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ORIGINAL RESEARCH

FORENSIC ASSESSMENT OF AGE FROM PULP CAVITY USING CONE BEAM COMPUTED TOMOGRAPHIC IMAGES (AN OBSERVATIONAL CROSS-SECTIONAL STUDY)

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Background: In human dentition, the size of pulp cavity decreases as deposition of secondary dentin increases with age which can be used as an age predictor. This study aims to investigate the correlation between chronological age with pulp to tooth volume ratio (PV/TV) and Kvaals' morphological ratios, evaluate Kvaal's approach age estimation applicability, validate original regression models suggested by Kvaal et al. and create population specific regression equations for age prediction utilizing PV/TV and Kvaals' variables.

Materials and Methods: This study examined CBCT images of 75 teeth of individuals aged 18-60 years. Volumetric analysis of maxillary central incisor pulp cavity and tooth was performed using 3D Slicer software and PV/TV was calculated. Linear measurements of three sorts of teeth were conducted in sagittal sections utilizing Kvaal's approach. Correlation and multiple linear regression analysis were conducted. Kvaals' original regression formulas were applied for age assessment. PV/TV and Kvaals' ratios errors were measured across voxel sizes.

Results: Regression models using PV/TV with varying voxel sizes were significant for age estimation with the best model with correlation coefficient of 0.775 and coefficient of determination of 0.601. Regression analysis utilizing stepwise method showed stronger correlation ($R=0.613-0.646$) and higher coefficient of determination ($R^2=0.376-0.417$) than utilizing Kvaals' M and W-L variables with all predictors were found significant. No significant difference between voxel sizes regarding PV/TV error, likewise Kvaals' ratios error except maxillary lateral incisor.

Conclusions: PV/TV proved to be a reliable age estimation indicator. Kvaal's approach was applicable to Egyptian adult subjects. Original Kvaals' formulae lacked precision. Population specific formulae using stepwise method had higher prediction ability than M & W-L predictors.

Key words: Forensic odontology; Age estimation; Dental pulp cavity; Pulp to tooth volume; Kvaal's approach; Cone-beam computed tomography.

INTRODUCTION

Medico-legal challenges, natural disasters like explosions, tsunamis and earthquakes, death confirmation for financial issues and social considerations are among instances necessitating identification. Forensic investigators utilize several ways for identifying the deceased for this reason ⁽¹⁾. Age, gender, stature and race are the main variables that define personal identification. These are the

characteristics of 'tentative identification' ⁽²⁾. In the field of anthropology and forensic medicine, age estimation is difficult at times, however, it is crucial ⁽³⁾. Dental age estimation has the benefit of that teeth are less influenced by external physical, chemical, or mechanical variables than other portions of the skeleton ⁽⁴⁾. In human dentition, the size of the dental pulp cavity decreases as deposition of secondary dentin increases with age which can be used as an age predictor. In a

study performed in 1995, Kvaal et al. primarily identified a substantial correlation between age and pulp width and developed regression formulas for age estimation through the measurement of pulp dimensions utilizing periapical radiography. The authors proposed that population-specific research should be performed to confirm their methodology because they believed their formulae might be applied to other ethnic groupings⁽⁵⁾. In addition, the evaluation of pulp to tooth volume ratio based on progressive decrease in pulp volume due to ongoing deposition of dentin throughout life is a recognized method for dental age assessment⁽⁴⁾. Cone beam computed tomography (CBCT) is applicable in forensic age evaluation owing to its non-invasive nature and its capability to reconstruct images in several planes, hence displaying anatomical and imaged structures in various planes⁽⁶⁾. Due to anthropological disparities among various ethnic groups, a formula developed for a population may not be suitable for another and a specific regression formula should be obtained for each population⁽⁷⁾. Also, there are few studies available on age assessment utilizing CBCT⁽⁸⁾. So, this study aims to investigate the correlation between chronological age with pulp to tooth volume ratio (PV/TV) and Kvaal et al.'s morphological ratios, assess the applicability of Kvaal's approach in age estimation and verify the validity of the original regression models suggested by Kvaal et al. also, create population specific regression equations for age prediction utilizing PV/TV and Kvaal's variables on CBCT images in a sample of the Egyptian adult population.

1. MATERIALS & METHODS

1.1 Study subjects

This was a retrospective study where archived CBCT images of patients who were admitted to the Faculty of Dentistry, Cairo University were screened. CBCT scans for Egyptian females and males aged 18 to 60 years with the necessary set of teeth (maxillary central incisor, maxillary lateral incisor and mandibular first premolar) were included in the study. CBCT scans were excluded from the study if they lacked verifiable age or birth date information. Additionally, scans were excluded if the required teeth exhibited any of the following conditions: apical bone pathology, dental fillings, prosthetic restorations, carious lesions, impacted teeth, visible attrition, root resorption, root canal treatment, orthodontic appliances, or were obscured by overlying teeth. Sample size calculation was done based on the primary outcome with type I error probability to 0.05,

80% power setting, the needed sample size was found to be 25 teeth regarding volumetric measurements and 25 patients including 75 teeth regarding linear measurements. Then, screening was done considering the inclusion and exclusion criteria and CBCT images of 75 teeth accounting for 25 patients were included in the study. By recording the participants' birth and imaging dates, the chronological age of each participant was determined, as well as recording the gender of the 25 patients (13 females and 12 males). Teeth were chosen from either left or right side, depending on which side was more suitable for measurement.

