Original Article

A Comparative Analysis between Various Teeth in Kvaal's and Cameriere's Methods of Age Estimation in a Specific Populace of Andhra Pradesh: An Original Study

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ABSTRACT

Context: Comparison between antemortem and postmortem dental records and radiographs produces results with a high degree of reliability and relative simplicity. Kvaal *et al*. introduced an age estimation method by indirectly measuring secondary dentin deposition on radiographs. Cameriere *et al*., later, put forth a method based on radiographic estimation of pulp/tooth area ratio (AR) in canines. The purpose of the present study was to compare the reliability of various teeth in Kvaal's and Cameriere's methods of age estimation in a specific populace of Andhra Pradesh origin.

Materials and Methods: One-hundred and ten patients aged between 15 and 75 years were selected, and the variables p = complete pulp length/root length (from enamel-cementum junction [ECJ]-root apex), r = complete pulp length/complete tooth length, a = complete pulp length/root width at ECJ level, b = pulp/root width at midpoint level between ECJ level and mid-root level, and c = pulp/root width at mid-root level and pulp/tooth AR were recorded as devised in Kvaal's and Cameriere's methods of age estimation, respectively.

Statistical Analysis: Statistical analysis was performed with SPSS (version 10.5) package. The mean comparison of morphological variables was carried out using Student's *t*-test. Intra- and inter-observer reproducibility of measurements was studied using the concordance correlation coefficient.

Results: In Kvaal's method, mandibular first premolar correlated best with age with an R^2 value of 81.90% and a standard error of the estimate in years (SEE) of 5.889 years followed by maxillary central incisor (R^2 = 80.30%), whereas in Cameriere's method, mandibular first premolar correlated best with an R^2 value of 93.50% and an SEE of 3.564 years followed by maxillary central incisor (R^2 = 87.90%), mandibular lateral incisor (R^2 = 86.30%), maxillary lateral incisor (R^2 = 85.50%), mandibular canine (R^2 = 85.40%), and maxillary second premolar (R^2 = 83.30%).

Conclusion: Although both Kvaal's and Cameriere's methods were found suitable for age estimation in Andhra Pradesh population, Cameriere's method, in particular, was found to be more reliable. Mandibular first premolar was found to be the best predictor of age followed by maxillary central incisor.

Key Words: *Age estimation, Cameriere's method, Kvaal's method, mandibular first premolar, maxillary central incisor*

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Introduction

Aging refers to irreversible and inevitable changes that occur with time, which encompass all aspects of human life, namely, anatomic, physiologic, and psychological aspects.[1] Aging, in forensic context, is necessary both for the dead and for the living. For the dead, it is principally to aid identification by creating a biological profile which can, then, be compared to missing individuals. For the living, the aim is to solve judicial or civil problems, concerning age of minors as regards questions of adoption, immutability, and for adults, civil issues, for individuals lacking valid identification documents.[2] Although several parts of the body can be used for age estimation, the poor condition of the remainings, particularly, in severe crashes or fires in cases of those recently dead or of moisture and burial

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conditions in cases of historic subjects, makes many parts of the body unusable.[3] Despite these problems, in the last few years, the literature has provided several skeletal and dental methods for assessing age. Most of them apply many age indicators related to degenerative changes in the skeleton.[4] Teeth can survive, in most of the conditions, encountered at death and during decomposition, even when the body is exposed to extreme forces and/or temperatures.[5] The specific composition and shape of teeth are a source for many different hereditary and acquired characteristics. Thus, they can serve as reliable biomarkers of aging. It is, also, observed that tooth development is not perceptibly affected by diseases, drugs, as well as the endocrine status as compared to the bones, consequently making them the preferred tissue in forensic and archeological investigations.[5] Once a tooth is fully mineralized and erupted, it forms a very stable entity. Both developmental and regressive changes affecting the teeth can be related to chronological age of the individual. In the last few years, forensic odontology has shown increasing interest in search for optimal age estimation methods in individuals using dental tissues/teeth as evidence. These methods are broadly classified as morphologic and radiologic methods. The former are further subclassified as clinical, histological, and biochemical methods which include methods analyzing the various forms of tooth modification such as wear, dentin transparency, tooth cementum annulations, racemization of aspartic acid, and apposition of secondary dentin.[3] However, all these methods have one or other limitations restricting their usage on a mass scale. In addition, radiography, being a nondestructive method, plays a vital role in forensic odontology to uncover the hidden facts, which cannot be seen by means of physical examination. Dental examination and comparison between antemortem and postmortem dental records and radiographs produce results with a high degree of reliability and relative simplicity.[6,7] Radiographic age estimation, using teeth, relies on the developmental stages of teeth especially in children, whereas in adults, continuous deposition of secondary dentin throughout the life depicted by reduction in pulp area can be employed. Several age estimation methods exploit changes undergone by teeth during the lifetime, but most are destructive warranting extraction of teeth. These methods, therefore, cannot be used in living individuals and in cases where it is not acceptable to extract teeth for various reasons.[8] Radiography, thus, plays an important role in such cases.[9] Dental pulp is a mesenchymal tissue surrounded by a pulp canal. Outside the pulp, there are some odontoblastic lines, which release dentin during the individual's life and reduce the size of the pulp canal. Changes in its size caused by the apposition of secondary dentin are the best morphometric parameters for estimating age in adult cases as it is a continuous process that takes place throughout the life of an individual. This apposition of secondary dentin can be indirectly measured by the reduction in pulp size on the radiographs. In 1925, Bodecker established that the apposition of secondary dentin correlated with age.[10] Kvaal *et al*. introduced an age estimation method by indirectly measuring secondary dentin deposition on radiographs and proposed a number of length and width measurements of tooth and pulp.[6] Cameriere *et al*., later, put forth a similar method based on radiographic estimation of pulp/tooth area ratio (AR) in canines.[7] The purpose of the present study was to compare the reliability of various teeth in Kvaal's and Cameriere's methods of age estimation in a specific populace of Andhra Pradesh origin.

