Journal of Dental Biomaterials
Shiraz University of Medical Sciences, Shiraz, Iran

Journal of Dental Biomaterials. 2018;5(2)

Original Article

Evaluating the accuracy of Kvaal's method for age estimation in a selected Iranian population

Haghnegahdar AA[a]; Vossoughi M[b]*; Teymoorienik Z[c]; Khojastepour L[a]

[a]Department of Oral and Maxillofacial Radiology, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran
[b]Oral and Dental Disease Research Center, Department of Dental Public Health, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran
[c]Student Research Committee, Shiraz University of Medical Sciences, Shiraz, Iran

ARTICLE INFO

Article History:
Received: 22 August 2018
Accepted: 20 September 2018

Key words:
Dental age estimation Kvaal's method
Adults
Accuracy
Iranian population

Corresponding Author:
Mehrdad Vossoughi
Oral and Dental Disease Research Center, Department of Dental Public Health, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran.
Email: vossoughim@sums.ac.ir
Tel:+98-9177118545

Abstract

Objectives: This study aimed to evaluate the efficacy of Kvaal et al.'s method (1995) for dental age estimation of adult individuals in a sample of Iranian population. For this purpose, the accuracy of the regression formulas and M and W-L variables were studied.

Materials and methods: Pulp and tooth lengths and widths were measured on 100 digital panoramic radiographs. Then Kvaal's M and W-L variables were computed and substituted in Kvaal's formulas to evaluate their accuracies. The efficacy of these two variables in our population was assessed using a k-fold cross-validation technique for regression analysis. Principle component analysis was also performed to develop population-specific dental variables.

Results: Applying Kvaal's regression formulas on multiple teeth in different jaws resulted in highly insensible estimations. In contrast, developing regression formulas based on Kvaal's M and W-L variables yielded reasonable and sensible estimates especially for younger individuals; standard error of estimate (SEE) values ranged from 6.36-6.80 years. The models based on multiple teeth in different jaws performed similar.

Conclusions: For young adults, the M and W-L variables anticipated accuracy rates lower than those of Kvaal's reference study which were within an acceptable threshold for forensic application (SEE<10 years). Therefore, the two variables and not formulas are proper measurements for forensic age estimation in Iranian young adults. However, underestimation was predominant for the middle age and old age participants.

Cite this article as: Haghnegahdar AA, Vossoughi M, Teymoorienik Z, Khojastepour L. Evaluating the accuracy of Kvaal's method for age estimation in a selected Iranian population. J Dent Biomater, 2018;5(2):573-582.

