

Original Research Article

THE CORRELATION BETWEEN DENTAL AND CHRONOLOGICAL AGE OF ORTHODONTIC PATIENTS; A CROSS-SECTIONAL STUDY USING THIRD MOLAR DEVELOPMENT

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Received : 18/07/2026
Received in revised form : 23/09/2026
Accepted : 02/10/2026

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DOI: 10.70034/ijmedph.2026.4.78

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2026; 16 (4); 527-532

ABSTRACT

Background: Dental development provides an important biological indicator of maturation and has applications in orthodontics, forensic odontology, and clinical dentistry. The objective is to determine the correlation between dental age and chronological age among orthodontic patients aged 10–14 years using third-molar development assessed according to the Köhler method.

Materials and Methods: A cross-sectional study was conducted among 100 orthodontic patients aged 10–14 years. Panoramic radiographs were evaluated for third-molar developmental stage using the ten-stage Gleiser–Hunt classification modified by Köhler. Chronological age was calculated from the date of birth and date of radiographic examination. Dental age was estimated according to the age corresponding to the recorded Köhler developmental stage. Descriptive statistics were calculated, and Spearman's rank correlation coefficient was used to assess the association between Köhler developmental stage and chronological age.

Results: The participants had a mean chronological age of 12.16 ± 1.39 years. The mean estimated dental age was 12.04 ± 1.42 years, with a mean chronological–dental age difference of 0.12 ± 0.74 years. A strong positive correlation was observed between chronological age and Köhler developmental stage (Spearman's $\rho = 0.82$, $p < 0.001$). Similar significant positive relationships were observed among males ($\rho = 0.84$, $p < 0.001$) and females ($\rho = 0.79$, $p < 0.001$).

Conclusion: Third-molar development assessed using the Köhler method showed a strong positive correlation with chronological age among orthodontic patients aged 10–14 years. The findings support the use of standardized third-molar developmental assessment as a useful component of dental-age estimation in this age group.

Keywords: Dental age; chronological age; Köhler method; third molar; orthodontic patients; dental development.

INTRODUCTION

Age estimation is an important component of clinical dentistry, orthodontics and forensic odontology.^[1] Chronological age is determined according to the date of birth, whereas dental age reflects the biological maturity of dentition. Because tooth

development occurs through a relatively ordered sequence of morphological changes, dental maturation can provide useful information about an individual's biological development. Dental age assessment has therefore been incorporated into orthodontic diagnosis, treatment planning, growth assessment and forensic investigations. Recent

literature continues to identify dental development as an important biological indicator for age estimation, particularly during childhood and adolescence.^[2] Radiographic assessment of tooth development has several advantages over methods based exclusively on physical characteristics. Tooth mineralization can be evaluated objectively through recognizable developmental landmarks, and panoramic radiography permits visualization of multiple teeth on a single image. However, dental-age estimation is not completely independent of biological variation. Differences associated with sex, ethnicity, population characteristics and developmental timing may affect the relationship between dental and chronological age. Consequently, methods developed in one population may not provide identical results when applied to another population.^[3,4]

Several dental-age estimation methods have been developed, including the Demirjian, Willems, Cameriere, Nolla and third-molar developmental approaches.^[5] Systematic reviews have demonstrated that the accuracy of dental-age methods varies according to population and age group, reinforcing the importance of population-specific evaluation and validation.^[6,7] Although methods based on several permanent teeth are particularly useful during childhood, their applicability becomes more limited as these teeth approach completion of development.^[8] Third molars are distinctive because their development continues over a considerably longer period than most other permanent teeth.^[9] Third-molar development has consequently been investigated extensively as a radiographic marker of biological maturity. The Gleiser–Hunt classification modified by Köhler divides third-molar development into ten recognizable stages. The early stages describe progressive crown formation, intermediate stages describe root formation, and the later stages correspond to advanced root and apical development. This staging system provides an ordered framework for evaluating the maturation of third molars on panoramic radiographs.^[10] Recent investigations have continued to support the usefulness of the Gleiser–Hunt system modified by Köhler. A study of Russian panoramic radiographs found that third-molar developmental staging could be used to distinguish individuals around clinically relevant age thresholds, although accuracy varied according to the age threshold and population.^[11] More recent work involving 1,475 panoramic radiographs also demonstrated that regression equations incorporating Köhler developmental stages, particularly the left third molar, provided useful predictions of chronological age.^[12] Evidence from Pakistan is especially relevant to the present study. A Pakistani study involving 385 individuals aged 12–28 years evaluated third-molar calcification using the ten-stage Köhler system and found a significant relationship between third-molar development and chronological age. The authors also reported strong measurement agreement and found the mandibular left third molar to be particularly informative.^[13]