CBCT image acquisition and measurements

All CBCT scans of patients were imaged utilizing a CBCT unit Planmeca Promax 3D Mid Helsinki (Finland) with 0.2 and 0.4 mm voxel sizes. The images were exported in the Digital Imaging and Communication in Medicine (DICOM) file format. DICOM data were then imported to 3D Slicer software program (open-source free software; version 5.6.2) for the calculation of volumetric and linear measurements.

1.2.1 Volumetric measurements:

Tooth volume (TV) and pulp volume (PV) of the maxillary central incisor were measured as follows. First, the images were oriented properly in axial, coronal and sagittal planes. Then, the segment editor module was used to add a new segment of the tooth structure, the threshold effect in the effects section was activated and the threshold range was adjusted by modifying the minimum and maximum greyscale threshold values of the tooth structure. In the next stage, by using the paint brush and the erase tools in the effects section, the segment was manually adjusted slice by slice for segmentation and separation of the investigated tooth from the surrounding structures in the three orthogonal planes. In addition, the same steps were repeated for segmentation of the pulp cavity of the same tooth. Then, three-dimensional models of tooth structure and pulp cavity were reconstructed, and the segment statistics module was used to calculate the volume of the tooth and pulp in mm³. The final segmentation of tooth and pulp cavity of maxillary central incisor is shown in figure (1). Finally, the pulp to tooth volume ratio (PV/TV) of the maxillary central incisor was calculated using the excel program.

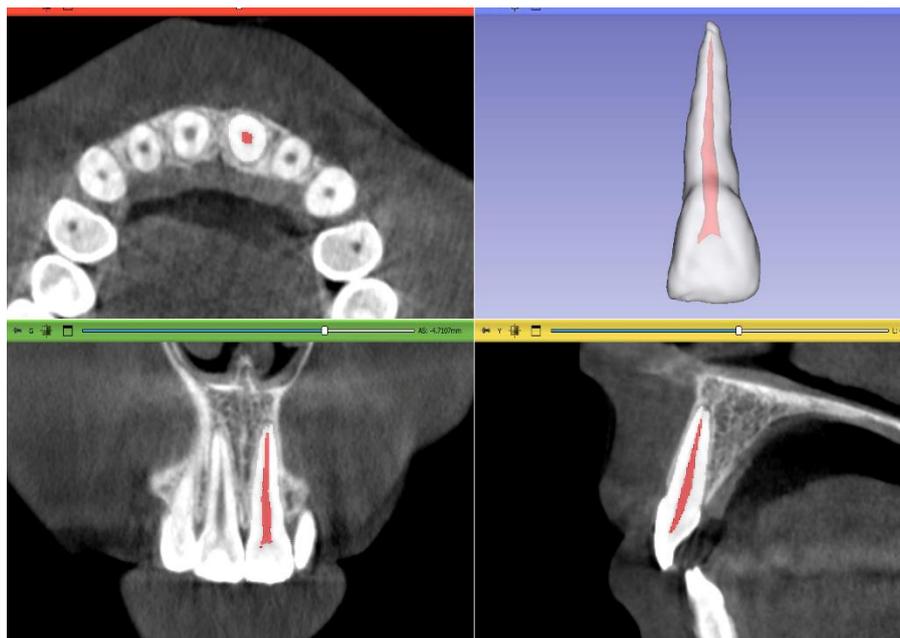


Figure 1. The final segmentation of tooth and pulp cavity of maxillary central incisor

1.1.1 Linear measurements:

Besides, linear measurements of pulp cavity and teeth of maxillary central incisor, maxillary lateral incisor and mandibular first premolar were done according to the method developed by Kvaal et al. on CBCT sagittal sections using the line and angle tools of the markups module of the 3d slicer software⁽⁵⁾. First, the tooth was determined and an oblique cut was made to process the image by adjusting the intersection lines with the long axis of the tooth. Then, the slice that shows complete length and width of the tooth and pulp cavity in the sagittal section was selected. For standardization, the long axis of the tooth was manually drawn (R1) then, 6 reference lines were made as follows: R2: the longest length of the tooth (highest point of cusp tip or incisal edge), R3: the highest point of the pulp chamber, R4: the cemento enamel junction (level A), R5: the location of the root apex, R6: midroot level which is midway between the cemento enamel junction and the root apex (level C) and R7: the midpoint between the cemento enamel junction and midroot level (level B) as shown in figure (2). All the reference lines were drawn perpendicular to the tooth long axis, all the length measurements were drawn perpendicular to the related reference lines in accordance to the rules of parallelism and perpendicularity.

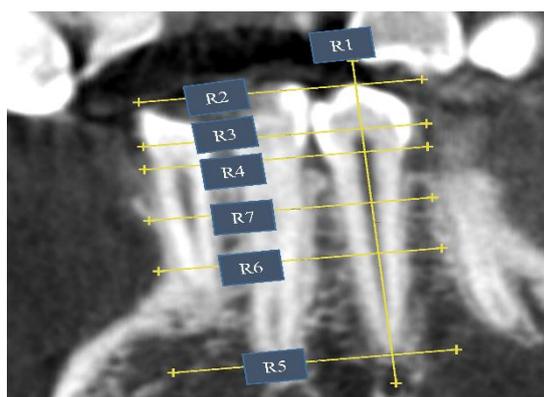


Figure 2. Reference lines drawn for standardization of linear measurements on CBCT sagittal sections in mandibular first premolar

According to Kvaal's method described by Kvaal et al.⁽⁵⁾, nine length and width measurements were performed for each tooth as follows: T: utmost length of a tooth, P: maximum length of pulp, R: length of root along the mesial aspect between root apex and cemento enamel junction, A: width of root at cemento enamel junction (level A), A': width of pulp at cemento enamel junction (level A), C: width of root at midroot level, C': width of pulp at midroot level, i.e. midroot level: midway between root apex and cemento enamel junction (level C), B: width of root at midpoint

between midroot level and cemento enamel junction (level B) and B': width of pulp at midpoint between midroot level and cemento enamel junction (level B) as shown in **figure (3)**.