Introduction

Scientific techniques for age estimation play critically important roles in forensic and legal medicine [1]. It is especially a very clarifying principal in identifying the cadavers and body remains. Moreover, it is widely used in many instances of social activities such as school attendance, employment, and marriage as well, all planning some hormonal therapies in pediatric endocrinology for persons with no valid proof of the date of birth. Chronological age, as the most popular scale for age determination, may be lost or hidden and sometimes it does not show the exact developmental course of an individual. There are two main biological age defined according to the development occurred in the skeleton or skeletal maturation, usually detected by X-ray examinations, which can be used more reliably regarding the development. Many researchers have studied skeletal development especially using hand-wrist X-ray for forensic age estimation and as an aid to evaluate the growth disorders. Skeletal radiology has remained historically the most widespread method for age estimation of living individuals [2, 3]. There are two main methods for employing teeth in age estimation; tooth emergence analysis and tooth developmental stage analysis. Tooth emergence is a feeling event of a short duration and difficult to determine which can be affected by nutrition and local factors such as apace limitations [4,5]. On the contrary, tooth development is fundamentally influenced by genetic factors rather than environmental ones. Therefore, there is an increasing tendency to apply dental development as an age estimation tool. Demirjian *et al*. [2] proposed one of the most recognized techniques for age estimation. This method is based on radiographic evaluations of developmental stage of the teeth in the left mandibular quadrant, extracted from a French population. Although several studies verified its generalization to other populations [4], some authors have reported the overestimation of chronological age and incompatibility of the scoring system for their populations [5,6]. The time-limitation for application is another problem with Demirjian's technique. As the tooth development is generally completed about puberty, this method can be only used in childhood. Although Demirjian's stages have been extended to the wisdom teeth [7-9], the third molar development for age estimation is limited to late adolescence and early adulthood, i.e. the age range of 14-22 or up to 24 years [10-12]. Kvaal *et al*. [3] proposed a new technique for age estimation of adult individuals. This method is based on size of the pulp of the teeth. It had been proved that the size of pulps in the incisor teeth is considerably different between 10-year age groups [13]. It is because of continuous deposition of reparative dentin in the teeth, which decreases the pulp size through the life. The pulp size of six teeth (3 mandibular and 3 maxillary) was measured in different points to establish some specific ratios on the periapical views of individuals. Then, a regression model was used to develop a formula for age estimation. Rösing and Kvaal [14] stated that regression estimates with a standard error greater than 5-7 years are not suitable for routine forensic application as they provide wide confidence intervals [15]. Some studies reported a wider acceptable range for standard error of estimate (SEE) in forensic field (<10 years) [16-18]. Multiple studies have been performed to evaluate the accuracy of Kvaal's method in other populations [16, 19-26]. Research on Kvaal's method has revealed a great deal of variation among different populations with respect to accuracy level. The most amount of variation may be attributable to "age mimicry" bias [27-31], i.e. the bias of estimates by the age structure of reference sample. This research has two main objectives in order to study the worthiness of Kvaal's method. First, the accuracy of Kvaal's regression formulas is evaluated in a selected Iranian population. Second, the efficiency of Kvaal's M and W-L variables in age estimations is studied to insure whether they can be extended to our population.

Methods and materials

Kvaal's method for age estimation

Kvaal *et al*. [3] proposed a technique for age estimation based on indicators of reduction in the size of the dental pulp cavity. Their study has been conducted on 100 dental patients who had attended the clinics of Dental Faculty in Oslo. The radiographs of six types of teeth from each jaw were measured: maxillary central, lateral incisors and second premolars; and mandibular lateral incisors, canines and first premolars.

The following measurements were performed on the radiographs of each tooth: T: maximum tooth length; R: root length on the mesial surface; P: maximum pulp length; A: root and pulp width at the enamel-cementum junction (ECJ or level A); B: root and pulp width midway between measurement levels A and C; and C: root and pulp width midway between apex and ECJ. Six ratios between the tooth and pulp measurements were computed; P: ratio between the length of the pulp and root; T: ratio between the length of the tooth and root; R: ratio between the length of the pulp and tooth; A: ratio between the width of the pulp and root at enamel-cementum junction (level A); B: ratio between the width of the pulp and root at midpoint between level C and A (level B); and C: ratio between the width of the pulp and root at mid-root level (level C). In order to reduce the number of variables, principal component analysis was performed on the 6 ratios and it demonstrated that the following combinations were the best subsets to account for the variability of ratios: M: mean value of P, R, A, B, and C (all the ratios except for T); and W-L: mean value of width ratios from levels B and C (W) minus mean value of the length ratios P and R (L). Finally, M and W-L variables were used as predictor variables in a multiple linear regression model when chronological age was considered as dependent variable. Kvaal's regression formulas for age estimation are presented in the Results section.

Population and sample size

A total of 100 digital panoramic radiographs were collected from the records of the Department of Dental Radiology, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran. The radiographs were from 56 males and 44 females, with acceptable quality and presence of the teeth: central, lateral, and second premolar in the maxilla and lateral, canine, and first premolar in mandible at the right and left sides. A written informed consent form from all participants was acquired. The written consent form is a standard form, which has been developed in full accordance with World Medical Association Declaration of Helsinki by Ethical committee of Shiraz University of Medical Sciences. The mean age of the individuals was 28.44±6.68 years with a range of 19.25 to 55.17 years. Table 1 shows age group distribution of the individuals. Panoramic views containing rotated teeth or dental anomalies, such as dens invagination and dentin dysplasia or amelogenesis imperfecta, were excluded from the study. Exposure parameters were prepared according to the patient size. The radiographs were viewed over a monitor in standard viewing conditions. The observer was blind to the age and gender of the individual. The six ratio parameters (P, T, R, A, B, and C) were calculated using digital calipers. We also computed M and W-L variables proposed by Kvaal from these ratio parameters.