These findings support the need for further assessment of the relationship between chronological age and third-molar development within more narrowly defined adolescent age groups. The use of dental age in orthodontic patients is clinically relevant because chronological age alone does not always reflect the biological stage of dental maturation. During adolescence, patients of the same chronological age may demonstrate different degrees of tooth development. Understanding the relationship between chronological age and dental maturation may therefore contribute to more appropriate interpretation of dental development during orthodontic assessment.^[14] Statistical methodology is also important when evaluating dental developmental stages. A developmental stage is an ordered categorical variable rather than a continuous measurement. Therefore, treating a stage score as though the intervals between successive stages were identical can result in inappropriate statistical interpretation. Rank-based methods such as Spearman's correlation are more appropriate when assessing the monotonic relationship between an ordinal developmental stage and chronological age. Contemporary research on third-molar developmental stages has similarly incorporated regression and non-parametric approaches according to the nature of the variables being analysed.^[11,12] The present study was therefore designed to examine the relationship between dental age and chronological age among orthodontic patients aged 10–14 years using third-molar development assessed according to the Köhler method. The study specifically focused on whether progressive third-molar developmental stages were associated with increasing chronological age within this defined adolescent age group.

Objective: To determine the correlation between dental age and chronological age among orthodontic patients aged 10–14 years using third-molar development assessed according to the Köhler method.

MATERIALS AND METHODS

A cross-sectional analytical study was conducted among orthodontic patients aged 10–14 years. Participants were recruited from the orthodontic patient population and were eligible when they fell within the specified age range and had a diagnostic-quality panoramic radiograph showing the mandibular third molar adequately for developmental assessment. The age range was restricted to 10–14 years to provide a clearly defined developmental period and to maintain consistency with the study objective. Patients were excluded when the third molar was absent, affected by a developmental anomaly that could interfere with staging, or inadequately visualized because of radiographic distortion or image-quality limitations. Radiographs were obtained as part of routine orthodontic assessment, and no additional radiographic exposure

was performed solely for the purpose of the study. Chronological age was calculated from the date of birth to the date on which the panoramic radiograph was obtained. Age was recorded in completed years and months and subsequently converted to decimal years for statistical analysis. For example, a participant aged 12 years and 6 months was recorded as 12.50 years. This approach allowed chronological age to be represented continuously while preserving the precision of the participant's actual age at the time of radiographic examination. Third-molar development was assessed using the ten-stage Gleiser–Hunt classification modified by Köhler. The method evaluates progressive morphological development of the third molar on panoramic radiographs. Stages 1–4 represent progressive crown formation, beginning with initial cusp calcification and progressing toward completion of the crown. Stages 5–8 represent progressive root formation, beginning with the initiation of root development and continuing through increasing root completion. Stages 9 and 10 represent advanced root and apical development. This ten-stage approach has been used in recent studies evaluating the relationship between third-molar maturation and chronological age.^[12]

The mandibular left third molar was selected as the principal tooth for analysis because previous Pakistani and international studies have demonstrated that the left mandibular third molar can provide a strong relationship with chronological age and can be particularly useful in regression-based age estimation.^[14] When the left mandibular third molar could not be assessed adequately, the radiograph was excluded rather than substituting a different tooth, thereby maintaining a consistent measurement strategy throughout the study. The radiographic developmental stage was assigned by comparing the morphology of the third molar with the standardized Köhler developmental criteria. The observer assessed the degree of crown and root development and assigned the stage corresponding to the closest morphological description. The developmental stage score was recorded as an ordinal value from 1 to 10. The stage score itself was not interpreted as a direct age in years. Instead, dental age was derived by matching the observed developmental stage with the corresponding age distribution used for the Köhler-based age-estimation approach. This distinction is important because the numerical stage represents a developmental category and not an interval-scale age measurement. Recent work using the Köhler method similarly relates developmental stage to chronological age through population-specific age distributions and regression equations.

For the purposes of age estimation, each developmental stage was assigned its corresponding expected age based on the reference relationship between third-molar developmental stage and chronological age. Where a regression-based estimate was used, the estimated dental age was obtained from the applicable relationship between developmental stage and chronological age rather

than by simply equating stage number with years of age. This approach avoids the methodological error of interpreting, for example, Köhler stage 5 as equivalent to 5 years of age.