Materials and Methods

Source of data

A total number of 110 patients, 59 males and 51 females, aged between 15 and 75 years, were selected from the outpatient department. Seven age groups (Group I–VII) were formed with both males and female patients. Group I included 15 patients with age between 15 and 20 years, Group II (age 20–30 years) with 47 patients, Group III (age 30–40 years) with 23 patients, Group IV (age 40–50 years) with 15 patients, Group V (age 50–60 years) with three patients, Group VI (age 60–70 years) with four patients, and Group VII (age 70–75 years) with three patients. The ethical approval was obtained from the Institutional Ethics Committee. All the patients provided informed consent before being included in the present study.

Selection criteria

Inclusion criteria

- Patients aged between 15 and 75 years
- The selected teeth were the right or left maxillary central incisor, lateral incisor, and second premolar and right or left mandibular lateral incisor, canine and first premolar which had fully erupted into the oral cavity
- The roots of the teeth were fully formed
- Individuals were of ethnic origin from Andhra Pradesh (history confirmed up to two generations).

Exclusion criteria

- Teeth with any of the pathologies, such as caries or periodontitis or periapical lesions that would alter the surface area of the tooth
- Teeth with any prosthetic rehabilitation and orthodontic appliance
- Fractured teeth
- Severely attrited teeth secondary to parafunctional habits
- Teeth with any developmental anomaly.

After clinical examination, patients who met the inclusion criteria were subjected to digital intraoral radiographs.

Methodology

Intraoral radiography

Patients were selected according to the decided inclusion criteria. After selection of the patients, their consent was taken for radiographic examination. All the guidelines were followed as per the ALARA principle while subjecting the patients to digital intraoral radiographs. The radiographic examination was carried out with the help of X-mind X-ray system, 70 kv, 8 mA, 0.425 kVA, 2 mm aluminum filter manufactured by SATELEC (India) Private Limited; DIGORA OPTIME DXR-50 5001, Digital Imaging System with Windows 2.8 Digital Imaging Programme. PSP Digital Sensor (DIGORA

OPTIME DXR-50 5001, Digital Imaging System) with size 2 sensor (31 mm × 41 mm) and Film holding instrument: RINN-Greene Stabe Disposable Film Holder were used with AutoCAD 2007 software (Autodesk Inc., San Rafael, CA, USA) for taking digital intraoral radiographs.

Positioning of the patient

For maxillary teeth: The patient's head was positioned upright with the sagittal plane vertical and the occlusal plane horizontal.

For mandibular teeth: The patient's head was tilted back slightly to compensate for the change in occlusal plane when the mouth was opened.

Measurement of teeth by Kvaal's method [Figure 1]: The following morphological variables were recorded by Kvaal's method:

p = complete pulp length/root length (from enamel-cementum junction [ECJ] to root apex);

r = complete pulp length/complete tooth length;

a = complete pulp length/root width at ECJlevel;

b = pulp/root width at midpoint level between ECJ level and mid-root level; and

c = pulp/root width at mid-root level.

Measurement of teeth by Cameriere's method [Figure 2]: Pulp/tooth AR was recorded. Measurements were made by the second observer to prevent any interobserver bias. The morphological variables, chronological age, and patient's gender were entered into a Microsoft Excel spreadsheet for use as predictive variables for age estimation. Correlation coefficients were evaluated between chronological age and morphological variables. Estimated age was obtained using morphological variables for each tooth.

Statistical analysis

Statistical analysis was performed with SPSS (version 10.5) package. The mean comparison of morphological variables was carried out using Student's *t*-test. Intra- and inter-observer reproducibility of measurements was studied using the concordance correlation coefficient.

Results

The chronological age of adults was estimated based on the measurements of the different said variables of the various teeth including maxillary central incisor, lateral incisor, and second premolar and mandibular lateral incisor, canine, and first premolar which were numbered 1–6, respectively, on images of digital intraoral radiographs from derived regression equations. The demographic data of the patients are presented in Table 1 and Graph 1. There was no significant difference observed between morphological variables among males and females, indicating that gender did not influence the estimation of chronological age [Tables 2-6] In Tooth #4 (mandibular lateral incisor), however, morphological variables, b = pulp/root width at midpoint level between ECJ level and mid-root level and width (W), showed a weakly positive correlation between gender and chronological age [Table 7]. Comparison of the readings of the two observers did not reveal any statistical significance [Table 8]. Karl Pearson's correlation coefficients between age and morphological variables showed that the variables p = complete pulp length/root length (from ECJ-root apex), r = complete pulp length/complete tooth length, mean (M), length (L), and pulp/tooth AR correlated significantly with age with variable p = complete pulp length/root length (from ECJ-root apex) correlating the best among them with correlation coefficient 'r' being −0.951 and −0.896, respectively, for mandibular premolar. The ratios