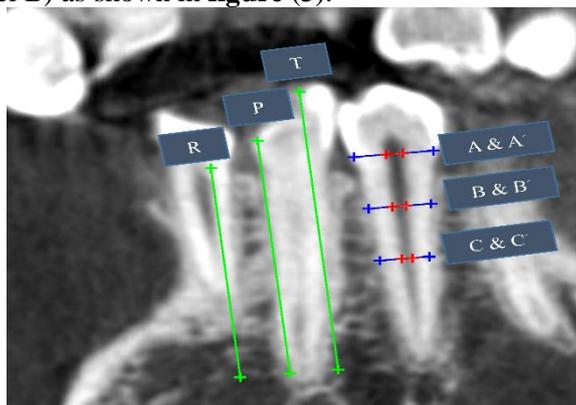


Figure 3. Length and width measurements performed according to Kvaal et al.'s approach on CBCT sagittal sections in mandibular first premolar

Then, data were entered into spreadsheets in Excel program and the following 10 ratios were calculated: P, pulp-to-root length ratio; T, tooth-to-root length ratio; R, pulp-to-tooth length ratio; A, pulp to root width ratio at cemento enamel junction (level A); B, pulp-to-root width ratio at halfway point between levels C and A (level B); C, pulp-to-root width ratio at mid-root level (level C); M, mean value of all ratios (first predictor); W, mean value of width ratios from levels B and C; L, mean value of the length ratios P and R; W-L, difference between W and L (second predictor).

Correlation analysis was employed to assess the association between chronological age and the assessed variables. The original regression formulas suggested by Kvaal et al, were used for age assessment to assess their applicability. The Kvaal's original formulae that were used for age estimation are as follows:

Maxillary central incisor: $\text{Age} = 110.2 - 201.4(M) - 31.3(W-L)$,
 Maxillary lateral incisor: $\text{Age} = 103.5 - 216.6(M) - 46.6(W-L)$,
 Mandibular first premolar: $\text{Age} = 133.0 - 318.3(M) - 65.0(W-L)$.

Multiple linear regression analysis was conducted with chronological age as dependent variable and PV/TV and morphological ratios of Kvaal's approach as independent variables to establish population specific regression formulas for age estimation. PV/TV error and Kvaal's ratios error were measured across both voxel sizes. Intraobserver and interobserver variability was measured by two oral radiologists with years of experience ranging from 10-34 years.

1.1 Statistical analysis

Data were statistically described in terms of mean \pm standard deviation (\pm SD), median and range, or frequencies (number of cases) and percentages when appropriate. Comparison of numerical variables between the study groups was done using Mann Whitney U test for independent samples. Correlation between various variables was done using Pearson moment correlation equation for linear relation of normally distributed variables and Spearman rank correlation equation for non-normal variables/non-linear monotonic relation. Linear regression analysis was used to test to construct an equation predicting chronological age using the different studied variables. Interobserver and intraobserver variability analysis was done using the intraclass correlation coefficient (ICC). Two-sided p values less than 0.05 were considered statistically significant. IBM SPSS (Statistical Package for the Social Science; IBM Corp, Armonk, NY, USA) release 22 for Microsoft Windows was used for all statistical analyses

2. RESULTS

2.1 Descriptive and variability analysis:

In the current study, 75 teeth of 25 patients were evaluated to estimate the age based on volumetric and linear measurements of tooth and pulp cavity. The age of the subjects was between 18 and 57 years. The mean age was 31.48 \pm 10.267 years. The study group consisted of 13 females (52%) and 12 males (48%). Twelve CBCT scans (48%) had a voxel size of 0.2 mm while 13 scans (52%) had a voxel size of 0.4 mm. Intra- and inter-observer variability for linear and volumetric measurements were analyzed using the intraclass correlation coefficient (ICC) and revealed high agreement across observers in the all assessed parameters.

2.2 Regression analysis based on PV/TV:

In regression analysis using age as the dependent variable and PV/TV as an independent variable, the coefficient of determination of values were obtained as $R^2 = 0.601$ for group 1 (0.2 mm voxel size) and $R^2 = 0.409$ for group 2 (0.4 mm voxel size) with standard error of 7.618 and 4.238 respectively indicating adequate fitness. Among regression models, the regression formula with the highest coefficient of determination with higher predictive accuracy was that for group 1, therefore the formula for group 1 was the one that best accounts for age.

The findings of regression model analysis demonstrated a strong negative correlation between age and PV/TV in both study groups. Also, there was a significant correlation between chronological age and PV/TV of maxillary central incisor in both groups ($p < 0.05$). The correlation between PV/TV and chronological age was higher in group 1 ($R = -0.775$) than group 2 ($R = -0.639$) (Table 1).

Table 1. Regression model results including the dependent and the predictor variables

	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Group 1 (0.2 mm voxel size)	1	0.775(*)	0.601	0.561	7.618
Group 2 (0.4 mm voxel size)	1	0.639(*)	0.409	0.355	4.238

(*) Predictors: constant, PV/TV

Scatter plots demonstrating the correlation between chronological age (in years) and PV/TV predicted age in both groups are shown in figures (4&5).

