Original Article

Age estimation using intraoral periapical radiographs

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Abstract

Context: Changes in the size of dental pulp caused by the apposition of secondary dentin and occlusal wear are morphometric parameters for estimating age. **Aim:** To estimate the accuracy of age evaluation by Kvaal's method and the effect of occlusal wear on age using digital intraoral periapical radiographs in a subset of the Indian population. **Materials and Methods:** A total of 300 teeth were radiographically evaluated using intraoral periapical digital radiographs from 50 adult patients. A few modifications were made in the design of the study compared to the original Kvaal's method. The radiographs of three teeth from each jaw were taken and morphometric measurements in ratios were analyzed, which included the pulp length to tooth length (X_1), pulp length to root length (X_2), pulp width to root widths at three defined levels (X_3), and tooth length to root length (X_4). **Statistical Analysis:** The Pearson product-moment correlation coefficient (PCC) between age and the morphological variables showed that among them X_1, X_2, and X_3 were statistically significant but not the tooth root length ratio (X_4). **Conclusions:** The ratios X_1, X_2, and X_3 were good indicators of age and hence a multiple linear regression model for age estimation was derived using these three variables. However, it was found that X_4 was not a good indicator of age estimation in said population.

Key words: Age estimation, dental radiographs, noninvasive, pulpal reduction, secondary dentin

Introduction

Developmental changes and regressive changes of the tooth have been related to chronological age in adult and subadult populations.[1,2]

The underlying concept of the study was that pulpal reduction caused by apposition of secondary dentin and occlusal tooth wear are used as morphometric parameters in estimating age.[3,4]

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The timing of the secondary dentin formation is fit by a curved line rather than a straight line with underlying chronological differences. Hence, there is a need for research to provide sufficient data for age estimation.[5]

The aim was thus to estimate the accuracy of age evaluation by the analysis of measurements of dental pulp and effects of occlusal wear using digital intraoral periapical radiographs in a subset of the Indian population.

Materials and Methods

Kvaal *et al*. in 1995[6] reported a method that allows age estimation based on the morphological measurements of two-dimensional radiographic features of individual teeth. The measurements include comparisons of pulp length and tooth length (X_1), pulp length and root length (X_2), pulp and root widths at three defined levels (X_3) and tooth length and root length (X_4). Our study of age estimation was based on the concept as given by Kvaal *et al*.,[6] although a few changes in the study design were made to assess whether the accuracy of age estimation can be influenced.

50 patients, ages 15-57 years old and each with known chronological age, were randomly selected irrespective of their religion or gender [Table 1]. Each patient's chronological age was noted after verifying his/her respective identity proof. Informed consent was obtained from all the patients. The institutional ethical committee approved the protocol of this study.

Six teeth were selected for each patient: One maxillary central incisor, one maxillary lateral incisor, one maxillary second premolar, one mandibular central incisor, one mandibular lateral incisor, and one mandibular second premolar. The teeth were selected from the right or the left side randomly.[6] The examined teeth had to be in normal functional occlusion and free from any manifestations of traumatic results. Furthermore, teeth with fillings, crowns, and carious lesions were excluded from evaluation. Teeth with pathologies in the apical bone, and rotated or endodontically treated teeth were also excluded.

High-quality digital intraoral periapical radiographs with respect to contrast and angulation were made at an exposure of 10 mA and 70 kVp using the Satelec X-mind intraoral x-ray machine (Acteon Company, Italy) and the Kodak RVG 5000 digital radiography system (Eastman Kodak Company, Rochester, NY). Paralleling technique was used, employing the Rinn XCP-DS positioning device (Dentsply International Inc. USA). All radiographs were obtained in DICOM format and analyzed using Kodak Dental Imaging Software Windows v6.0.1 software, (Eastman Kodak Company, Rochester, NY) which gave a digital quantification of measurements between any two reference points with a resolution of ≥ 14 lp/mm.