The sample size was determined according to the primary statistical objective of assessing the correlation between chronological age and dental developmental stage. Assuming a moderate expected correlation of 0.30, a two-sided significance level of 5% and 80% statistical power, the Fisher z-transformation approach produced a minimum sample size of approximately 85 participants. Allowing for approximately 15% potential exclusion due to incomplete demographic information, inadequate radiographic visualization or other eligibility problems, the required recruitment target was approximately 100 participants. Accordingly, 100 eligible orthodontic patients were included in the analysis.

Data was entered into a structured database and analyzed using statistical software. Continuous variables were summarized using mean and standard deviation, while categorical variables were summarized using frequencies and percentages. The mean chronological age estimated dental age and difference between chronological and estimated dental age were calculated for the overall sample and separately by sex. The primary association was evaluated between chronological age and Köhler developmental stage. Spearman's rank correlation coefficient was used because the Köhler developmental-stage score is ordinal. A positive coefficient indicated that higher developmental stages were associated with higher chronological age. Statistical significance was established at $p < 0.05$ using a two-sided test. Because correlation assesses the strength and direction of association rather than agreement, the difference between chronological age and estimated dental age was also examined descriptively. The mean difference was calculated as chronological age minus estimated dental age. A positive value indicated that estimated dental age was lower than chronological age, whereas a negative value indicated that estimated dental age was higher than chronological age. To assess reproducibility of developmental-stage assignment, a subset of radiographs was independently reassessed by the same observer after an interval and by a second trained observer. Agreement was evaluated using appropriate reliability statistics for ordinal data. A high level of agreement was considered evidence that developmental-stage classification was reproducible. Ethical approval was obtained from the relevant institutional ethics committee before initiation of the study. The study used panoramic radiographs obtained for routine orthodontic assessment, and no additional radiation exposure was required for research purposes. Participant information was kept confidential, and identifying information was not included in the analytical database or manuscript.

RESULTS

A total of 100 orthodontic patients aged 10–14 years were included in the analysis. There were 52 males

(52.0%) and 48 females (48.0%). The overall mean chronological age was 12.16 ± 1.39 years. The age distribution was balanced across the five years of the study population, with 20 participants represented in each chronological-year group as shown in [Table 1].

Table 1: Distribution of participants according to chronological age and sex

Chronological age	Male n (%)	Female n (%)	Total n (%)
10 years	10 (19.2)	10 (20.8)	20 (20.0)
11 years	10 (19.2)	10 (20.8)	20 (20.0)
12 years	11 (21.2)	9 (18.8)	20 (20.0)
13 years	11 (21.2)	9 (18.8)	20 (20.0)
14 years	10 (19.2)	10 (20.8)	20 (20.0)
Total	52 (100)	48 (100)	100 (100)

The mean chronological age was 12.18 ± 1.42 years among males and 12.14 ± 1.37 years among females. The corresponding mean estimated dental age was

12.11 ± 1.46 years among males and 11.97 ± 1.38 years among females as shown in [Table 2].

Table 2: Chronological age and estimated dental age according to sex

Variable	Total (n=100)	Male (n=52)	Female (n=48)
Chronological age, mean $\pm$ SD	12.16 ± 1.39	12.18 ± 1.42	12.14 ± 1.37
Dental age, mean $\pm$ SD	12.04 ± 1.42	12.11 ± 1.46	11.97 ± 1.38
Mean age difference	0.12 ± 0.74	0.07 ± 0.76	0.17 ± 0.71

The distribution of developmental stages demonstrated progressive maturation with increasing chronological age. Earlier stages were observed predominantly among younger participants, whereas more advanced stages occurred with increasing frequency among participants aged 13–14 years. The overall association between chronological age and

Köhler developmental stage was strong and statistically significant. Spearman's correlation coefficient was 0.82 ($p < 0.001$), indicating that participants with higher chronological age generally demonstrated more advanced third-molar developmental stages as shown in [Table 3].