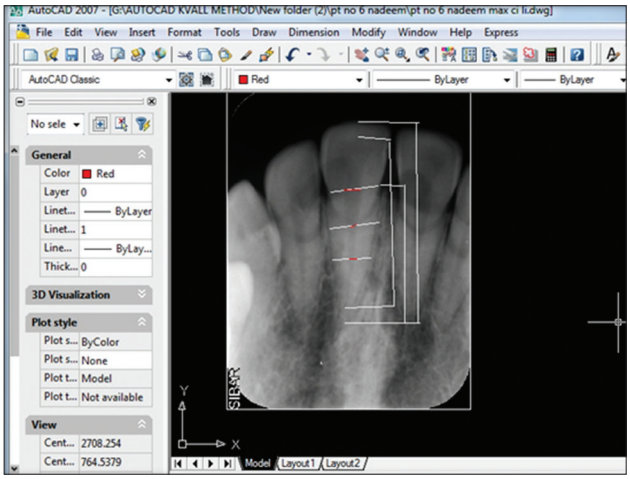


Figure 1: Measurement of variables by Kvaal's method

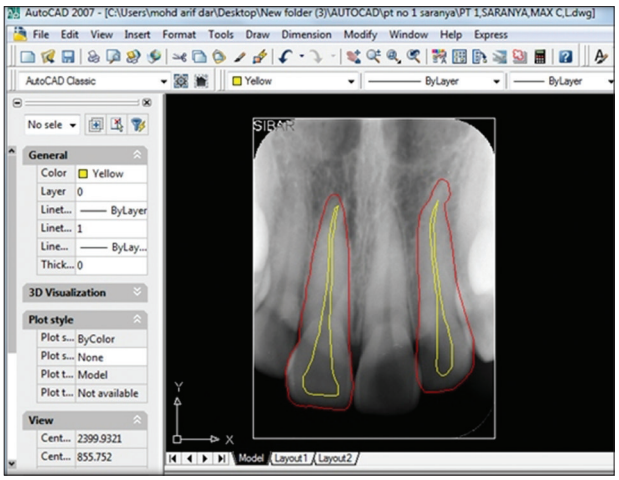
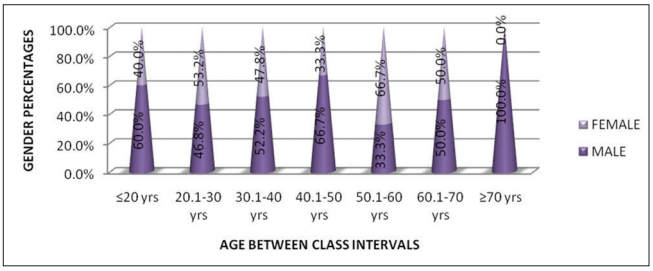


Figure 2: Measurement of variable by Cameriere's method

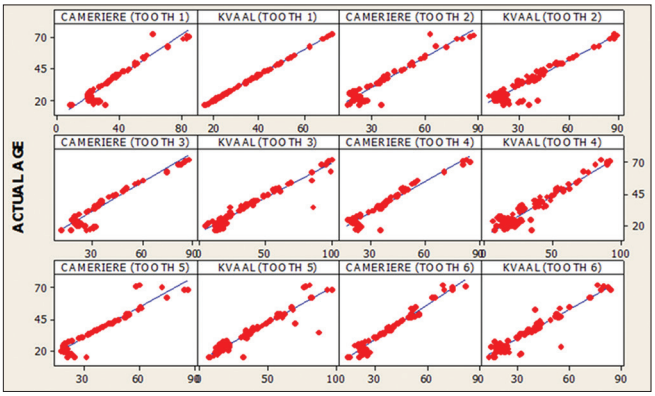


Graph 1: Age and gender distribution of the study population

between width measurements (a = complete pulp length/root width at ECJ level, b = pulp/root width at midpoint level between ECJ level and mid-root level, and c = pulp/root width at mid-root level) correlated least with age and were not found to be statistically significant and, therefore, were excluded from further statistical analysis. Variable p = complete pulp length/root length (from ECJ-root apex) had highest $P = -0.920$ for central incisor and 0.951 for mandibular first premolar [Table 9]. The scatter plot graph between predicted age and chronological age showed that the resultant values were equally distributed along the line. Comparing between Kvaal's and Cameriere's methods, results of the latter method were found to be more accurate in predicting age. The scatter plot graph of predicted versus chronological age showed better distribution in Cameriere's method than Kvaal's method (Graphs 2-4; with Graph 2 showing comparative analysis between Kvaal's and Cameriere's methods; Graph 3 for Kvaal's method and Graph 4 for Cameriere's method). Separate regression equations were derived for each tooth for both methods. The variables such as mean (M) (mean of variables complete pulp length/root length (from ECJ-root apex) (p), complete pulp length/complete tooth length (r), complete pulp length/root width at ECJ level (a), pulp/root width at midpoint level between ECJ level and mid-root level (b), and pulp/root width at mid-root level (c)) and difference between width and length (W−L) contributed significantly and were utilized in regression equation for Kvaal's method [Table 10]. Variable pulp/tooth AR contributed