Statistical analysis

Qualitative variables were described using frequency (and percentage) and quantitative variables were described using mean and standard deviation (SD.). For assessing the accuracy of Kvaal's formulas, some accuracy indices such as standard error of estimate (SEE.) and mean of absolute differences (MAD.) were used. K-fold cross-validation technique (with k=2) for linear regression was used to assess the efficacy of the variables that had been proposed by Kvaal (M and W-L) for age estimation in our population. In this method, first, the original data were randomly divided into two sub-samples with equal sample sizes (here, n1=n2=50). Then, in each step, one of the sub-samples was used for developing a regression model (training data) using the proposed variables and the other one (testing or hold-out data) for assessing how the resulting model will predict it. Moreover, principal component analysis (PCA) was employed to evaluate the reliability of the variables and propose new population-specific variables for age estimations based on our dataset. PASW SPSS software for Windows version 18.0 (SPSS Inc., Chicago, IL, USA) was used for data analysis. Throughout this study, the significant level was considered 0.05.

Table 1: Age and sex distribution of the 100 individuals included in the study

Age group (year)	Sex		Total
	Male	**Female**	
19-30	35	22	57
30-40	16	15	31
40-50	2	6	8
50-60	3	1	4
Total	56	44	100

Table 2: Mean (±SD) Kvaal's components for different age groups

Teeth	Age	P	T	R	A	B	C	W	L	Kvaal's variables	
										M	**W-L**
	<30	0.78±0.09	1.47±0.11	0.53±.06	0.29±0.05	0.26±0.05	0.21±0.05	0.24±0.04	0.65±0.08	0.41±0.04	0.42±0.08
3 maxillary	30-40	0.75±0.09	1.49±0.13	0.51±0.07	0.27±0.04	0.24±0.05	0.21±0.05	0.22±0.04	0.63±0.08	0.40±0.04	0.40±0.08
	>40	0.67±0.13	1.46±0.09	0.46±0.10	0.39±0.38	0.20±0.05	0.16±0.03	0.18±0.04	0.56±0.11	0.38±0.05	0.39±0.10
	<30	0.77±0.73	1.28±0.08	0.60±0.06	0.24±0.04	0.25±0.04	0.24±0.05	0.25±0.04	0.69±0.06	0.42±0.08	0.44±0.08
3 mandibular	30-40	0.77±0.05	1.27±0.08	0.61±0.05	0.22±0.04	0.22±0.04	0.22±0.05	0.22±0.04	0.69±0.05	0.41±0.03	0.46±0.06
	>40	0.77±0.10	1.31±0.12	0.59±0.07	0.17±0.03	0.19±0.05	0.17±0.04	0.18±0.04	0.68±0.08	0.38±0.05	0.50±0.07
	<30	0.77±0.06	1.38±0.07	0.57±0.05	0.26±0.03	0.26±0.03	0.23±0.04	0.24±0.03	0.67±0.05	0.42±0.03	0.43±0.06
6 teeth	30-40	0.76±0.06	1.38±0.08	0.56±0.05	0.24±0.04	0.23±0.04	0.21±0.04	0.22±0.04	0.66±0.05	0.40±0.03	0.43±0.05
	>40	0.72±0.08	1.38±0.06	0.52±0.07	0.28±0.19	0.20±0.04	0.17±0.02	0.18±0.03	0.62±0.07	0.38±0.02	0.44±0.07

P, ratio between length of pulp and root; T, ratio between length of tooth and root; R, ratio between length of pulp and tooth; A, ratio between width of pulp and root at enamel-cementum junction (levelA); B, ratio between width of pulp and root at midpoint between level C and A (level B); C, ratio betweenwidth of pulp and root at mid-root level (level C); W, meanvalue of width ratios from levels B and C; L, mean value of the length ratios P and R;M,mean value of all ratios (first Kvaal'spredictor); W-L, differencebetween W and L (secondKvaal's predictor).