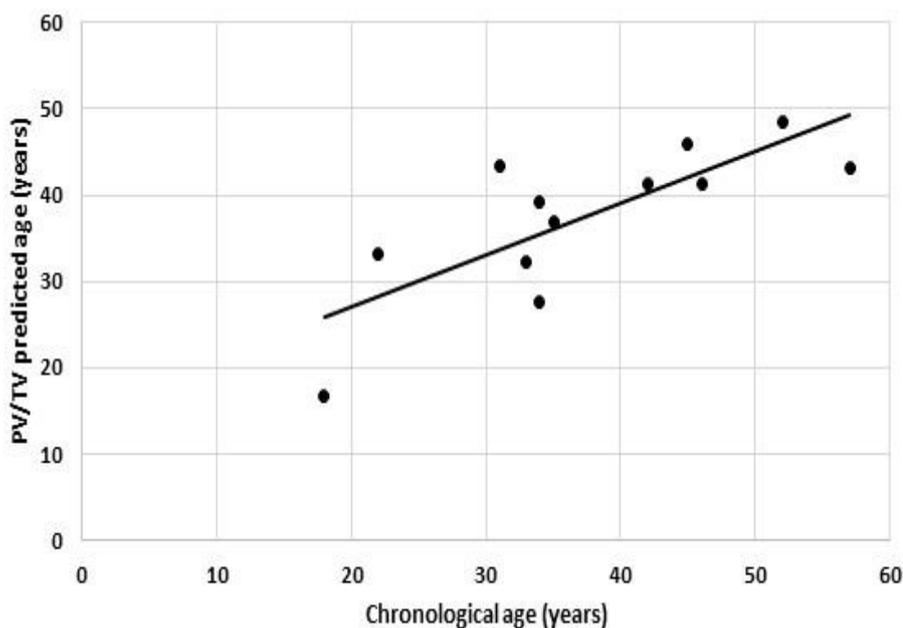


Figure 4. Scatter plot demonstrating the correlation between chronological age (years) and pulp to tooth volume ratio (PV/TV) predicted age in 0.2 mm voxel size group

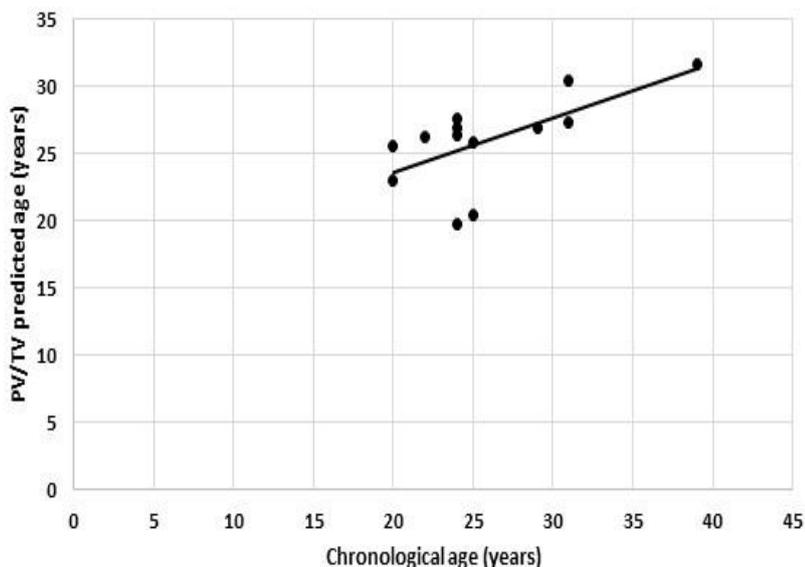


Figure 5. Scatter plot demonstrating the correlation between chronological age (years) and pulp to tooth volume ratio (PV/TV) predicted age in 0.4 mm voxel size group

ANOVA showed that the total regression with regard to the correlation of age with PV/TV variable was significant (p-value < 0.05) (Table 2).

Table 2. Results of the ANOVA in both study groups

	Model		Sum of Squares	df	Mean Square	F	Sig.
Group 1 (0.2 mm voxel size)	1	Regression	872.639	1	872.639	15.038	0.003(*)
		Residual	580.278	10	58.028		
		Total	1,452.917	11			
Group 2 (0.4 mm voxel size)	1	Regression	136.461	1	136.461	7.599	0.019(*)
		Residual	197.539	11	17.958		
		Total	334.000	12			

(*) Predictors: constant, PV/TV

The outcomes of the logarithmic regression model including the dependent and predictor variables are presented in **table 3**. Regression models utilizing various voxel sizes provided statistical significance for age assessment across both voxel groups.

According to **table 3**, age, as an effective factor, can easily be estimated by PV/TV in the 0.2 mm voxel size group, the regression model analysis was achieved as follows:

$$\text{Age} = 63.307 - 800.781 (PV/TV)$$

Besides, age, can also easily be estimated by PV/TV in the 0.4 mm voxel size group, the regression model analysis was achieved as follows:

$$\text{Age} = 40.429 - 253.085 (PV/TV)$$

Table 3. The outcomes of the logarithmic regression model including the dependent and predictor variables

	Mode 1	Unstandardized Coefficients	Standardized Coefficients		t	Sig.	95% CI for B	
			B	Std. Error			Beta	Lower
Group 1 (0.2 mm voxel size)	1 (Constant) PV/TV	63.307	7.029		9.006	0.000	47.645	78.969
		-800.781	206.497	-0.775	-3.878	0.003	-1,260.885	-340.676
Group 2 (0.4 mm voxel size)	1 (Constant) PV/TV	40.429	5.365		7.536	0.000	28.622	52.237
		-253.085	91.810	-0.639	-2.757	0.019	-455.159	-51.012

1.1 Correlation analysis:

In the present study, a negative correlation was found between chronological age and PV/TV as well as most of morphological variables of Kvaal’s method as a result of Pearson correlation analysis for Kvaals’ parameters.

