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Research Paper

Application of the Kvaal method for adult dental age estimation using Cone Beam Computed Tomography (CBCT)

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ABSTRACT

Different non-invasive methods have been proposed for dental age estimation in adults, with the Kvaal et al. method as one of the more frequently tested in different populations.

The purpose of this study was to apply the Kvaal et al. method for dental age estimation on modern volumetric data from 3D digital systems. To this end, 101 CBCT images from a Malaysian population were used. Fifty-five per cent were female (n = 55), and forty-five percent were male (n = 46), with a median age of 31 years for both sexes. As tomographs allow the observer to obtain a sagittal and coronal view of the teeth, the Kvaal pulp/root width measurements and ratios were calculated in the bucco-lingual and mesio-distal aspects of the tooth. From these data different linear regression models and formulae were built. The most accurate models for estimating age were obtained from a diverse combination of measurements (SEE ±10.58 years), and for the mesio-distal measurements of the central incisor at level A (SEE ±12.84 years). This accuracy, however is outside an acceptable range in for forensic application (SEE ±10.00 years), and is also more time consuming than the original approach based on dental radiographs.

1. Introduction

Currently, the need for developing more accurate and non-invasive methods for age estimation, as part of the identification of adult individuals in situations of forensic scenarios is increasing globally.[1] Gustafson first proposed a method for dental age estimation in adults,[2] since then, the analysis of dental changes in adults relative to chronological age has continued. The adult dentition is relatively resistant to environmental and chemical influences, and methods based on the assessment of teeth are considered advantageous for this reason.[3,4] Furthermore, methods based on odontometric measurement of pulp and tooth structures from dental radiographs or tomographs are non-invasive/non-destructive and can be applied to both living or deceased individuals.[5] Kvaal et al., proposed a method for age estimation in adults which has been tested in different populations around the world since 1995, but all reported a high standard error (±8.5 to ±13 years).[1,5,6] The basis of this method is the analysis of the narrowing of the pulp chamber with age, which is observable and measurable in dental radiographs. However, there is scope for improvement in the accuracy of the age estimations.

With the emergence of computer tomography (CT) and cone beam computer tomography (CBCT), new methods based on volumetric reconstruction of tooth and pulp volume and ratio calculations have been proposed for dental age estimation in adults.[7,8] However, those techniques have not provided better accuracy relative to the previously described Kvaal method, using dental radiographs. Moreover, pulp/tooth volume calculation is labour intensive,[9] and can require the use of complex, and often costly computer software.[10] Clearly, these more technical multi-

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dimensional systems provide considerably more data, at a substantially more detailed level, and with a reduction in many of the complications of simple plane film images. The method described by Kvaal et al.[5] was initially proposed, with measuring dimensions on periapical radiographs with a microscope and a pair of calligraphers. The applications of this method have been expanded to include panoramic radiographs using different analytical software.[6,11] The purpose of the present study is to apply the Kvaal et al.[5] method for dental age estimation using modern computer tomographic data from 3D digital systems. The null hypothesis is that the substantially increased quantity (and quality) of the data from these systems will provide greater accuracy of dental age estimation in adults.

2. Materials and methods

2.1. Sample

The study sample included a total of 101 tomographs obtained as part of normal treatment from the radiology department of the University of Keibangsaan Malaysia. Almost half (n = 47) were obtained with a Kodak device, reference K9000-3D (exposure parameters: scanning time: 10.8 s, 3–15 mA, 60–85kVp, field of view FOV: 5.2 cm × 5.2 cm–5.5 cm to 5.5 cm, 180° rotation, slice thickness 0.076–0.2 mm), and 54 were obtained with an i-CAT device (Dental Imaging Technologies Corporation. i-CAT® FLX™) (exposure parameters: scanning time 4 s, 5 mA, 120 kVp, FOV: 16 cm × 16 cm, Slice thickness 0.3 mm–0.4 mm). Of these tomographs, 55% were from female (n = 55), and 45% were from male (n = 46) patients, with a median age of 31 years for both sexes (Table 1). All the images were received in DICOM format, and analysed using the Osirix® software package (OnDemand 3D software CyberMed Inc, Seoul, South Korea). The study sample included teeth with very small coronal restorations, as long as they did not compromise the pulp chamber and secondary caries was not present. Teeth with shape abnormalities, active caries, root canal treatment, prosthetic restorations, signs of pulp or periapical pathologies, or open root apex, were duly excluded from the sample. Multi-rooted upper second premolars were also excluded.