Table 1: Distribution of the study sample by age groups and gender

Group	Age (in years)	Gender, *n* (%)		Total, *n* (%)
		Male	Female	
I	≤20	9 (60.0)	6 (40.0)	15 (100.0)
II	20.1-30	22 (46.8)	25 (53.2)	47 (100.0)
III	30.1-40	12 (52.2)	11 (47.8)	23 (100.0)
IV	40.1-50	10 (66.7)	5 (33.3)	15 (100.0)
V	50.1-60	1 (33.30)	2 (66.70)	3 (100)
VI	60.1-70	2 (50.0)	2 (50.0)	4 (100.0)
VII	≥70	3 (100.0)	0	3 (100.0)
Total		59 (53.60)	51 (46.40)	110 (100.00)



Graph 2: Scatter plot of predicted age vs. chronological age by Kvaal's and Cameriere's methods

Table 2: Comparison of the morphological variables among males and females

Statistics for tooth #1 (maxillary central incisor)

Variable	Gender	*n*	Mean	SD	*t*	*P*
Age (years)	Male	59	33.416	15.105	1.047	0.297
	Female	51	30.671	11.892		
Complete pulp length/root length, from ECJ to root apex (p)	Male	59	1.175	0.123	−0.803	0.424
	Female	51	1.192	0.104		
Complete pulp length/complete tooth length (r)	Male	59	0.803	0.066	−0.388	0.699
	Female	51	0.808	0.053		
Complete pulp length/root width at ECJ level (a)	Male	59	0.265	0.058	0.786	0.434
	Female	51	0.256	0.051		
pulp/root width at midpoint level between ECJ level and mid-root level (b)	Male	59	0.221	0.052	−1.231	0.221
	Female	51	0.233	0.052		
Pulp/root width at mid-root level (c)	Male	59	0.218	0.267	−0.537	0.592
	Female	51	0.248	0.325		
Mean (M)	Male	59	0.536	0.074	−0.759	0.449
	Female	51	0.548	0.082		
Width (W)	Male	59	0.219	0.141	−0.720	0.473
	Female	51	0.241	0.169		
Length (L)	Male	59	0.989	0.089	−0.697	0.488
	Female	51	1.000	0.075		
Difference between width and length (W-L)	Male	59	−0.769	0.157	−0.325	0.746
	Female	51	−0.759	0.174		
Pulp/tooth AR	Male	59	0.248	0.363	0.358	0.721
	Female	51	0.225	0.278		

Statistical analysis: Student's *t*-test (unpaired); statistically significant at $P<0.05$. AR: Area ratio, ECJ: Enamel-cementum junction, SD: Standard deviation

Table 3: Comparison of the morphological variables among males and females

Statistics for tooth #2 (maxillary lateral incisor)

Variable	Gender	*n*	Mean	SD	*t*	*P*
Age (years)	Male	59	33.416	15.105	1.047	0.297
	Female	51	30.671	11.892		
Complete pulp length/root length, from ECJ to root apex (p)	Male	59	1.214	0.197	−0.369	0.713
	Female	51	1.226	0.156		
Complete pulp length/complete tooth length (r)	Male	59	0.785	0.131	0.726	0.470
	Female	51	0.769	0.096		
Complete pulp length/root width at ECJ level (a)	Male	59	0.235	0.057	0.574	0.567
	Female	51	0.229	0.053		
Pulp/root width at midpoint level between ECJ level and mid-root level (b)	Male	59	0.204	0.050	−0.63	0.530
	Female	51	0.210	0.045		
Pulp/root width at mid-root level (c)	Male	59	0.166	0.046	−0.032	0.975
	Female	51	0.167	0.054		
Mean (M)	Male	59	0.521	0.069	0.059	0.953
	Female	51	0.520	0.051		
Width (W)	Male	59	0.185	0.037	−0.398	0.692
	Female	51	0.188	0.043		
Length (L)	Male	59	0.999	0.152	0.066	0.947
	Female	51	0.998	0.118		
Difference between width and length (W-L)	Male	59	−0.814	0.151	−0.177	0.860
	Female	51	−0.809	0.127		
Pulp/tooth AR	Male	59	0.147	0.049	−0.587	0.559
	Female	51	0.152	0.041		

Statistical analysis: Student's *t*-test (unpaired); statistically significant at $P<0.05$. AR: Area ratio, ECJ: Enamel-cementum junction, SD: Standard deviation

Table 4: Comparison of the morphological variables among males and females

Statistics for tooth #3 (maxillary second premolar)

Variable	Gender	*n*	Mean	SD	*t*	*P*
Age (years)	Male	59	33.416	15.105	1.047	0.297
	Female	51	30.671	11.892		
Complete pulp length/root length, from ECJ to root apex (p)	Male	59	1.036	0.123	−0.361	0.719
	Female	51	1.044	0.101		
Complete pulp length/complete tooth length (r)	Male	59	0.641	0.075	−0.657	0.100
	Female	51	0.689	0.204		
Complete pulp length/root width at ECJ level (a)	Male	59	0.214	0.199	1.181	0.240
	Female	51	0.180	0.050		
Pulp/root width at midpoint level between ECJ level and mid-root level (b)	Male	59	0.186	0.056	1.004	0.318
	Female	51	0.176	0.050		
Pulp/root width at mid-root level (c)	Male	59	0.163	0.126	−0.373	0.710
	Female	51	0.176	0.214		
Mean (M)	Male	59	0.448	0.059	−0.379	0.705
	Female	51	0.453	0.070		
Width (W)	Male	59	0.175	0.073	−0.058	0.954
	Female	51	0.176	0.109		
Length (L)	Male	59	0.839	0.091	−1.382	0.170
	Female	51	0.866	0.118		
Difference between width and length (W-L)	Male	59	−0.664	0.103	1.087	0.279
	Female	51	−0.691	0.151		
Pulp/tooth AR	Male	59	0.099	0.152	−0.118	0.906
	Female	51	0.102	0.161		