The following measurements were then made from the radiographs using the Kodak RVG 5000 digital radiography system on all six teeth from each patient: [Figure 1]

- The maximum tooth length—from the occlusal surface to the apex of the tooth (T)
- The pulp length—from the highest pulp horn to the radiographic apex (P)
- The root length on the mesial surface—from the cementoenamel junction (CEJ) to the root apex (R),
- The root and pulp width at three levels—the levels being at the CEJ (W_1), at the midroot level (W_2), and the apex of the root (W_3); then a mean width was derived.

The following ratios were then calculated from the above measurements:

- The ratio between the lengths of the pulp and the tooth (X_1)

Table 1: Age and gender distribution of the study sample

Age (in years)	No. of males	No. of females	Total
15-24	9	5	14
25-34	5	5	10
35-44	6	7	13
45-54	3	6	9
55-64	4	0	4
Total	27	23	50

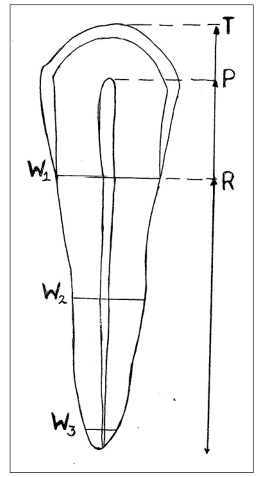

Figure 1: Diagram showing measurements: Tooth length (T); Pulp length (P); Root length (R); Root and pulp width at the cementoenamel junction (CEJ) (W_1); Root and pulp width midway between CEJ and apex (W_2); Root and pulp width at apex (W_3)

- The ratio between the lengths of the pulp and the root (X_2)
- The ratio between the mean widths of the pulp and the root (X_3)
- The ratio between the lengths of the tooth and the root (X_4).

The ratios of measurements were used rather than the measurements directly in the analysis in order to reduce the effect of a possible variation between the magnification and angulations of the radiographs.[6]

A single observer carried out all the measurements. To test the intraobserver reproducibility, a random sample of 30 radiographs was reexamined after a week.

All four morphological ratios X_1, X_2, X_3, and X_4 were used as variables for age estimation in the statistical analysis. The Pearson product-moment correlation coefficient (PCC) was evaluated between chronological age and the predictive variables. Multiple regression analysis was then made, employing age as the dependent variable and the predictive variables as the independent variables. Besides evaluating the age using measurements from all six teeth, we also evaluated separate predictions restricted exclusively to either the maxillary or mandibular teeth.

Results

Patients were selected from the age group of 15-57 years, with a mean age of 34.9 years. The patients included 27 males and 23 females [Table 1].

PCC between age and the morphological variables were significant except for X_4 [Table 2]. The correlation coefficient between age and tooth root length ratio was poor with the *P* value of 0.8973 showing less significance, indicating that occlusal wear is not well correlated with age.

From the calculated mean values, standard deviation (SD) and standard error of mean (SEM) between the chronological age and the predicted age were determined, as presented in Table 3.

Figures 2,3 and 4 show the scatterplot diagrams between the chronological age and the predicted age when all six teeth, three maxillary teeth and three mandibular teeth, were used respectively.

The relationship between these variables and the dependent variable could be expressed as $Y = A + B_1X_1 + B_2X_2 + B_3X_3 + \ldots B_nX_n + E$.

Where Y = predictive dependent variable value

A = Value of Y when all Xs are zero
X_1, X_2, X_3 = Independent variables
B = Coefficients corresponding to the independent variables
n = The number of independent variables
E = An error term

The predictive variables X_1, X_2, and X_3 were used as an input dataset in the multiple regression analysis, yielding the following regression formulas. It should be noted that X_4 was not included in the multiple regression analysis, as it did not correlate significantly with age [Tables 4 and 5].

