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Estimation of Dental Age Using the Kvaal Method with Digital Panoramic Radiographs in Peruvian Adults

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Estimación de la edad dental según el método de Kvaal con radiografías panorámicas digitales en adultos peruanos

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ABSTRACT: To determine the accuracy of the Kvaal method in the estimation of dental age through the analysis of digital panoramic radiographs of patients between 20 and 47 years of age who attended the stomatological clinic of the Universidad Científica del Sur, (2018 to 2019), Lima-Perú. 289 digital panoramic radiographs belonging to individuals of both sexes, aged 20 to 47 years were analyzed. Length and width measurements were obtained in the dental and pulp chamber in the upper central incisors. These data were subsequently evaluated by calculating the proportions between the pulp and root length of the upper central incisor by applying the formula of the method of Kvaal *et al.* to obtain the accuracy of the method in estimating dental age. Applying the formula of Kvaal *et al.* indicates that the relationship between the width of the pulp and the length of the root has a higher level of significance in relation to others proportions: M mean value of all ratios except T (-0.659) and W-L difference between W and L (-0.643). The coefficient of determination (r^2) and standard error of estimation (SEE) using the original Kvaal formula is r^2 : 0.70, SEE: 4.90 years, then a modified Kvaal formula was proposed for the Peruvian population. The Method of Kvaal *et al.* has an accuracy of 1.24 in estimating the dental age of individuals, using the upper central incisor in digital panoramic radiographs.

KEY WORDS: Age estimation; Kvaal method; Upper central incisor; Secondary dentin; Dental pulp.

RESUMEN: Determinar la precisión del método de Kvaal en la estimación de la edad dental mediante el análisis de radiografías panorámicas digitales de pacientes entre 20 a 47 años atendidos en la clínica estomatológica de la Universidad Científica del Sur, (2018 a 2019), Lima-Perú. Se analizaron 289 radiografías panorámicas digitales pertenecientes a individuos de ambos sexos, de 20 a 47 años. Se obtuvo medidas de longitud y anchura en la cámara dental y pulpar en los incisivos centrales superiores. Estos datos se valoraron posteriormente al calcular las proporciones entre la pulpa y longitud de la raíz del incisivo central superior aplicando la fórmula del método de Kvaal *et al.* para obtener la precisión del método en la estimación de la edad dental. Al aplicar la fórmula de Kvaal *et al.* indica que la relación entre la anchura de pulpa y la longitud de la raíz presentan un nivel de significancia mayor en relación a otras proporciones: M valor medio de todas las proporciones excepto T (-0.659) y W-L: diferencia entre los valores de W y L (-0.643). El coeficiente de determinación (r^2) y el error estándar de la estimación (SEE) utilizando la fórmula original de Kvaal es de r^2 : 0.70, SEE: 4.90 años, después se propuso una fórmula modificada de Kvaal para la población peruana. El Método de Kvaal *et al.* tiene una precisión del 1.24 en la estimación de la edad dental de los individuos, utilizando el incisivo central superior en radiografías panorámicas digitales.

PALABRAS CLAVES: Estimación de edad; Método de Kvaal; Incisivo central superior; Dentina secundaria; Pulpa dental.

INTRODUCTION

In the field of forensic science, human identification is the main task to be performed by forensic experts. Age estimation is one of the most important biological parameters of identification (1), which is obtained through the study of the various parts of the human body. Among them are the dental pieces due to their durability over time and with few structural modifications affected by the taphonomic process (1,2). In addition, these present characteristics such as hardness, resistance to external factors allowing them to be considered as a durable source analysis in the estimation of age (3) being an important tool for medical-legal (4).

The estimation of dental age is an important parameter in the process of identification and

reconstruction of the biological profile, especially when the bodies are in an advanced state of putrefaction, carbonization and/or fragmentation; in these conditions dental pieces are always preserved and present structural changes according to the age of the individual. One of these changes is associated with regressive phenomena or dental involution such as the apposition of secondary dentin (3); produced by an increasing and sequential physiological process through the deposit of dentin in the walls of the pulp chamber and root canal (a process that lasts a lifetime), the measurement of this pulp reduction can be used as a parameter to estimate the dental age of individuals, made by calculating the measures of length, width and pulp area in dental radiographs (6-7).

It has been calculated that dentin thickness increases at a rate of approximately 0.5 μ m per day

and decreases throughout life; while pulp width at the cervical level of the crown decreases by 2mm in the average age range from 28 to 74 years, giving an approximate rate of secondary deposition of 43 μ m per year, or 0.119 μ m per day (8). Quantitative studies have established a reduction in the total number of pulp cells by 50% between the ages of 20 and 70 years (8).