Statistical analysis: Student's *t*-test (unpaired); statistically significant at $P<0.05$. AR: Area ratio, ECJ: Enamel-cementum junction, SD: Standard deviation

Table 5: Comparison of the morphological variables among males and females

Statistics for tooth #5 (mandibular canine)

Variable	Gender	*n*	Mean	SD	*t*	*P*
Age (years)	Male	59	33.416	15.105	1.047	0.297
	Female	51	30.671	11.892		
Complete pulp length/root length, from ECJ to root apex (p)	Male	59	0.984	0.244	−1.253	0.297
	Female	51	1.031	0.116		
Complete pulp length/complete tooth length (r)	Male	59	0.695	0.164	−1.878	0.063
	Female	51	0.742	0.072		
Complete pulp length/root width at ECJ level (a)	Male	59	0.245	0.342	1.106	0.271
	Female	51	0.192	0.044		
Pulp/root width at midpoint level between ECJ level and mid-root level (b)	Male	59	0.203	0.050	−0.553	0.581
	Female	51	0.216	0.171		
Pulp/root width at mid-root level (c)	Male	59	0.161	0.053	0.07	0.944
	Female	51	0.161	0.053		
Mean (M)	Male	59	0.458	0.107	−0.63	0.530
	Female	51	0.468	0.056		
Width (W)	Male	59	0.182	0.042	−0.452	0.652
	Female	51	0.188	0.093		
Length (L)	Male	59	0.840	0.201	−1.428	0.156
	Female	51	1.000	0.836		
Difference between width and length (W−L)	Male	59	−0.658	0.204	1.346	0.181
	Female	51	−0.812	0.853		
Pulp/tooth AR	Male	59	0.116	0.032	−0.781	0.436
	Female	51	0.120	0.024		

Statistical analysis: Student's *t*-test (unpaired); statistically significant at $P<0.05$. AR: Area ratio, ECJ: Enamel-cementum junction, SD: Standard deviation

Table 6: Comparison of the morphological variables among males and females

Statistics for tooth #6 (mandibular first premolar)

Variable	Gender	n	Mean	SD	*t*	*P*
Age (years)	Male	59	33.4163	15.105	1.047	0.297
	Female	51	30.671	11.892		
Complete pulp length/root length, from ECJ to root apex (p)	Male	59	1.054	0.157	−0.536	0.593
	Female	51	1.069	0.124		
Complete pulp length/complete tooth length (r)	Male	59	0.687	0.096	−0.277	0.783
	Female	51	0.691	0.067		
Complete pulp length/root width at ECJ level (a)	Male	59	0.193	0.062	−1.666	0.999
	Female	51	0.251	0.261		
Pulp/root width at midpoint level between ECJ level and mid-root level (b)	Male	59	0.197	0.059	−1.452	0.149
	Female	51	0.212	0.052		
Pulp/root width at mid-root level (c)	Male	59	0.160	0.068	−0.871	0.386
	Female	51	0.179	0.156		
Mean (M)	Male	59	0.458	0.058	−1.796	0.075
	Female	51	0.481	0.073		
Width (W)	Male	59	0.178	0.051	−1.347	0.181
	Female	51	0.196	0.083		
Length (L)	Male	59	0.871	0.121	−0.46	0.646
	Female	51	0.880	0.090		
Difference between width and length (W-L)	Male	59	−0.692	0.121	−0.34	0.735
	Female	51	−0.684	0.126		
Pulp/tooth AR	Male	59	0.113	0.036	−0.475	0.636
	Female	51	0.116	0.029		

Statistical analysis: Student's *t*-test (unpaired); statistically significant at $P<0.05$. AR: Area ratio, ECJ: Enamel-cementum junction, SD: Standard deviation

Table 7: Comparison of the morphological variables among males and females

Statistics for tooth #4 (mandibular lateral incisor)						
Variable	**Gender**	***n***	**Mean**	**SD**	***t***	***P***
Age (years)	Male	59	33.416	15.105	1.047	0.297
	Female	51	30.671	11.892		
Complete pulp length/root length, from ECJ to root apex (p)	Male	59	1.038	0.096	−0.834	0.406
	Female	51	1.053	0.088		
Complete pulp length/complete tooth length (r)	Male	59	0.757	0.053	−0.348	0.728
	Female	51	0.760	0.043		
Complete pulp length/root width at ECJ level (a)	Male	59	0.207	0.052	0.432	0.667
	Female	51	0.203	0.049		
Pulp/root width at midpoint level between ECJ level and mid-root level (b)	Male	59	0.204	0.056	2.227	0.028
	Female	51	0.180	0.056		
Pulp/root width at mid-root level (c)	Male	59	0.165	0.058	1.467	0.145
	Female	51	0.150	0.048		
Mean (M)	Male	59	0.474	0.037	0.765	0.446
	Female	51	0.469	0.030		
Width (W)	Male	59	0.185	0.046	2.331	0.022
	Female	51	0.165	0.041		
Length (L)	Male	59	0.897	0.069	−0.714	0.477
	Female	51	0.906	0.061		
Difference between width and length (W-L)	Male	59	−0.713	0.080	1.886	0.062
	Female	51	−0.741	0.077		
Pulp/tooth (AR)	Male	59	0.118	0.038	−0.519	0.605
	Female	51	0.121	0.031		