Equation 1: When all six teeth were considered together

$$Age = -161.04 X_1 + -28.30 X_2 + -191.59 X_3 + 236.98 (+/-6.42)$$

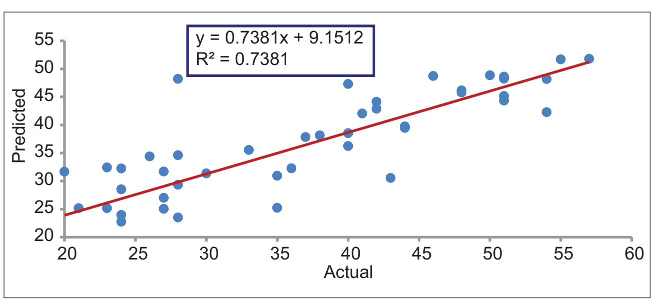

Figure 2: Plots of observed age against the predicted age using the regression model for all six teeth

Where X_1, X_2, and X_3 are the mean values

The coefficient of determination (R^2) for all six teeth was 0.7381, with a standard error of estimate of 6.42 years (F = 43.272).

F: F Statistic

Analysis was done for only the maxillary teeth and the regression equation obtained was as follows:

Table 2: Pearson product-moment correlation coefficient

	N	*P*
All teeth		
Dependent	50	
X_1	50	<0.001
X_2	50	<0.001
X_3	50	<0.001
X_4	50	0.8973
Maxillary teeth		
Dependent	50	
X_1	50	<0.001
X_2	50	<0.001
X_3	50	<0.001
X_4	50	0.7069
Mandibular teeth		
Dependent	50	
X_1	50	<0.001
X_2	50	<0.001
X_3	50	<0.001
X_4	50	0.6179

X_1: The ratio between the lengths of the pulp and the tooth, X_2: The ratio between the lengths of the pulp and the root, X_3: The ratio between the mean widths of the pulp and the root, X_4: The ratio between the lengths of the tooth and the root

Table 3: Descriptive statistics

	Mean	SD	*N*
All teeth			
Dependent	34.94	12.16	50
X_1	0.81	0.03	50
X_2	1.37	0.06	50
X_3	0.17	0.03	50
Maxillary teeth			
Dependent	34.94	12.16	50
X_1	0.81	0.03	50
X_2	1.37	0.07	50
X_3	0.18	0.04	50
Mandibular teeth			
Dependent	34.94	12.16	50
X_1	0.82	0.03	50
X_2	1.36	0.06	50
X_3	0.15	0.04	50

X_1: The ratio between the lengths of the pulp and the tooth, X_2: The ratio between the lengths of the pulp and the root, X_3: The ratio between the mean widths of the pulp and the root, X_4: The ratio between the lengths of the tooth and the root, SD: Standard deviation

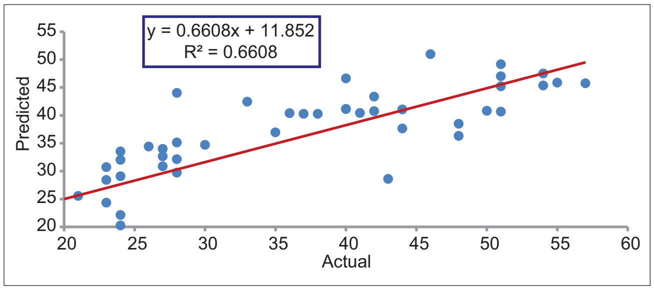

Figure 3: Plots of observed age against the predicted age using the regression model for three maxillary teeth

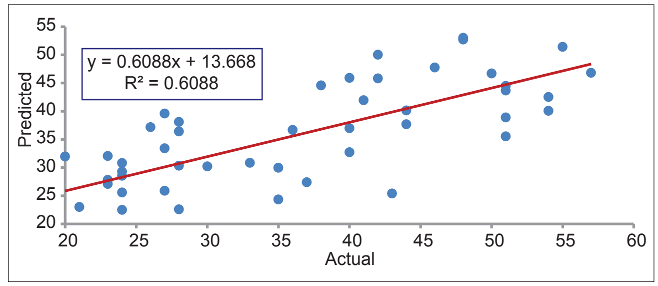

Figure 4: Plots of observed age against the predicted age using the regression model for three mandibular teeth