In forensic dentistry, non-invasive, precise and ethical methods of dental age estimation are required to help establish human identification; among these methods is image analysis, including digital panoramic radiography (9,10), which is a simple technique, regularly used in dental practice and can be applied in forensic studies (11-13).

Methods for estimating dental age based on the analysis of the dental pulp have been presented, such as Kvaal's method, which is characterized by analyzing the regression of pulp size (12,13).

Kvaal *et al.* (1995) developed a non-invasive method for the estimation of dental age (14). The study was initially applied in periapical radiographs and later in panoramic radiographs and tomography, making measurements of pulp length and width, the different relationships established results in each tooth that could be correlated with chronological age, obtaining a coefficient of determination of 0.70 for the upper central incisor with a standard error of the estimate in years of 9.5 years, being Kvaal's method applied to different ethnic groups (14-17).

Research has been carried out to test the reproducibility of Kvaal's method in independent samples using different radiological techniques, determining that the left or right upper central incisor, are the teeth that best adapted to the measurement (13), are suitable for the measurement (no significant differences were found between the sides) and that in age groups from 20 to 50 years the method presents greater appli-

cability (14). Bosmans *et al.* applied the method proposed by Kvaal *et al.* and concluded that there was no significant difference in estimating age when using digital panoramic radiographs and conventional periapical radiographs (18).

Studies based on the method proposed by Kvaal *et al.* were performed by:

Erbudak HÖ *et al.* (2012), evaluated the length and width of the pulp cavity in Turkish population, using digital panoramic radiographs, upper central incisor (r^2 : 0.124, SEE: 10.01 years), they concluded that their study was insufficient to accurately estimate the age of Turkish individuals (12).

Karkhanis S. *et al.* (2014), in a study in Australia evaluated the reliability and applicability of the method, the sample consisted of 279 individuals, of both sexes. They established that among the regression models for the analysis of teeth individually, the most accurate is the maxillary central incisor (r^2 : 0.35, SEE: 9.36 years) (9).

Chandan *et al.* (2020), in a study in India based on a sample of 100 panoramic radiographs, established that the formula is accurate for estimating the dental age in the six teeth, these investigations validate the use and applicability of this method in the estimation of the dental age of the adult population where the accuracy and precision is of greater range (19).

The purpose of the present research was to determine the accuracy of Kvaal's method in the estimation of dental age in digital panoramic radiographs of patients between 20 to 47 years old who attended the stomatological clinic of the Scientific University of the South, (2018 to 2019).

MATERIALS AND METHODS

The study was quantitative, observational, descriptive, cross-sectional and retrospective.

The study sample was 289 upper central incisors from digital panoramic radiographs belonging to patients of the Stomatological Clinic of the Scientific University of the South, aged 20 to 47 years. The digital panoramic radiographs were taken with the Vatech PAX-I series equipment of the UCSUR Stomatology Clinic. The research was approved by the Institutional Research Ethics Committee of the Scientific University of the South, assigning registration code 475-2020-POS99, indicating that the dignity, integrity and identity of the patients should be respected.

The samples complied with the inclusion criteria that the dental pieces analyzed should be of right or left upper permanent central incisors that do not present any kind of dental treatment or dental pathologies and that the digital panoramic radiograph has good image quality; likewise, the

exclusion criteria are: digital panoramic radiographs with right or left upper central incisors that present periodontal disease, bone resorption and with orthodontic treatments.

Prior to data collection, a specialist in oral and maxillofacial radiology conducted training with the principal investigator using the Intraclass Correlation Coefficient (ICC) test, achieving an interobserver ICC of 0.89 and an intraobserver ICC in the first measurement of 0.90 and in the second measurement of 0.88, demonstrating adequate reliability.

The measurements of the upper central incisors in digital panoramic radiographs were made using the EasyDent V4 Simple Viewer program (software of the Vatech Pax-I series digital panoramic X-ray equipment) the following measurements were obtained: (Figure 1. A-E).