Regarding the maxillary central incisor, the highest correlation values were observed in variables C (R=-0.702), W (R=-0.665) and A (R=-0.584) in group 1 and variables R (R=-0.767), L (R=-0.638), B (R=-0.618), A (R=-0.567) and W (R=-0.560) in group 2. There were significant correlations between the former morphological variables and chronological age (P-value < 0.05). The correlation coefficient of the predicted age based on Kvaal’s original equation was 0.334 in group 1 and 0.484 in group 2 (P-value > 0.05). (Table 4).

Table 4. Pearson correlation coefficients between the studied variables and chronological age in both groups of the maxillary central incisor

		Group 1 - 0.2 mm voxel	Group 2 - 0.4 mm voxel
PV/TV	Pearson	-0.775	-0.639
	p value	0.003	0.019
P Ratio	Pearson	-0.058	-0.458
	p value	0.857	0.115
T Ratio	Pearson	0.383	0.272
	p value	0.219	0.368
R Ratio	Pearson	-0.520	-0.767
	p value	0.083	0.002
A Ratio	Pearson	-0.584	-0.567
	p value	0.046	0.043
C Ratio	Pearson	-0.702	-0.367
	p value	0.011	0.217
B Ratio	Pearson	-0.502	-0.618
	p value	0.097	0.024
M Ratio	Pearson	-0.262	-0.511
	p value	0.410	0.075
W Ratio	Pearson	-0.665	-0.560
	p value	0.018	0.046
L Ratio	Pearson	-0.230	-0.638
	p value	0.471	0.019
W-L Ratio	Pearson	-0.141	0.308
	p value	0.663	0.307

Kvaal's Predicted Age	Pearson	0.334	0.484
	p value	0.289	0.094
PV/TV based Predicted Value	Pearson	0.775	0.639
	p value	0.003	0.019
	N	12	13

Regarding the maxillary lateral incisor, the highest correlation values were observed in variables C (R=-0.535) and W (R=-0.508) in group 1 and variables B (R=-0.484) and W (R=-0.476) in group 2. The correlation coefficient of the predicted age based on Kvaal's original equation was 0.430 in group 1 and 0.426 in group 2 (P-value > 0.05). (Table 5).

Table 5. Pearson correlation coefficients between the studied variables and chronological age in both groups of the maxillary lateral incisor

		Group 1 - 0.2 mm voxel size	Group 2 - 0.4 mm voxel size
P Ratio	Pearson Correlation	-0.104	-0.313
	p value	0.748	0.297
T Ratio	Pearson Correlation	0.126	-0.057
	p value	0.696	0.854
R Ratio	Pearson Correlation	-0.270	-0.263
	p value	0.397	0.385
A Ratio	Pearson Correlation	-0.371	-0.094
	p value	0.235	0.761
C Ratio	Pearson Correlation	-0.535	-0.347
	p value	0.073	0.246
B Ratio	Pearson Correlation	-0.404	-0.484
	p value	0.193	0.094
M Ratio	Pearson Correlation	-0.383	-0.420
	p value	0.219	0.153
W Ratio	Pearson Correlation	-0.508	-0.476
	p value	0.092	0.100
L Ratio	Pearson Correlation	-0.207	-0.363
	p value	0.519	0.223
W-L Ratio	Pearson Correlation	-0.300	-0.176
	p value	0.343	0.565
Kvaal's Predicted Age	Pearson Correlation	0.430	0.426
	p value	0.163	0.147
	N	12	13

Regarding the mandibular first premolar, the highest correlation value were observed in variable A (R=-0.615) (statistically significant as p-value=0.033, p-value<0.05) in group 1 and variable L (R=-0.352) in group 2. The correlation coefficient of the predicted age based on Kvaal's original equation was 0.375 in group 1 and 0.197 in group 2 (P-value > 0.05). (Table 6).

Table 6. Pearson correlation coefficients between the studied variables and chronological age in both groups of the mandibular first premolar

		Group 1 - 0.2 mm voxel size	Group 2 - 0.4 mm voxel size
P Ratio	Pearson Correlation	0.003	-0.309
	p value	0.994	0.304
T Ratio	Pearson Correlation	-0.028	-0.124
	p value	0.930	0.688

R Ratio	Pearson Correlation	0.024	-0.205
	p value	0.941	0.501
A Ratio	Pearson Correlation	-0.615	-0.219
	p value	0.033	0.472
C Ratio	Pearson Correlation	-0.247	-0.066
	p value	0.439	0.830
B Ratio	Pearson Correlation	-0.366	-0.308
	p value	0.242	0.305
M Ratio	Pearson Correlation	-0.289	-0.254
	p value	0.363	0.402
W Ratio	Pearson Correlation	-0.321	-0.150
	p value	0.309	0.626
L Ratio	Pearson Correlation	0.009	-0.352
	p value	0.977	0.239
W-L Ratio	Pearson Correlation	-0.255	0.022
	p value	0.424	0.943
Kvaal's Predicted Age	Pearson Correlation	0.375	0.197
	p value	0.230	0.519
	N	12	13

1.1 Regression analysis based on Kvaals' morphological ratios:

Also, multiple regression analysis was performed with age as dependent variable and the morphological ratios of Kvaal's approach as independent variables with separate equations given to each study group as demonstrated in **table (7)**.