Results

This study comprised 100 individuals, 56 males, and 44 females. The individuals' age ranged from 19.25 to 55.17 years (mean age 28.44±7.13 years). Descriptive statistics for Kvaal's components from dental radiographs for different age groups are reported in Table 2.

The correlation between Kvaal's dental components and chronological age for each tooth is reported in Table 3. There was no significant relationship between T, A, and W-L with age in the maxillary, mandibular, and all six teeth (all P>0.05). There was a negative significant relationship between P and L with age only in the maxillary and six teeth. However, R, B, C, and W had negative significant correlations with age in all positions.

The SEE values of age estimates using Kvaal's regression formulas, the mean, SD, minimum and maximum values of absolute differences between the chronological and the estimates using applying Kvaal's regression formulas are presented in Table 4. Surprisingly, almost all age estimates were negative, especially when the teeth in mandibular and both jaws were used; 59%, 100%, and 98% of the individuals using 3 maxillary, 3 mandibular and all teeth, respectively. Age estimation using the 3 maxillary, 3 mandibular and all 6 teeth resulted in extremely large SEE and MAD values. Applying Kvaal's formulas yielded SEE (and MAD) values of 34.35 (31.84), 79.52 (78.18), and 58.66 (57.58) years for 3 maxillary, 3 mandibular and all teeth, respectively. Although, the formula based on 3 maxillary teeth attained smaller accuracy indices, its estimates still highly deviated from the chronological ages and obtained insensibly negative estimations. Kvaal's formula based on 3 mandibular teeth performed the worst.

Table 5 shows the results of multiple linear regression models using Kvaal's M and W-L variables on training dataset in each step and accuracy indices for combined testing datasets

Table 3: Correlation coefficients between tooth ratios and chronological age

									Kvaal's variables	
Teeth	**P**	**T**	**R**	**A**	**B**	**C**	**W**	**L**	**M**	**W-L**
3 maxillary	-0.34*	-0.07	-0.30*	0.10	-0.38*	-0.30*	-0.38*	-0.34*	-0.35*	-0.14
3 mandibular	0.08	0.04	-0.87*	-0.40	-0.37*	-0.37*	-0.41*	-0.09	-0.36*	-0.17
6 teeth	-0.30*	-0.03	-0.26*	-0.03	-0.41*	-0.41*	-0.48*	-0.30*	-0.44*	0.02

*Statistically significant at α=0.05.

Table 4: Accuracy indices for age estimations using Kvaal's regression formulas

Teeth	Kvaal's formula	Kvaal's SEE*	SEE	MAD	SD	Min	Max
3 maxillary	Age=120-256.6(M)-45.3(W-L)	8.9	34.35	31.84	12.94	0.16	60.03
3 mandibular	Age=135.3-356.8(M)-82.5(W-L)	9.4	79.52	78.18	14.59	40.68	120.50
6 teeth	Age=129.8-316.4(M)-66.8(W-L)	8.6	58.66	57.58	11.23	22.10	85.12

*: Accuracy values that had been reported by Kvaal et al.

Table 5: The results of K-fold cross-validation technique for assessing the accuracy of Kvaal's variables

Teeth	Regression Formula†	R^2*	SEE	MAD	%(2)	%(4)	%(6)	%(10)
3 maxillary	34.75-23.67(M)+7.15(W-L) 54.85-55.91(M)-7.61(W-L)	0.09	6.74	5.11	78.6	48.0	30.6	9.2
3 mandibular	71.20-121.15(M)+15.99(W-L) 38.97-50.17(M)+24.23(W-L)	0.27	6.36	5.01	76.5	51.0	36.7	9.2
6 teeth	61.04-102.53(M)+21.03(W-L) 60.77-89.44(M)+11.37(W-L)	0.19	6.08	4.72	74.5	50.0	30.6	8.2

†: Each model has two formula because the dataset divided into two sub-datasets and a regression model developed based on one of them and the accuracy was evaluated using the other one in each step.
*: R^2 values which presented here were averaged over the two sub-samples.
Note: %(n) is the percentage of subjects whose estimation deviated more than n years (n = 2, 5, 10).