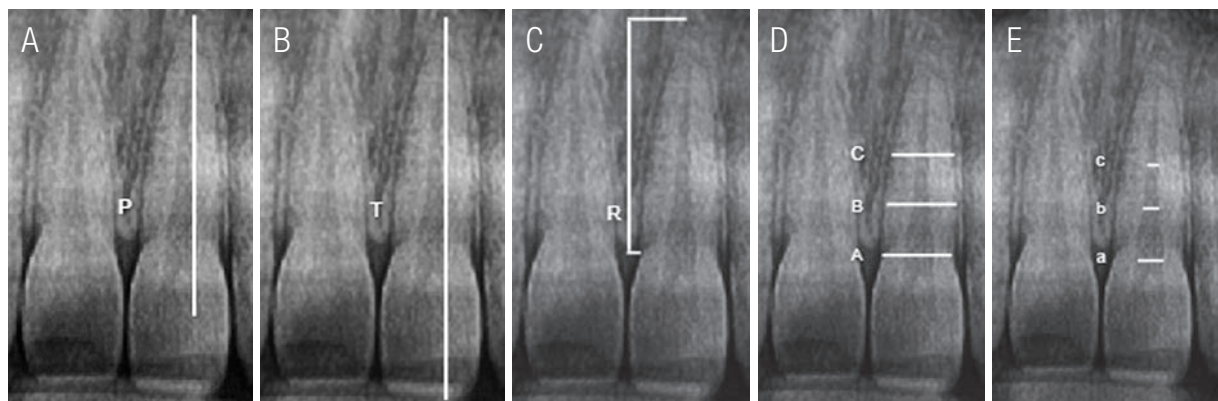


Figure 1. A: Total tooth length, B: Total pulp length, C: Total root length, D: Root width, E: Pulp width

- T (Total tooth length): measurement from the incisal edge to the root apex.
- P (Total pulp length): measurement from the highest pulp horn to the root apex.
- R (Total root length): length of the root on the mesial surface from the enamel cementum junction (ECJ) to the root apex.
- a: pulp width at the ECJ.
- b: pulp width at the midpoint between level C and A.
- c: pulp width at the midpoint of the level.
- A: Root width at the ECJ.
- B: Root width at the midpoint between C and A level.
- C: Pulp and root width at the midpoint of the level.

The results obtained were recorded in the training cards and in the data collection card prepared by the principal investigator, thus proceeding to make the following proportions:

- P: ratio between length of pulp and root.
- R: ratio between length of pulp and tooth.
- A: ratio between width of pulp and root at enamel-cementum junction (level A).
- B: ratio between width of pulp and root at midpoint between level C and A (level B).
- C: ratio between width of pulp and root at level of the middle root (level C).
- M: mean value of all ratios except T. ($M = \frac{P+R+A+B+C}{5}$).
- W: mean value of the width ratios of levels B and C. ($W = \frac{B+C}{2}$).
- L: mean value of the length ratios P and R. ($L = \frac{P+R}{2}$).
- W-L: difference between W and L.

The determination of the size of secondary dentin with the above measurements was obtained by Kvaal's original formula:

- Kvaal's original formula: $110.2 - 201.4 (M) - 31.3 (W-L)$.

The result obtained provides the dental age in years.

Data processing was performed with SPSS version 25 software. For the analysis of descriptive statistics, measurements of central tendency and dispersion were elaborated for each numerical variable; quantitative variables were analyzed by means of the mean, standard deviation with a 95% confidence interval. A Pearson correlation test was performed between the chronological age and the proportions of the measurements with a significance level of 0.01 oriented to establish the degree of correlation ($p < 0.001$). To know the precision at the moment of comparing the chronological age with the estimated age, first the Kolmogorov-Smirnov test was performed, which revealed that the data had a normal distribution, then the T test was performed for related tests, obtaining mean, 95% confidence interval (minimum and maximum), degree to freedom and level of significance.

RESULTS

The sample was distributed according to sex (female and male) showing that 70.24% (203) were females while 29.76% (86) were males and the age group with the highest frequency of cases was 20 to 26 years (Table 1).

The ratio of measurement proposed by Kvaal's method were analyzed, where the highest mean was W-L with 1.12 years, while the radius with the lowest mean was "C" with 0.21 years. The average age of the sample was 27.64 years with a variability of 23.98% with respect to this average, indicating a relative homogeneity. When observing the variation of the measurement ratio, homogeneity was found in the ratio of: P (6.54%), R (7.14%), M (8%), L (5.68%), W-L (6.25%), as for those with relative homogeneity were: B (23.07%), C (28.57%), W (17.39%) and the most heterogeneous with respect to the sample was A (40%) (Table 2).

Table 1. Distribution of samples according to sex and age group.