Statistical analysis: Student's *t*-test (unpaired); statistically significant at $P<0.05$. AR: Area ratio, ECJ: Enamel-cementum junction, SD: Standard deviation

Table 8: Comparison of interobserver observations

Parameters	***n***	**Tooth #1 (maxillary central incisor)**	**Tooth #2 (maxillary lateral incisor)**	**Tooth #3 (maxillary second premolar)**	**Tooth #4 (mandibular lateral incisor)**	**Tooth #5 (mandibular canine)**	**Tooth #6 (mandibular first premolar)**
Complete pulp length/root length, from ECJ to root apex (p) reading between observers 1 and 2	110	97.15	96.30	97.79	98.70	98.65	98.88
Complete pulp length/complete tooth length (r) reading between observer 1 and 2	110	96.04	97.22	98.59	96.42	96.74	96.14
Complete pulp length/root width at ECJ level (a) reading between observers 1 and 2	110	96.10	96.49	96.66	96.05	96.86	97.03
Pulp/root width at midpoint level between ECJ level and mid-root level (b) reading between observers 1 and 2	110	97.66	97.07	97.12	97.07	98.73	97.40
Pulp/root width at mid−root level (c) reading between observers 1 and 2	110	97.28	96.91	98.93	98.42	98.97	96.77
Mean (M) reading between observers 1 and 2	110	98.86	96.16	98.12	98.45	98.92	97.40
Width (W) reading between observers 1 and 2	110	96.90	98.25	97.05	98.33	96.22	96.60
Length (L) reading between observers 1 and 2	110	96.19	97.08	97.46	97.53	97.12	98.96
Difference between width and length (W-L) reading between observers 1 and 2	110	96.12	96.69	96.01	98.78	96.30	96.77
Pulp/tooth AR reading between observers 1 and 2	110	98.33	98.04	98.43	98.17	96.26	96.40

Statistical analysis: Karl Pearson's correlation coefficient. AR: Area ratio, ECJ: Enamel-cementum junction

significantly and was utilized in regression equation for Cameriere's method [Table 11]. In Kvaal's method, Tooth #6 (mandibular first premolar) correlated best with age with an R^2 value of 81.90% and a standard error of the estimate in years (SEE) of 5.889 years followed by Tooth #1 (maxillary central incisor) (R^2 = 80.30%), Tooth #2 (maxillary

Table 9: Correlation between age and morphological variables

Parameters	Correlation coefficients	Tooth #1 (maxillary central incisor)	Tooth #2 (maxillary lateral incisor)	Tooth #3 (maxillary second premolar)	Tooth #4 (mandibular lateral incisor)	Tooth #5 (mandibular canine)	Tooth #6 (mandibular first premolar)
Complete pulp length/root length, from ECJ to root apex (p)	Correlation coefficient	−0.920*	0.881*	0.903*	0.639*	0.895*	0.951*
	P	0.000	0.000	0.000	0.000	0.000	0.000
Complete pulp length/complete tooth length (r)	Correlation coefficient	−0.764*	0.619*	0.234*	0.919*	0.758*	0.810*
	P	0.000	0.000	0.014	0.000	0.000	0.000
Complete pulp length/root width at ECJ level (a)	Correlation coefficient	−0.106	−0.150	0.285*	−0.031	−0.008	−0.063
	P	0.272	0.119	0.003	0.747	0.936	0.512
Pulp/root width at midpoint level between ECJ level and mid-root level (b)	Correlation coefficient	−0.216*	0.191*	−0.038	−0.084	−0.021	0.290*
	P	0.023	0.045	0.692	0.385	0.828	0.002
Pulp/root width at mid-root level (c)	Correlation coefficient	−0.111	−0.061	−0.107	0.125	−0.104	0.036
	P	0.247	0.526	0.267	0.193	0.279	0.707
Mean (M)	Correlation coefficient	−0.520*	0.812*	0.359*	0.602*	0.657*	0.683*
	P	0.000	0.000	0.000	0.000	0.000	0.000
Width (W)	Correlation coefficient	−0.142	−0.153	−0.112	0.022	−0.057	−0.088
	P	0.138	0.110	0.246	0.823	0.554	0.361
Length (L)	Correlation coefficient	−0.917*	0.835*	0.655*	−0.787	−0.341	0.941*
	P	0.000	0.000	0.000	0.000	0.000	0.000
Difference between width and length (W-L)	Correlation coefficient	0.327*	0.776*	0.457*	0.661*	0.328*	0.775*
	P	0.000	0.000	0.000	0.000	0.000	0.000
Pulp/tooth AR	Correlation coefficient	−0.348*	0.915*	0.332*	0.927*	0.912*	0.896*
	P	0.000	0.000	0.000	0.000	0.000	0.000