Table 7. Population specific multiple regression models for chronological age estimation in years using Kvaals' variables for both study groups

Variables	Study group	Equation	R	R ²	SEE	Significant predictor (5%)
Original Kvaal's article: M & W-L ratios	Group 1 (0.2 mm voxel size)	Chronological age = 31.802-77.968(<i>M ratio</i>)-69.174(<i>W-L ratio</i>)	0.370	0.137	10.677	W-L ratio (P-value=0.046)
Original Kvaal's article: M & W-L ratios	Group 2 (0.4 mm voxel size)	Chronological age = 39.559-23.450(<i>M ratio</i>)-3.917(<i>W-L ratio</i>)	0.256	0.065	5.101	Constant (P-value=0.005)
Stepwise regression C, A & T ratios	Group 1 (0.2 mm voxel size)	Chronological age = 39.783-95.124(<i>C ratio</i>)-117.760(<i>A ratio</i>)+21.623(<i>T ratio</i>)	0.646	0.417	8.913	All predictors are significant Constant (p-value=0.01) C ratio (p-value=0.007) A ratio (p-value=0.0015) T ratio (p-value=0.030)

Stepwise regression R & B ratios	Group 2 (0.4 mm voxel size)	Chronological age = 83.893-62.961(<i>R ratio</i>)- 39.792(<i>B ratio</i>)	0.613	0.376	4.168	All predictors are significant Constant (p-value=0.000) R ratio (p-value=0.0019) B ratio (p-value=0.002)
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First, regression analysis was created for all the three teeth with age as dependent variable and M and W-L ratios as the first and second predictors respectively. M and W-L variables were used as suggested in original Kvaal’s article to create a population specific regression formulae. Regarding the significant predictors, for group 1, only W-L ratio and for group 2, only the constant were found significant. ANOVA was found insignificant. The correlation coefficients were found 0.370 and 0.256 in both groups respectively. The coefficient of determination for both groups of the mentioned variables was found to be low ($R^2=0.137$ and 0.065).

So, stepwise regression was performed, for group 1, the variables C, A and T ratios and for group 2, R & B ratios were assessed. All predictors included in both study groups were found significant up to 5%. ANOVA demonstrated that the total regression regarding the correlation of age with all variables in both study groups was found significant (p-value<0.05, in group1, p-value=0.001 and in group 2, p-value= 0.000).

The regression formula with the highest coefficient of determination (R^2) and the highest correlation coefficient (R) between Kvaals’ variables and chronological age came from the equation derived from stepwise regression in group 1 ($R=0.646$, $R^2=0.417$) and the formula with the least standard error of the estimate came from the equation derived from stepwise regression in group 2 ($SEE=4.168$).

1.1 Comparative analysis:

The difference between predicted and chronological ages based on PV/TV across both groups was measured in terms of PV/TV error and there was no statistically significant difference between both groups indicating that no significant difference was found between both voxel sizes.

The absolute difference between predicted and chronological ages was measured in terms of Kvaals’ ratios error across both groups and there was no statistically significant difference between both groups indicating that no significant difference was

found between both voxel sizes except for the maxillary lateral incisor.

2. DISCUSSION

Identification of individuals is a crucial component of forensic medicine and dentistry. Important characteristics such as age, gender, ethnicity, and other characteristics are used to identify individuals⁽⁹⁾. Dental structures withstand decomposition and elevated temperatures, remaining among the final entities that decay post-mortem.⁽¹⁰⁾. Evidence reinforces the superiority of using maxillary incisors with a pulp volume to tooth volume ratio for age assessment and that the correlation between PV/TV was the strongest for the maxillary central incisor^{(11) (12)}. Therefore, regarding volumetric measurements, maxillary central incisor teeth with PV/TV were used for age estimation in the current study.

In the current study, the highest correlation of PV/TV with chronological age was found to be -0.775, also, the highest explanatory coefficient of the regression model based on PV/TV was found to be 0.601.

Yang et al. conducted volumetric measurements, PV/TV was calculated, their results revealed correlation between PV/TV with chronological age to be -0.54 and coefficient of determination to be 0.29⁽¹³⁾. Our results was higher than that reported by Yang et al. Star et al. measured PV/TV of single rooted teeth, their results revealed that the correlation of PV/TV with chronological age was -0.64 for incisor teeth⁽¹¹⁾. In the current study, our results were similar to that reported by Star et al, however, the correlation strength for maxillary central incisor in our study was stronger than that observed in Star et al.

Abdinian et al. carried out a similar study, their results revealed that Pearson’s correlation of PV/TV was -0.46 for maxillary central incisor and coefficient of determination to be 0.21⁽¹⁴⁾. In the current study, our results were higher than that reported by Abdinian et al. also, Yang et al. reported that Pearson correlation coefficient of maxillary central incisors was -0.67 for global samples also, the coefficient of determination was found to be 0.44⁽¹⁵⁾. In the current study, our results were higher than that reported by Yang et al.

In addition, Asif et al. in 2018 performed volumetric analysis of maxillary central incisors using two methods. Method 1 utilized PV/TV while method 2 utilized pulp chamber to crown volume ratio. The Pearson correlation coefficient (R) of PV/TV was found to be 0.799 and the coefficient of determination (R^2) was 0.639⁽¹⁶⁾. Asif et al. in 2019 conducted similar measurements, their results showed that the coefficient of correlation was the strongest for the maxillary right central incisors ($R= 0.83$ indicating strong correlation), also, the highest coefficient of determination value was found in the maxillary right central incisors ($R^2= 0.7$)⁽¹⁷⁾. In the current study, our results were lower than that reported by Asif et al. 2018 and Asif et al. 2019, variations in the correlation coefficients and coefficients of determination between PV/TV and chronological age across different races may have resulted in this discrepancy.