Sex	Age Group				Total	
	20 to 26	27 to 32	33 to 38	39 to 47	N	%
Female	113 (39.10%)	51 (17.65%)	18 (6.23%)	21 (7.27%)	203	70.24%
Male	53 (18.34%)	20 (6.92%)	12 (4.15%)	1 (0.35%)	86	29.76%
Total	166 (57.44%)	71 (24.57%)	30 (10.38%)	22 (7.61%)	289	100%

Table 2. Values of the measurements used in the Kvaal method for the estimation of dental age.

Measurement	Mean	Minimal	Maximum	D.E	C.V. (%)
Chronological age	27.64	20.00	51.64	6.63	23.98
"P"	1.07	0.84	1.24	0.07	6.54
"R"	0.70	0.56	0.81	0.05	7.14
"A"	0.25	0.00	0.46	0.10	40
"B"	0.26	0.13	0.52	0.06	23.07
"C"	0.21	0.08	0.49	0.06	28.57
M	0.50	0.36	0.58	0.04	8
W	0.23	0.11	0.41	0.04	17.39
L	0.88	0.70	1.02	0.05	5.68
W-L	1.12	0.90	1.30	0.07	6.25

D.E.: Standard deviation.

C.V.: coefficient of variation.

On analyzing the chronological age with the estimated dental age according to sex, the chronological age for the male sex has an average of 25.75 years and for the female sex an average of 27.61 years; while the estimated dental age according to the Kvaal method obtained values for the male sex of 29.49 years and for the female sex of 31.36 years. The analysis was made according to age groups, where it was found that the most predominant group was between 33 and 38 years of age with an average of 35.56 years for the chronological age and for the estimated dental age according to the Kvaal method it was 39.33 years. The average chronological age of the sample is

27.05 years with a variability of 23.98 % and the estimated dental age is 30.80 years with a variability of 23.79%. It is observed that both variables do not show differences in variability; they vary in mean age, but not in variability (Table 3).

Pearson's correlation showed that the radii with the highest level of significance were: M with a value of $r=0.659$, W with a value of $r=0.511$ and W-L with a value of $r=0.643$. Chronological age has a higher linear correlation with the variables M and W-L, but the correlations between measurement radii and chronological age are all significant (Table 4).

Table 3. Comparison between estimated dental age and chronological age by sex and age group.

Age	Sex		Age group (years)				Total
	Female	Male	20 to 26	27 to 32	33 to 38	39 to 47	
Chronological age	27.61 ± 6.88	25.75 ± 5.31	22.52 ± 1.99	29.33 ± 1.62	35.56 ± 1.95	42.27 ± 2.89	27.05 ± 6.64
Estimated dental age	31.36 ± 7.65	29.49 ± 6.38	42.27 ± 2.89	32.45 ± 5.67	39.33 ± 5.63	42.43 ± 6.31	30.80 ± 7.33

Table 4. Pearson correlation coefficient between chronological age and the measurement radii used in Kvaal's method.

Measurement	Relationship with age		
	r-value	P value	Significance
P	-0.370	<0,001	**
R	-0.357	<0,001	**
T	-0.397	<0,001	**
B	-0.387	<0,001	**
C	-0.408	<0,001	**
M	-0.659	<0,001	**
W	-0.511	<0,001	**
L	-0.403	<0,001	**
W-L	-0.643	<0,001	**

Pearson correlation,

P: ratio between length of pulp and root. R: ratio between length of pulp and tooth. A: ratio between width of pulp and root at enamel-cementum junction (level A). B: ratio between width of pulp and root at midpoint between level C and A (level B). C: ratio between width of pulp and root at level of the middle root (level C). M: mean value of all ratios except T. W: mean value of the width ratios of levels B and C. L: mean value of the length ratios P and R. W-L, difference between W and L.

r-value: correlation coefficient;

**P <0.001: highly significant.

Each of the estimated dental age and chronological age variables for each age group have a significant normal probability behavior, for which the Kolmogorov Smirnov test was used. The correlation between the chronological ages and the estimated dental ages for each age group showed high correlations (27 to 32 years and 39 to 47 years), but when the correlation was made by age group, it was found to have a low correlation. The confidence intervals for the total sample calculating the average of the chronological age, the estimated dental age, the total average and for the different age groups have negative lower and upper limits, which implies that the estimated dental age is greater than the chronological age on average. As for the significance for the difference between the averages between the chronological age and the estimated dental age, all are significant with the exception of the age group 39 to 47 years. The t-test was performed for related tests in order to find the precision

between the chronological age and the estimated age according to the Kvaal method, where found that the total sample achieved a mean of -3.160 with 95% confidence intervals (-3.78 to -2.53), which indicates that the precision of the method is -1.24 (Table 5).