Statistical analysis: Karl Pearson's correlation coefficient, *Correlation coefficients statistically significant at $P<0.05$. AR: Area ratio, ECJ: Enamel-cementum junction

Table 10: Regression equations for age in years based on dental radiographs from six teeth by Kvaal's method

Teeth	Regression equation	R^2 (%)	SEE (in years)
Tooth #1 (maxillary central incisor)	Age = 183 − 176 M + 72.8 W-L	80.30	6.137
Tooth #2 (maxillary lateral incisor)	Age = 122 − 118 M + 35.0 W-L	70.70	7.495
Tooth #3 (maxillary second premolar)	Age = 95.1 − 70.1 M + 46.5 W-L	31.50	11.458
Tooth #4 (mandibular lateral incisor)	Age = 183 − 179 M + 91.1 W-L	61.90	8.544
Tooth #5 (mandibular canine)	Age = 81.0 − 97.8 M + 5.04 W-L	47.90	9.990
Tooth #6 (mandibular first premolar)	Age = 128 − 102 M + 69.6 W-L	81.90	5.889

R^2: Coefficient of determination, SEE: Standard error of the estimate in years

lateral incisor) (R^2 = 70.70%), Tooth #4 (mandibular lateral incisor) (R^2 = 61.90), Tooth #5 (mandibular canine) (R^2 = 47.90%), and Tooth #3 (maxillary second premolar) (R^2 = 31.50%) [Table 10]. In Cameriere's method, Tooth #6 (mandibular first premolar) correlated best with age with an R^2 value of 93.50% and an SEE of 3.564 years followed by Tooth #1 (maxillary central incisor) (R^2 = 87.90%), Tooth #4 (mandibular lateral incisor) (R^2 = 86.30%), Tooth #2 (maxillary lateral incisor) (R^2 = 85.50%), Tooth #5 (mandibular canine) (R^2 = 85.40%), and Tooth #3 (maxillary second premolar) (R^2 = 83.30%) [Table 11].

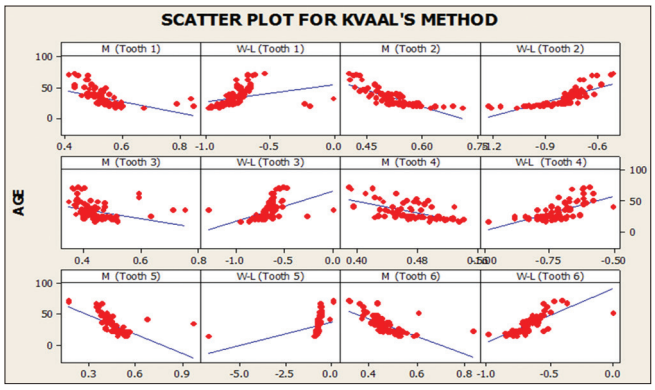
Discussion

In 1995, Kvaal *et al.*[6] presented a method for age estimation which was based on investigation of periapical radiographs while Paewinsky *et al.*[11] verified the applicability of this method on orthopantomographs. Cameriere *et al.*, in 2004, for the first time conducted a preliminary study to evaluate the

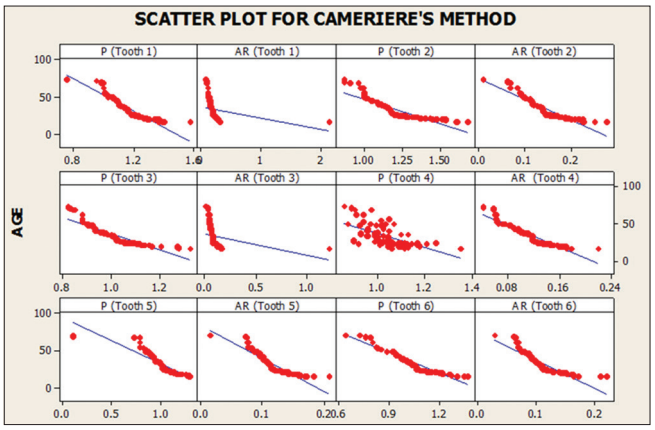
Table 11: Regression equations for age in years based on dental radiographs from six teeth by Cameriere's method

Teeth	Regression equation	R^2 (%)	SEE (in years)
Tooth #1 (maxillary central incisor)	Age = 177 − 124 p + 9.02 AR	87.90	4.761
Tooth #2 (maxillary lateral incisor)	Age = 35.8 + 58.9 p − 506 AR	85.50	5.209
Tooth #3 (maxillary second premolar)	Age = 154 − 119 p + 13.7 AR	83.30	5.595
Tooth #4 (mandibular lateral incisor)	Age = 66.7 + 11.4 p − 390 AR	86.30	5.197
Tooth #5 (mandibular canine)	Age = 90.8 − 26.0 p − 275 AR	85.40	5.295
Tooth #6 (mandibular first premolar)	Age = 176 − 175 p + 370 AR	93.50	3.564

R^2: Coefficient of determination; SEE: Standard error of the estimate in years, AR: Area ratio