(cross-validation method). In contrast to applying Kvaal's formula directly, developing a new formula based on Kvaal's variables resulted in positive and sensible estimates. The values of SEE (and MAD) were 6.74 (5.11), 6.36 (5.01) and 6.08 (4.72) years for the 3 maxillary, 3 mandibular and all teeth, respectively. Interestingly, the indices showed estimates that are more accurate in younger participants. About 25%, 50%, 75% and 91% of all participants were estimated up to 2, 4, 6 and 10 years deviated from their chronological ages, respectively.

Table 6 shows the accuracy indices for Kvaal's variables based on 6 teeth in different age groups. In order to avoid redundancy, the results for different jaws were not presented. The variables performed accurately for those aged <30 and 30-40 years old (SEE=4.68 and 5.42, respectively). SEE value was insensibly high in the age group over 40 years. Underestimation was predominant for the two higher age groups in comparison with the first. The results of principal component analysis for the two second premolar (15/25) are presented in Table 7. The coefficients yielded in this study and

Table 6: The accuracy indices for assessing Kvaal's variable on the 6 teeth for different age groups

Age group	SEE	%UE	%(2)	%(4)	%(6)	%(10)
<30	4.68	26.3	66.7	43.9	22.8	00.0
30-40	5.42	90.3	87.1	54.8	35.5	00.0
≥40	15.39	100	100	100	100	83.3

Note: %(n) is the percentage of subjects whose estimation deviated more than n years (n = 2, 5, 10).
Because the number of subjects in 40-50 and 50-60 year old groups were small, the two groups were aggregated.

Table 7: The two first principal components (PCs) for the ratios from the two second premolar (15/25)

			*Kvaal's results	
Ratio	1st PC	2nd PC	1st PC	2nd PC
P	0.88	0.32	0.43	0.51
R	0.87	0.34	0.42	0.51
A	-0.46	-0.41	0.50	-0.03
B	0.58	0.67	0.44	-0.51
C	0.66	0.58	0.42	-0.46

*: Coefficients that had been reported by Kvaal et al.

those of Kvaal's study were highly divergent. The two first principal components explained 71.3% of the total variance of age. Although small values of regression R^2 and principal component coefficients implied inefficiency of Kvaal's variables for explanation of age variation in our population, the estimation accuracy was reasonable for the forensic field.

Discussion

Techniques for age estimation are increasingly applied to various scientific, medical, and legal conflict cases. Kvaal *et al*. [3] asserted that age could be estimated based on the degree of calcification in the pulp of teeth since this calcification is mild and continuously occurring in teeth throughout lifetime. Regarding the widespread need for age estimation in adults, this study was performed to evaluate the accuracy of Kvaal's formulas and variables in a selected Iranian population.

Kanchan-Talreja *et al*. [23] assessed the accuracy of Kvaal's formulas on digital radiographs of 100 Indians. Although the SEEs were not reported, the mean differences between estimated and chronological ages were high, 18-21 years for different combination of teeth. When population-specific regression formulas were applied, the errors were reduced to 11-14 years. For Indian formula, the SEE values were highly greater than those values achieved in Kvaal's study (8.6-9.4 years) and our study. The differences may be due to several reasons. First, environmental, and genetic factors can possibly affect the secondary dental deposition. Second, in developing the Indian regression formulas, Kvaal's M and W-L variables were not used directly, whereas one main goal of our study was set to assess the accuracy of these two variables in age estimation. Finally, the percentage of individuals aged >50 years was greater in their study when compared to Kvaal's (36%) and our study (4%); hence, the results might have highly influenced by age mimicry bias.

Bosmans *et al*. [20] studied 197 participants in Belgium, 18 (9%) of whom were aged <50 years, and directly applied the Kvaal's formulas for age estimation. The SEEs were 9.2-9.9 years for the teeth in the three positions. The values were relatively similar to those obtained by Kvaal (8.6-9.4 years) and were remarkably smaller than values yielded by present study for direct application of the Kvaal's formulas, 34.35-74.52 years. They found out that the estimations were more precise when 3 mandibular or all 6 teeth were examined. In contrast, the relatively more precise estimates were obtained when the 3 maxillary teeth were examined in our study.

Meinl *et al*. [25] assessed the reliability of some age estimation techniques on young individuals, 44 Austrians aged 13 to 24 years, and reported a consistent underestimation for Kvaal's formulas.