Besides, Porto et al. performed a similar study and their results showed that Pearson's correlation coefficient of PV/TV for maxillary central incisors was -0.390 for males and -0.545 for females and the coefficient of determination was 0.21 (0.152 for males and 0.297 for females)⁽¹⁸⁾. In the current study, our results were higher than that reported by Porto et al.

In 1995, Kvaal et al. developed an approach that could be utilized to calculate an adult's chronological age based on measurements of the pulp's size using periapical radiographs based on the reduction of pulp cavity size due to the deposition of secondary dentine with advancing age which can be utilized as an age indicator⁽⁵⁾.

In the current study, width measurements demonstrated the strongest correlation with chronological age. Kazmi et al. in 2023 systematically reviewed the correlation accuracy between length ratios and width ratios according to Kvaal's approach in relation to chronological age, the findings indicate that width ratios had a stronger correlation compared to length ratios in line with our study⁽¹⁹⁾.

Kolltveit et al. and Erbudak et al. applied Kvaal's method and their results showed that the strongest correlation for maxillary central incisor was the R ratio⁽²⁰⁾ ⁽²¹⁾. Similarly, in the current study the strongest correlation for maxillary central incisor in group 2 was the R ratio.

In the current study, the validity of Kvaal's approach using the original Kvaal's equations was evaluated using the absolute difference between predicted and chronological ages, the standard deviation of the evaluated teeth ranged from 9.4 to 12.1 for the whole sample and Pearson correlation coefficient of predicted age ranged from 0.197 to 0.484 with no statistically significant correlation between predicted and chronological ages ($P\text{-value} > 0.05$) indicating

low validity. Bosman et al. applied Kvaal's approach and their results showed no significant differences between estimated and chronological ages including all six teeth or three mandibular teeth only using the original regression formulas⁽²²⁾. However, Erbudak et al. documented that a high difference of more than 12 years was found between estimated and chronological ages using the original regression models indicating its insufficiency to precisely estimate age⁽²¹⁾. Our results are in contrast with Bosman et al. and in agreement with Erbudak et al., the reason for the difference in findings between Bosman et al. and our study may be due to different methodologies as Bosman et al. utilized orthopantomograms however, CBCT scans were used in the current study.

In the original study of Kvaal et al., regression models were created with age as dependent variable, M as the first predictor and W-L as the second predictor⁽⁵⁾, similarly in the current study, the former predictors were used to create population specific regression equations. In the current study, our results showed that the coefficient of determination for both groups using M and W-L parameters was found to be low ($R^2=0.137$ and 0.065).

Alharbi Sr et al. developed regression models utilizing same predictors as Kvaal's original study, the R^2 ranged from 0.447 to 0.752 and their study concluded that the most effective indicators for age evaluation were "M" and "W-L" variables⁽²³⁾. However, Haghnegahdar et al. found that R^2 for M and W-L parameters was low with respect to chronological age ($R^2= 0.09- 0.27$)⁽²⁴⁾. Also, Akay, Gungor and Gurcan found that R^2 for same parameters was also low with respect to chronological age ($R^2= 0.162-0.550$)⁽²⁵⁾.

In the current study, our results are in agreement with Haghnegahdar et al. and Akay, Gungor and Gurcan and in contrast with Alharbi Sr et al., different methodologies utilized for linear measurements may have resulted in this variation as Alharbi Sr et al. utilized digital orthopantomograms however, CBCT scans were used in the current study.

In addition, Çelik et al., developed regression formulae using stepwise regression, similarly, in the current study, stepwise regression was employed to create population specific regression formulae where all predictors were found significant in both groups yielding higher correlation coefficients and coefficients of determination than M and W-L parameters⁽²⁶⁾.

3. CONCLUSION

PV/TV proved to be a reliable indicator for age estimation. Kvaal's approach was found to be applicable to age estimation of Egyptian adult subjects. The original Kvaal's formulae were not capable of providing a precise estimate of age. Age estimation using population specific formulae using

the Kvaals' M & W-L predictors was insufficient in Egyptian subjects however population specific formulae using stepwise method had higher prediction ability. CBCT serves as an effective technique for age assessment in adults. It is recommended to perform this study on a larger sample size on different teeth, also it is advised to perform the study on different populations to create population specific regression models.

DECLARATION

Conflict of interest

Authors declare that there is no conflict of interest

Source of funding

There are no funds procured

Author Contribution

All authors have contributed substantially to the manuscript and all have reviewed the final manuscript

Ethical approval

This research project was approved by the Research Ethics Committee of the Faculty of Dentistry of Cairo University, Egypt, approval number (15-10-21), in accordance with 1964 Declaration of Helsinki

