third molars in males; r = 0.77 for maxillary and 0.89 for mandibular third molars in females). Interestingly, that group found that mandibular third molars are more reliable for age estimation. Furthermore, Engstrom et al. (1983) also showed stronger correlation values than our study (r = 0.72, $P \leq .001$). Likewise, Mehta et al. (2016) found correlations close to those of Suma et al. (0.809 and 0.723) in males and females, respectively. In patients at CVM stage III, 60% were at Demirjian stage C and 40.9% were at stage D; 50% of males at CVM stage IV were at Demirjian stage D. That study found that CVM stages III and IV among females corresponded to Demirjian stages B and C (42.9% and 53.3%, respectively) and stages C and D (33.3% and 31.8%, respectively).

All of the above-mentioned studies disagreed with our results, which surprisingly showed that the right and left maxillary third molars had a stronger correlation coefficient (r = 0.610 and r = 0.639, respectively) than the right and left mandibular third molars (r = 0.497 and r = 0.396, respectively) according to the Nolla method in male patients. In contrast, females had a lower correlation coefficient than males for the maxillary right and left third molars (r = 0.540 and r = 0.519, respectively), but better correlation coefficients than males for the mandibular right and left third molars (r = 0.480 and r = 0.472, respectively), according to the Nolla method. As expected, mandibular third molars exhibited better correlation coefficients in males and females according to the Demirjian method (r = 0.578 and 0.501, respectively; $P \leq .001$) (Tables 2–4). Our results with both methods still show weaker correlations than those reported by Suma et al. (2011), Engstrom et al. (1983), and Mehta et al. (2016).

Contrary to the findings of the previously mentioned studies but similar to our results, Garn and Rohman (1962), and Lewis and Garn (1959) found low correlation between lower third molar calcification stages and skeletal maturation. This difference in results among studies is attributed to the fact that different methodologies were used to assess skeletal and dental ages in the earlier studies. However, the correlation coefficients of the studies are highly significant, with $P \leq .001$.

The Demirjian method provided higher correlation coefficient values for both genders than the Nolla method, which exhibited higher values for the maxillary than mandibular third molar, especially in males. Moreover, the maxillary third molars are more prone to be missing than mandibular third molars. The Demirjian method could be considered a more reliable method for age estimation than the Nolla method. We used the Nolla and Demirjian methods because they are simple, based on orthopantograms, and allow for reliable standardization. These are widely used methods and have good reproducibility and inter- and intra-examiner concordance.

Our study focused on both the canine teeth and third molars because previous studies on chronological age have been performed using either the canine tooth or the third molar and evaluating skeletal age with hand-wrist skeletal maturational indicators, not maturational stage of the cervical vertebra. The only exception is a study conducted in the Saudi population assessing the correlation between skeletal maturational stage and dental developmental stage by Al-Hadlaq et al. (2008). That group reported a strong correlation between skeletal maturational stage and dental developmental stage of the canine tooth (r = 0.679). However, the highest correlations were with the first premolar and second molar (r = 0.729 and 0.720, respectively) among Saudi male children with HWM. Also, Al-Hadlaq et al. (2007) and Baidas (2012) found a strong correlation between HWM and CVM stages and chronological age among Saudi adolescents and Saudi male children, respectively. Al-Emran (2008) assessed the dental age in relation to chronological age using the Demirjian method and found that Saudi children showed more advanced dental age than their chronological age. Moreover, a study by Taher and Foda (2001) in Egyptian children using the same method to assess cervical vertebrae and canine calcification stages as skeletal maturational indicators found a highly significant relationship between all of the cervical vertebrae maturational stages and mandibular canine calcification stages.

Thorough review of the literature indicates that our study might be the first to evaluate both the canine teeth and third molars simultaneously using the two most popular assessment methods. Furthermore, our study compared their correlations with cervical vertebrae skeletal maturation, as well as with each other. Focusing on the evidence of the previously illustrated findings, our results indicate that with the Nolla method clinicians can detect the growth spurt in Saudi patients by looking either at the canine calcification stage at stage 9 (root is complete but apex remains open) or at stage 10 (closed apex). Using the third molar, the growth spurt can be predicted at stage 5 (crown almost complete) or stage 7 (one-third of the root complete).

Lastly, with the Demirjian method practitioners can detect the growth spurt by evaluating either the lower left canine at stage H (complete apex) or lower third molar at stage D (complete crown). This might be considered a primary diagnostic step to determine the exact timing of the pubertal growth spurt without exposing patients to extra radiographs. One of the foremost limitations of our study was the sample size, which should be larger to confirm the present results in further extensive studies.

## 5. Conclusions

1. The growth spurt in Saudi patients can be estimated using the Nolla method by evaluating either the canine calcification at stage 9 (root is completed but apex remains open) or 10 (apex is closed). Using the third molar, the growth spurt occurs at stage 5 (crown almost completed) or stage 7 (1/3 of the root is completed).
2. Using the Demirjian method, the growth spurt can be predicted when the lower left canine is at stage H (apex is completed) or when the lower third molar is at stage D (crown is completed), with the canine favored over the third molar.
3. Development of the left mandibular canine according to the Demirjian method showed a stronger correlation with skeletal maturational stages CVM III and CVM IV, especially in male subjects, than either the mandibular third molar with the same method or the maxillary right or left canine and maxillary or mandibular third molar with Nolla's method.

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## Conflict of interest

The authors have no affiliation or financial involvement with organizations or entities with a direct financial interest in the subject matter or materials discussed in the manuscript. No funding was received for this work from any organization.

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