Table 4: Multiple regression analysis predicting chronological age from chosen predictors

	Value	Standard error	*P*
All teeth			
Intercept	236.98	6.4217	<0.001
X_1	−161.040	59.755	<0.001
X_2	−28.30	20.284	<0.001
X_3	−191.588	36.798	<0.001
Maxillary teeth			
Intercept	211.894	7.302	<0.001
X_1	−175.180	48.064	<0.001
X_2	−8.846	20.531	<0.001
X_3	−127.691	35.677	<0.001
Mandibular teeth			
Intercept	265.601	7.85	<0.001
X_1	−167.890	47.50	<0.001
X_2	−51.549	21.033	<0.001
X_3	−151.318	34.864	<0.001

X_1: The ratio between the lengths of the pulp and the tooth, X_2: The ratio between the lengths of the pulp and the root, X_3: The ratio between the mean widths of the pulp and the root

Table 5: Multiple regression analysis

	R^2	Adjusted R^2	Std. error (in years)	*P*	*F* Statistic
All teeth					
	0.7381	0.721	6.4217	<0.001	43.272
Maxillary teeth					
	0.6608	0.6387	7.3082	<0.001	29.87
Mandibular teeth					
	0.6088	0.583	7.848	<0.001	23.865

Equation 2:

Age = -175.18 X_1 +-8.85 X_2 + -127.96 X_3 + 211.89(+/-7.31)

Where X_1, X_2, and X_3 are the mean values

The coefficient of determination (R^2) for only maxillary teeth was 0.6608, with a standard error of estimate of 7.3 years (F = 29.87).

Analysis was done for only the mandibular teeth and the regression equation obtained was as follows:

Equation 3:

Age = -167.89 X_1 + -51.55 X_2 + -151.32 X_3 + 265.60 (+/-7.85)

Where X_1, X_2, and X_3 are the mean values

The coefficient of determination (R^2) for only mandibular teeth was 0.6088, with a standard error of estimate of 7.8 years (F = 23.865).

A higher correlation coefficient was obtained when all the six teeth were included.

Discussion

Dental age estimation requires the use of morphologic, radiographic, histological, and biochemical methods to estimate age-dependent changes in teeth. For age estimation, different methods are available; however, invasive methods using extracted teeth, ribs, and femurs cannot be used in living individuals. Assessment of sexual and skeletal maturation, radiological examination of bones, and also clinical and radiological examination of the dentition are noninvasive ways to determine age. Dental age estimation can be based on different properties of the dentition. Age estimation methods employ various forms of tooth modification, including tooth wear,[7,8] root dentin transparency,[9,10] tooth cementum annulation,[11] racemization of aspartic acid,[12] and apposition of secondary dentin.[6,13]

Gottlieb was the first person to correlate changes in dentition with age.[14] In 1925, Bodeckar also established that the apposition of the secondary dentin was correlated with age.[15] The secondary dentin is laid down by the odontoblasts throughout a person's life, causing a reduction in the size of the pulpal cavity.[16] Secondary dentin deposition was introduced for age estimation in the method by Gustafson, so that secondary dentin was one of the parameters in addition to attrition, periodontal recession, cementum apposition, apical translucency, and external root resorption.[17]

Presently, there is no evidence that the process of secondary dentin formation occurs in a linear manner, or that every age group needs the same time span to present itself with a defined amount of secondary dentin. Although linear regression is widely used in forensics to provide the estimate of the measurement, for instance the age at death or the living stature, it should be kept in mind that human growth is not a linear process.[18] The quality of secondary dentin deposition is also influenced by factors like race, ethnicity, diet, and lifestyle. Authors have highlighted the need for population-specific formulas due to differences in ethnicity to achieve precise and accurate results.[19-21]

A study of radiographs of teeth is a nondestructive simple method to obtain information and is a technique used daily in dental practice. The advent of digital radiography has increased the quality of the images as also the ease of measurements and maintenance of records. The accuracy of digital method has been proven in intraoral radiography.[22] In the present study, the selection of the dental parameters used for age assessment was based on their implementation in dental practice and on their reproducibility.