REFERENCES

1. Kumar R, Athota A, Rastogi T, Karumuri SK. Forensic radiology: An emerging tool in identification. *J Indian Acad Oral Med Radiol.* 2015;27(3):416.
2. Kanchan T, Krishan K. Personal identification in forensic examinations. *Anthropol.* 2013;2(1):114.
3. Jagannathan N, Neelakantan P, Thiruvengadam C, Ramani P, Premkumar P, Natesan A, et al. Age estimation in an Indian population using pulp/tooth volume ratio of mandibular canines obtained from cone beam computed tomography. *J Forensic Odontostomatol.* 2011;29(1):1.
4. Molina A, Bravo M, Fonseca GM, Márquez-Grant N, Martín-de-Las-Heras S. Dental age estimation based on pulp chamber/crown volume ratio measured on CBCT images in a Spanish population. *Int J Legal Med.* 2021;135(1):359-64.
5. Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age estimation of adults from dental radiographs. *Forensic Sci Int.* 1995;74(3):175-85.
6. TS B, Natarajan S, Thilak N, Binnal A. The Coronal Pulp Cavity Index an aid in age determination-A Cone Beam Computed Tomography Study. *Indian J Forensic Med Toxicol.* 2021;15(1).
7. Tajdini F, Hemati SM, Tajdini F. Estimation of Age Using Kvaal Technique Based on Cone-beam Computed Tomography Images of Mandibular Canine Teeth in Bojnourd. *Indian J Forensic Med Toxicol.* 2020;14(3):1894-9.
8. Yousefi F, Lari S, Shokri A, Hashemi S, Hosseini M. Age estimation based on the pulp chamber volume of multi-rooted teeth using cone beam computed tomography. *Avicenna J Dent Res.* 2020;12(1):19-24.
9. Puranik M, Priyadarshini C, Uma S. Dental age estimation methods: A review. *Int J Adv Health Sci.* 2015;1:19-25.
10. Krishan K, Kanchan T, Garg AK. Dental Evidence in Forensic Identification – An Overview, Methodology and Present Status. *Open Dent J.* 2015;9(1):250-6.
11. Star H, Thevissen P, Jacobs R, Fieuws S, Solheim T, Willems G. Human Dental Age Estimation by Calculation of Pulp–Tooth Volume Ratios Yielded on Clinically Acquired Cone Beam Computed Tomography Images of Monoradicular Teeth*. *J Forensic Sci.* 2011;56(s1):S77-S82.
12. Barbosa MG, Franco A, de Oliveira RDB, Mamani MP, Junqueira JLC, Soares MQS. Pulp volume quantification methods in cone-beam computed tomography for age estimation: A critical review and meta-analysis. *J Forensic Sci.* 2023;68(3):743-56.
13. Yang F, Jacobs R, Willems G. Dental age estimation through volume matching of teeth imaged by cone-beam CT. *Forensic Sci Int.* 2006;159:S78-S83.
14. Abdinian M, Katiraei M, Zahedi H, Rengo C, Soltani P, Spagnuolo G. Age Estimation Based on Pulp–Tooth Volume Ratio of Anterior Teeth in Cone-Beam Computed Tomographic Images in a Selected Population: A Cross-Sectional Study. *Appl Sci.* 2021;11(21):9984.
15. Yang Z, Fan L, Kwon K, Pan J, Shen C, Tao J, et al. Age estimation for children and young adults by volumetric analysis of upper anterior teeth using cone-beam computed tomography data. *Folia Morphol.* 2020;79(4):851-9.
16. Asif MK, Nambiar P, Mani SA, Ibrahim NB, Khan IM, Sukumaran P. Dental age estimation employing CBCT scans enhanced with Mimics software: Comparison of two different approaches using pulp/tooth volumetric analysis. *J Forensic Leg Med.* 2018;54:53-61.
17. Asif MK, Nambiar P, Mani SA, Ibrahim NB, Khan IM, Lokman NB. Dental age estimation in Malaysian adults based on volumetric analysis of pulp/tooth ratio using CBCT data. *Leg Med.* 2019;36:50-8.
18. Porto LVMG, Celestino da Silva Neto J, Anjos Pontual Ad, Catunda RQ. Evaluation of volumetric changes of teeth in a Brazilian population by using cone beam computed tomography. *J Forensic Leg Med.* 2015;36:4-9.
19. Kazmi S, Zaidi SJA, Reesu GV, Shepherd S. Dental age estimation using the Kvaal method—an evaluation of length and width ratios: a systematic review. *Forensic Sci Med Pathol.* 2023;20(1):239-48.

20. Kolltveit KM, Solheim T, Kvaal SI. Methods of measuring morphological parameters in dental radiographs: Comparison between image analysis and manual measurements. *Forensic Sci Int.* 1998;94(1):87-95.
21. Erbudak HÖ, Özbek M, Uysal S, Karabulut E. Application of Kvaal et al.'s age estimation method to panoramic radiographs from Turkish individuals. *Forensic Sci Int.* 2012;219(1):141-6.
22. Bosmans N, Ann P, Aly M, Willems G. The application of Kvaal's dental age calculation technique on panoramic dental radiographs. *Forensic Sci Int.* 2005;153(2-3):208-12.
23. Alharbi Sr HS, Alharbi AM, Alenazi AO, Kolarkodi SH, Elmoazen R, Alharbi Sr A, et al. Age estimation by Kvaal's method using digital panoramic radiographs in the Saudi population. *Cureus.* 2022;14(4).
24. Haghnegahdar A, 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):573-82.
25. Akay G, Gungor K, Gurcan S. The applicability of Kvaal methods and pulp/tooth volume ratio for age estimation of the Turkish adult population on cone beam computed tomography images. *Aust J Forensic Sci.* 2019;51(3):251-65.
26. Çelik H, Kılıçarslan MA, Boyacioglu H, Bilecen B. Application of the Kvaal method to CBCT reconstructed panoramic images for age estimation. *Forensic Sci Med Pathol.* 2024;20(3):823-30.