Graph 3: Scatter plot of predicted age vs. chronological age by Kvaal's method



Graph 4: Scatter plot of predicted age vs. chronological age by Cameriere's method

variations in pulp/tooth AR as an indicator of age and their method of age estimation seemed promising.[7] While the authors obtained high levels of accuracy in age prediction, they advised that future research should investigate "the effect of race and culture in model parameters". Indeed, other researchers have also advocated the verification of age estimation methods on independent samples and some have concluded that best results are derived when population-specific formulas are used. Babshet *et al*. found that Cameriere's formula, based on the Italian population, is not as applicable to the Indian population as was the case of naive population.[12] The purpose of the present study was to compare the reliability of various teeth in Kvaal's and Cameriere's methods of age estimation in a specific populace of Andhra Pradesh origin based on the relationship between chronological age and measurement of different variables, as used in Kvaal's and Cameriere's methods, of selected teeth, using digital intraoral periapical radiographs. The study sample included, 110 patients aged between 15 and 75 years, only of Andhra Pradesh origin with at least last two generations residing in the location of the study. This was done to ensure ethnic uniformity of the study sample, considering that the development of teeth varies among populations and that it is genetically determined. Digital radiography was selected because of less radiation exposure than the conventional film-based radiography. Since Kvaal *et al*. did not find significant differences between teeth from the left and right side of the jaw,[6] teeth from either the left or right side were processed depending on whichever were best suited for measurements. Ratios between the teeth and pulp size were calculated. This procedure helped reduce the effect of the possible variation in magnification and angulation of the intraoral radiographs. The present study revealed that gender had no significant influence on the morphological variables of teeth, except for morphological variables, b = pulp/root width at midpoint level between ECJ level and mid-root level and width (W), which showed a weakly positive correlation between gender and chronological age for mandibular lateral incisor, similar to the findings of the studies conducted by Kvaal *et al*.[6] and Cameriere *et al*.[7] Few other studies by Jeevan *et al*.[13] and Cameriere *et al*.,[14,15] also, showed similar results. In the present study, width ratios (a = complete pulp length/root width at ECJ level, b = pulp/root width at midpoint level between ECJ level and mid-root level, and c = pulp/root width at mid-root level) correlated least with age did not show significant correlation with age. In addition, there were no significant differences between inter- and intra-observer measurements in the present study, similar to the studies conducted by Kvaal *et al*.,[6] Cameriere *et al*.,[7,14,15] Paewinsky *et al*.,[11] Jeevan *et al*.,[13] and Zaheer *et al*.[16] In the present study, Pearson's correlation coefficients between chronological age and morphological variables showed that the variables p = complete pulp length/root length (from ECJ-root apex), r = complete pulp length/complete tooth length, length (L), and pulp/tooth AR correlated well with the chronological age. Using Cameriere's method, it was found that the morphological variable pulp/tooth AR contributed significantly to the chronological age estimation in contrast to the findings of the study conducted by Saxena S.[3] Similarly, contrasting results were found with the studies conducted by Kvaal *et al*.[6] and Bosman *et al*.[17] which showed better correlation of chronological age with morphological variables associated with width ratios (a = complete pulp length/root width at ECJ level, b = pulp/root width at midpoint level between ECJ

level and mid-root level, and c = pulp/root width at mid-root level) rather than length ratios (p = complete pulp length/root length [from ECJ to root apex] and r = complete pulp length/complete tooth length). The results of the present study were in slight disagreement with the findings of the studies conducted by Meinl *et al*.[9] and Kanchan Preeti[18] with the variations observed explained on the basis of the diversity in the ethnicity of the population under study. In the present study, mandibular first premolar correlated well with age for Kvaal's method with an R^2 value of 81.90% and an SEE of 5.889 which was in contrast with the study conducted by Kvaal *et al*.,[6] in which maxillary central incisor correlated best with age with an R^2 value of 70.00% and an SEE of 9.5 years. The differences in the findings of the present study as against the other studies might be explained on the basis of the regional, cultural, and ethnic variations seen in the populations studied. This is the reason as to why population-specific regression equations are supposed to be kept in mind while arriving at specific conclusions. Comparing the present study with Cameriere *et al*.'s[7] study, the study showed better results for mandibular canine with an R^2 value of 85.40% as compared to an R^2 value of 84.90% in the Cameriere's study. Separate linear regression equations were formulated for all teeth because correlation was stronger with individual tooth rather than the mean value of all teeth together in contrast with the study conducted by Kvaal *et al*.,[6] in which the R^2 value was strongest when the mean values (M and W−L) from all the six teeth were included together (R^2 value of 76.00%) and weakest when only one type of tooth was considered. The present study also showed statistical difference between chronological age and predicted age (SEE between 5.889 years and 11.458 years) to be lesser than in Kvaal *et al*.'s[6] study (SEE between 8.6 and 11.5 years). Based on these variables, chronological age could be determined with an accuracy of 81.90% with Kvaal's and 93.50% with Cameriere's methods.

Conclusion

In the present study, individual teeth correlated best with chronological age than all the teeth taken together. Therefore, separate regression equations for each tooth taken in the study were formulated for both Kvaal's and Cameriere's methods. In addition, although both Kvaal's and Cameriere's methods were found suitable for age estimation in Andhra Pradesh Population, Cameriere's method, in particular, was found to be more consistent and reliable.

Limitations of the study

- Although the results of the study are promising, they cannot be generalized to other populations. Therefore, separate regression equations were formulated
- Rotated teeth, decayed teeth, or teeth with any prosthesis were excluded from the study. If the individual has any of the mentioned conditions, this method cannot be employed to estimate the age, as these conditions alter the tooth surface area.

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Conflicts of interest

There are no conflicts of interest.

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