This study was based on the concept established by Kvaal *et al*.[6] Reviewing the literature, we found that age estimation using Kvaal's method showed varied results, some underestimating the exact age by approximately 30 years, whereas some were as close as 8-9 years.[18,23] Hence, we designed a study with a few modifications. Multirooted teeth and canines have not been good predictors for the determination of age.[6,23] Thus, we selected the maxillary central incisor, maxillary lateral incisor, maxillary second premolar, mandibular central incisor, mandibular lateral incisor, and mandibular second premolar for determining age for our study. In addition, the pulp root width was measured at three different levels, namely at the CEJ, at the midroot level, and at the apex. Correlation coefficients for X_1, X_2, and X_3 were statistically significant, indicating that the ratios decrease with increasing age.

However, the correlation coefficient for X_4 was poor for all types of teeth, with the P value of 0.8973, showing less significance. A possible explanation could be that the whole length of the tooth was measured instead of only the crown, which has been shown to be strongly correlated with age.[24]

Statistically significant values were noted when maxillary or mandibular teeth were used alone. As in other studies, a higher correlation coefficient was obtained when all the six teeth were included, indicating that the more the information gained from the patient, the greater are the chances of an accurate age estimation; in addition, it would also reduce the effect of unusual anatomy of any one tooth.

In the present study, X_1 showed the strongest correlation compared to the width ratios as depicted in the study conducted by Kvaal *et al*.[6]

A study conducted using conventional orthopantomograms[18] using the equations of Kvaal *et al*. has shown a mean underestimation of age ranging 38-47 years when three to six teeth were included, whereas a study done on digital orthopantomograms[23] showed an estimation of ± 8.3 years in an Indian population. Patil *et al*. concluded a standard error of estimate of 6.5 years with a modified Kvaal's formula on a sample of the Indian population.[19]

The accuracy of age estimation in this study was ± 6.42 years when all six teeth were included. The better accuracy may be due to the better resolution of digital intraoral periapical radiographs compared to orthopantomograms and also because of the exclusion of multirooted teeth and canines. Furthermore, we employed the paralleling technique, which helps in reducing angulation and technique errors and has better reproducibility.

Some authors[18] have indicated an inapplicability of the regression equations of Kvaal *et al*.[6] and Pawensky *et al*.[13] in younger populations. Our results, however, differ, as we could estimate the age in a population ranging 15-57 years old with an overall accuracy of ± 6.4-7.8 years with the design employed in our study using the Kvaal's method. From this study, we have derived regression equations for age estimation in the Indian population.

It is also important to emphasize that any methodological approach to age assessment of a living individual establishes the physiological age, and that sexual, dental, or skeletal development is representative of the overall physical maturity and not chronological age.[25,26] A careful approach to age determination is necessary, taking into consideration the influence of pathological conditions, ethnicity and gender variation. Therefore, comprehensive approaches to age estimation, which considers multiple maturity indicators, are superior to those which use non comprehensive methods.[25,27]

Conclusion

We conclude that the ratios X_1, X_2, and X_3 are good indicators of age, while X_4 is not correlated with age estimation in said population. According to the authors, the results of this study indicate that Kvaal's method is a reliable method to estimate age in both young and older populations. With a few modifications of Kvaal's method, we could estimate age with a standard error of estimate of ± 6.4-7.8 years in a sample of the Indian population. Only limited conclusions can be drawn from a single study. Because of the small sample size of this study, we are conservative in our interpretation of the results. However, further studies can be carried out using the regression formulas derived in this study.

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