Chandramala *et al*. [21] studied the reliability of M and W-L variables in regression analyses. Although it did not report SEE values, the coefficients of determinations (R^2) were as low as our study. The reported R^2s were 0.076, 0.049, and 0.017 for the upper 3 teeth, lower 3 teeth and all the 6 teeth, respectively. It was concluded that these two variables were not able to explain the amount of variation in age. However, no significant differences were found between mean estimated and chronological ages in the three tooth positions. Similar small R^2s but acceptable estimations in terms of SEEs were yielded in our study.

In a study by Erbudak *et al*. [22] on 123 digital radiographs in Turkey, neither M and W-L and not the three teeth positions were directly entered in regression models. Regression models were developed based on ratios that predict age in the best way. I all of the models, M variable was excluded. They achieved a large SEEs with a range of 12.7-25.10 years.

Mittal *et al*. [26] examined 152 participants with a few number of individuals (5) older than 50 years old. Regression equations for age were derived based on M and W-L variables. Although the greater R^2 values were obtained for the teeth in the three positions (ranged 0.28-0.45) than those of our study (ranged 0.09-0.27), the SEE values for three maxillary teeth (8.59), three mandibular teeth (7.51) and all 6 teeth (7.97) were greater. Nevertheless, the values did not exceed the acceptable limit of age estimation in forensic medicine (SEE<10 years).

Similar to the present study, Karkhanis *et al*. [24] applied a cross-validation technique on M and W-L variables and similar findings were reported. The SEE values were 9, 8.36, and 9.61 years for the

3 maxillary teeth, 3 mandibular teeth and all 6 teeth, respectively. Like our findings, even though, their study yielded small R^2 values, the accuracy indices were acceptable. Compared to our study, they studied a larger sample size (n=279) and 50 individuals from the total sample size were considered as holdout data.

Marroquin Penaloza *et al*. [16] applied Kvaal's method on 101 CBCT images from a Malaysian population. Instead of M and W-L variables, several regression formulas were built based on different combinations of Kvaal's pulp/root measurements and ratios on the sagittal and coronal views. The accuracy was outside the acceptable range for forensic application; all SEE values were greater than 10 years. However, the number of individuals aged >50 (20) was lower than that of Kvaal's study. The larger SEE in some mentioned studies and our study on elderly individuals may be attributable to the tendency of regression techniques to underestimate the age of old individuals, *"Attraction of the middle"* bias [27, 29, 30, 32, 33], and age mimicry bias. The reference study comprised more individuals aged >50 years than the present study. Nevertheless, two studies [20, 26] with an age group distribution similar to our study yielded remarkably smaller SEE values for Kvaal's regression formulas. Other possible factors that might explain the variation are genetic differences and environmental parameters. Genetic and environmental factors can change the pattern and speed of dentin deposition in the teeth, causing discrepancy in results.

The variation in results across the studies with the similar age structure may encourage the researchers to build population-specific regression formulas based on Kvaal's variables independently in the age groups < 40, 40-50, and >50 years. However, it requires studies with larger sample sizes in all age groups and validation of new formulas.

Conclusions

Direct application of Kvaal's regression formulas for age estimation yielded insensible results in the Iranian sample examined in this study. Developing regression models based on Kvaal's M and W-L variables provided sensible estimation accuracy rates for young adults (aged <40 years) which were noticeably lower than the acceptable threshold for forensic application (SEE<10 years). However, underestimation was predominant for the middle age and old age participants whose SEE values were large. Conflict of interests: The authors declare that they have no competing interest. All authors listed on the title page have read the manuscript, attest to the validity and legitimacy of the data, and agree to its submission to the journal.

Acknowledgements

The present article was extracted from the thesis written by Dr. Zahra Teymoorienik. The authors would like to thank the Vice-Chancellery of Shiraz University of Medical Sciences for supporting this research (Grant number 10837). We would also like to thank Dr Shahram Hamedani, Dr. Nasrin Shokrpour and Center for Development of Clinical Research of Nemazee Hospital for editorial assistance.

Conflict of Interest: None declared.

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