Table 3: Correlation between chronological age and Köhler developmental stage

Analysis	Spearman's ρ	p-value
Total sample	0.82	< 0.001
Male participants	0.84	< 0.001
Female participants	0.79	< 0.001

DISCUSSION

The present study demonstrated a strong positive correlation between chronological age and third-molar developmental stage among orthodontic patients aged 10–14 years. The principal finding was a Spearman's correlation coefficient of 0.82, indicating that increasing chronological age was accompanied by progressive advancement in third-molar development. This finding is consistent with the biological basis of dental-age estimation. Tooth development occurs through recognizable morphological stages, and radiographic assessment allows these stages to be identified objectively. The third molar is particularly relevant during adolescence because its development continues after most other permanent teeth have reached advanced stages of formation. Consequently, third-molar maturation can provide additional information regarding biological development during periods when other dental markers become less informative.^[15] The findings are also consistent with evidence from Pakistan. Bashir and colleagues evaluated 385 Pakistani individuals using the ten-

stage Köhler system and found a significant relationship between chronological age and third-molar developmental stage. Their analysis also identified the mandibular left third molar as particularly informative.^[16] The present findings extend this evidence by focusing specifically on the narrower 10–14-year age range. The strength of the association observed in this study indicates that the Köhler developmental stage contains substantial age-related information within the study population. However, the correlation should not be interpreted as demonstrating that every individual at a particular chronological age will have the same developmental stage. Dental maturation is a biological process and consequently demonstrates individual variability.^[17,18]

This distinction is important when interpreting dental-age estimates. A strong correlation indicates that two variables tend to increase together, whereas agreement evaluates how closely two measurements correspond for individual participants. A method may therefore demonstrate a strong correlation while still producing clinically relevant individual differences. For this reason, the present study reports both the

correlation coefficient and the difference between chronological and estimated dental age. The mean chronological age was 12.16 years, compared with an estimated dental age of 12.04 years. The mean difference of 0.12 years suggests only a small group-level discrepancy. Similar small differences between chronological and estimated dental age have been reported for several established dental-age methods, although the direction and magnitude of error vary according to population and method. Systematic reviews have demonstrated that ethnicity and population characteristics can influence dental-age estimation.^[19] A radiographic assessment of third-molar development may provide supplementary information regarding biological maturity. This does not replace chronological age but can contribute to a broader understanding of the developmental status of the patient. The results are also relevant to forensic dentistry, although the age range examined here is narrower than that used in many medico-legal investigations. Recent research has shown that Köhler-based third-molar assessment can assist with age classification, but accuracy is influenced by the age threshold, population and developmental distribution.^[12,16] Therefore, the findings should be applied within the age range and population represented by the study rather than generalized to other populations without validation. An important consideration is that third molars are biologically variable. Variation in their presence, formation and maturation can affect their usefulness for age estimation. The use of strict inclusion and exclusion criteria in the present study was therefore important for ensuring that developmental stages could be assessed consistently. The study had several strengths. First, the age range was clearly restricted to 10–14 years, reducing heterogeneity related to widely different developmental periods. Second, the same radiographic developmental classification was used for all participants. Third, the primary statistical analysis used a method appropriate for ordinal developmental-stage data. Fourth, the mandibular left third molar was selected consistently, allowing a uniform assessment strategy. The study also has limitations. Its cross-sectional design does not permit assessment of developmental progression within the same individuals over time. The sample was derived from orthodontic patients and may therefore not represent all children in the general Pakistani population. The relatively narrow age range also limits generalizability beyond 10–14 years. In addition, dental development demonstrates individual biological variability, meaning that an estimated dental age should not be interpreted as an exact substitute for documented chronological age. The sample size was based on the primary correlation objective using a moderate anticipated correlation. Although the resulting sample provided adequate statistical power for detecting the expected association, larger multicenter studies would provide greater precision and permit development of sex-specific and population-specific reference models.

Future research should evaluate larger samples from multiple regions of Pakistan and should examine whether developmental timing differs among geographical and demographic groups. Studies could also compare Köhler-based estimates with other established dental-age methods to determine which approach provides the smallest individual prediction error in Pakistani children. Recent literature emphasizes the importance of population-specific calibration and appropriate interpretation of uncertainty when applying dental-age methods.^[20,21] Overall, the strong association observed in the present study supports the biological usefulness of third-molar developmental staging during adolescence. The findings indicate that as chronological age increased from 10 to 14 years, third-molar developmental stage generally progressed in an ordered manner. This supports the use of Köhler staging as a component of dental-age assessment in orthodontic patients within this age range.

CONCLUSION

A strong positive correlation was observed between chronological age and third-molar developmental stage assessed using the Köhler method among orthodontic patients aged 10–14 years. The estimated dental age was close to chronological age at the group level, with a mean difference of 0.12 years. The significant Spearman correlation demonstrated that advancement in Köhler developmental stage was associated with increasing chronological age. The Köhler method may therefore provide a useful radiographic approach for assessing dental maturation and estimating dental age in orthodontic patients aged 10–14 years, while individual estimates should be interpreted in consideration of normal biological variation and population-specific differences.

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