When obtaining the standard error of the estimation in years of the original Kvaal formula was 4.90 years, with a coefficient of determination of 0.70, a precision of 1.24 and a percentage of accuracy of 55.36% (Table 6).

After the precision obtained and taking into account the importance of applying specific formulas for each study population, a linear regression analysis was carried out, taking into account the most representative variables of the study M and W-L. This formula had an R^2 : 0.99, which indicates that the formula presents a good model fit (Table 7).

Table 5. Comparison and accuracy between the chronological age and the dental age estimated according to the Kvaal method.

	N	r	Mean	95% I.C.		t	Significant
				Lower	Upper		
Total sample	289	0.708	-3.160	-3.783	-2.537	-9.986	0.000
20 to 26 years	166	0.189	-3.800	-4.588	-3.012	-9.952	0.015
27 to 32 years	71	0.342	-2.664	-3.926	-1.401	-4.208	0.000
33 to 38 years	30	0.172	-3.334	-5.437	-1.231	-3.243	0.003
39 to 47 years	22	0.392	0.299	-2.285	-2.883	0.241	0.812

r=correlation coefficient

t: t-test for paired tests

Table 6. Comparison between the original Kvaal formula and the modified Kvaal formula.

Regression formula	R^2	SEE (years)	Mean	D.S	Accuracy	+/-0.5 years
Original Kvaal Age= Formula 110.2-201.4(M)-31.3(W-L)	0.70	4.90	30.80	7.33	1.24	55.36% (160/289)

Table 7. Modified Kvaal formula proposal.

Modified Kvaal Formula	R^2	SEE (years)
Age= 110.987-192.224 M-32.85 W + 25.66 L	0.99	4.87

DISCUSSION

In the process of human identification there are different methodologies for estimating the dental age of living individuals and corpses, which can be based on invasive and non-invasive methods. The present study is a noninvasive method, because it is oriented to the Kvaal methodology, which estimates the age in adults through intraoral periapical radiographs (14). Thus, we developed this study in a Peruvian population to analyze the accuracy of the Kvaal *et al.* method using the upper central incisor through digital panoramic radiographs.

In our study the Pearson correlation between chronological age and the ratio between pulp and root length were the indicators with the highest level of significance, being: M (-0.659) and W-L (-0.643), similar to Sharma R. *et al.* (6) where they observed that the relationship between pulp width and root length were better indicators for age: W-L (-0.36) and W (-0.34). In the following studies with higher indicators Li Mj *et al.* (15): B (-0.381) and M (-0.381), and Kvaal *et al.* (14): M (-0.83) and P (-0.77). In contrast to other studies where they found results that pulp width is the best indicator compared to root length for age estimation, such as Karkhanis *et al.* (9): C (-0.295) and W (-0.3.19), Patil *et al.* (11): B (-0.52) and W (-0.57), Mittal S. *et al.* (13): A (-0.680) and C (-0.626) and Bosmans *et al.*: A (-0.70) and M (-0.76). These variations between the studies could be attributed to the fact that they were performed in different populations, therefore, secondary dentin deposition will vary with advancing age, due to the fact that the deposition is along the wall of the dental pulp chamber, which causes a reduction in the size of the pulp chamber. The amount of secondary dentin deposition is influenced by factors such as race, ethnicity, diet, and lifestyle (11).

Sharma R. *et al.* (6) by comparing the mean chronological age with the estimated dental

age in an Indian population obtained results for the estimated dental age of 24.30 years with a standard deviation of ± 5.06 . Mittal S. *et al.* (13) found a value of 29.20 years for the estimated dental age with a standard deviation of ± 10.09 in an Indian population. Chandan *et al.* (19) in a population in North India shows that the estimated dental age is 32.63 years with a standard deviation of ± 3.96 . And in our investigation it was obtained that the estimated dental age is 30.80 years with a standard deviation of ± 7.33 . When compared with previous studies it reveals that the Kvaal method is an adaptable and reproducible method of estimating dental age in adults. The estimated dental age was found to be close in both variability and mean to the chronological age in almost all the upper central incisors studied.

When the correlation coefficient was obtained by performing the t-test for paired tests between age groups, it was observed that the results were low, while the correlation for the total sample obtained a high value of $r: 0.708$, therefore, there is greater precision when the entire sample is studied together.

The correlation coefficient of the present study was 0.70, being higher than in previous studies, such as in: Kvaal *et al.* (14) $R^2: 0.70$, Sharma R. *et al.* (6) $R^2: 0.183$, Karkhanis *et al.* (9) $R^2: 0.135$, Erbudak HÖ *et al.* (12) $R^2: 0.124$, Mittal S. *et al.* (13) $R^2: 0.356$ and Li Mj *et al.* (15) $R^2: 0.12$. The standard error of the estimate in years found in the present study for the original Kvaal formula 4. 90 years is lower than other studies performed in different populations: Karkhanis *et al.* (9) SEE: 9.367 years, Patil *et al.* (11) SEE: 6.5 years, Erbudak HÖ *et al.* (12) SEE: 10.01 years, Mittal S. *et al.* (13) SEE: 8.15 years, Li Mj *et al.* (15) SEE: 12.2 years, Kvaal *et al.* (14) 9.5 years and Bosmans *et al.* (18) SEE: 9.7 years. Thus, our study showed better results at the time of estimating dental age. Taking into account that any diffe-

rences found can be attributed to multiple variables, among them the precision of the method, the age distribution of the sample, the sample size. (6)

Karkhanis *et al.* (9) in their results found that the upper central incisor is accurate when comparing chronological age with estimated dental age, with a standard deviation of 9.36 years. Chandan *et al.* (19) established that the Kvaal formula proves to be accurate with a value of 1.72 for estimating dental age with a standard deviation of 3.96 years. Similar to our study which obtained an accuracy between chronological age and dental age estimated according to Kvaal's method of 1.24, with a standard deviation of 7.33 years, thus achieving agreement with the studies of Karkhanis *et al.* (9) and Chandan *et al.* (19) pointed out that Kvaal's method is accurate for estimating dental age estimated using the upper central incisor in digital panoramic radiographs. However, in the study of Li Mj *et al.* (15) the opposite was evidenced, they concluded that Kvaal's method could not estimate the accuracy of age, as the chronological age was overestimated when using this method with a standard deviation of 11.8 years. Like Erbudak HÖ *et al.* (12) obtained a standard deviation of 11.82 years, therefore, they concluded that the results obtained were insufficient to accurately estimate the age of Turkish individuals. And when comparing with other studies, it is considered that ethnic differences and secondary dentin deposition influence the differences between dental age and chronological age.

When comparing previous studies applying the Kvaal method formula in different populations, some differences were found between the results with the present study, this could be attributed to various factors, such as: ethnicity, race, living conditions. Recalling that the stage of tooth development, tooth size and the shape of the pulp

cavity vary not only in populations, but also within people of the same ethnicity, which could affect the speed of secondary dentin formation (15). It may also be due to the fact that the previous studies and the present one used different types of radiographs: conventional or digital periapical radiographs and digital panoramic radiographs. In a study conducted to evaluate the reliability of the crown-root ratio using panoramic radiographs, they concluded that tooth length and crown-root ratio can be measured accurately and reliably, taking into account the correct positioning of the patient and especially in the sagittal plane (upward or downward tilting of the occlusal plane) (20).

Due to the factors presented above, different studies have presented modified Kvaal formulas to be applied to their type of population in order to better evaluate the accuracy of the method when estimating dental age with chronological age (1,15).

There is no further research conducted in the Peruvian population, which makes it necessary to conduct more studies with a larger sample size and in a diverse ethnic and geographic origin (due to the great diversity of ethnic groups in Peru) that can help to estimate the accuracy of the method.

CONCLUSION

Our study determined the Kvaal Method had an accuracy of -1.24 years when it used in Peruvian population. This result showed they accuracy between the chronological age and dental age estimation when we analyse the upper central incisor tooth.

Also we found the importance to create a new formula for age estimation specific for Peruvian population.

FINANCING

The study was self-funded.

CONFLICT OF INTEREST

The authors have no conflict of interest related to this article.

AUTHOR CONTRIBUTION STATEMENT

Conceptualization and design: H.N.I.L.
 Literature review: H.N.I.L., E.R.A.M.
 Methodology: H.N.I.L.
 Validation: M.Q.M.
 Formal analysis: H.N.I.L.
 Research and data collection: H.N.I.L.
 Resources: H.N.I.L.
 Data analysis and Interpretation: V.A.N.S.
 Writing-preparation of the priginal draft: H.N.I.L.
 Writing: review and editing: H.N.I.L., E.R.A.M.,
 D.G.S.P., M.Q.M.
 Supervision: E.R.A.M.
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