2.2. Teeth analysed

Initially, Kvaal et al.[5] proposed a set of linear measurements, including the length of the tooth, pulp and root, in addition to the width of the root and pulp chamber at different levels, in six different teeth: upper central and lateral incisors, and the second premolar; and the lower lateral incisor, canine and first premolar. In the present study, due to the unclear definition of the pulp chamber and tooth boundaries for the lower teeth (most likely related to their small dimensions) only upper teeth were included: central incisor, lateral incisor, canine, and second upper premolar (when possible). As the dental images are tomographs, it is possible to assess the teeth in sagittal and coronal views; accordingly, the root length, and pulp/tooth width measurements proposed by Kvaal et al.[5] were acquired in the mesio-distal and bucco-lingual aspects of the teeth (see below). Significant differences between teeth of the left and right side of the maxilla have not been reported previously,[5] and therefore in this study, teeth from either the left or right side was measured.

Table 1
Age and sex distribution for CBCT and i-CAT tomographs.

Sex	Female		Male		Total
Age range (years)	CBCT n = 23	i-CAT n = 32	CBCT n = 24	i-CAT n = 22	
15–20	2	1	7	2	12
20–29	12	9	5	8	34
30–39	3	5	2	2	12
40–49	4	6	8	5	23
50–59	2	6	2	0	10
60–75	0	5	0	5	10
TOTAL	55		46		101

2.3. Measurements

As proposed by Kvaal et al.,[5] the mesio-distal measurements of the teeth (coronal view) were performed as follows: first, the level A, was located at the CEJ (cemento-enamel junction) on the mesial side of the tooth, then level C was located halfway between point A and the root apex, and finally point B was located halfway between point A and C. As this is the first study applying the Kvaal et al. method exclusively in tomographs, bucco-lingual measurements were also acquired (sagittal view). Point A was located at the vestibular CEJ, point C halfway between the vestibular CEJ and the root apex, and point B, halfway between point A and point C. In this way, there were six pulp/tooth width measurements per tooth. All the measurements were recorded by one observer (TYM) using the Osirix® software.

2.4. Statistical analysis

Intra-observer error was tested, four tomographs were randomly selected (two Kodak and two i-CAT) and all the measurements were recorded by one observer (TYM). Upper central, lateral and canine were measured on four separate occasions, with a minimum of one day between repetitions ensuring that the observer did not remember the previously recorded measurements. Measurement error was assessed by calculating the technical error of measurement (TEM), coefficient of reliability (R) and relative technical error of measurement (rTEM).[12]

All data were collected in an Excel spreadsheet, Excel (version 2013 Microsoft, Redmont, USA), and statistical analysis was completed using R Core Team version 3.1.3 (2015). (R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/). Descriptive statistics were used to summarise the data (mean, standard deviation, and frequency distributions). Normality was also tested (skewness, kurtosis and Shapiro-Wilk) to establish whether parametric or non-parametric analysis was required. Pearson correlation coefficient (r) was calculated to assess the relationship between the dental ratios and age, for the data obtained from the Kodak CBCT and for the data obtained from i-CAT CBCT individually, and also when both data sets were combined. This was done with the aim of testing if the difference between the resolutions of both devices could cause any statistically significant differences (Table 2). Linear regression models were built with age designated as the dependant variable. Different age estimation equations were then formulated using different groupings of age predictors: 1) the tooth/pulp ratios at the levels A, B or C individually; 2) calculating the average of the pulp/tooth ratios of all the teeth at the different levels (A, B or C) obtaining a formula for each level; 3) calculating the average of the pulp/tooth ratios of the lateral (Lat) and central (Cent) upper incisor at the different levels (A, B and C); 4) Average of the pulp/tooth ratios from all the teeth at the levels A, B and C in the same formula (A + B + C); and 5) same as 4, but excluding the ratios obtained from the canines (Cent-Lat). A total of 17 linear regression models were thus generated per dataset: sagittal (s) view (bucco-lingual measurements); coronal (c) view; and the average of both (sc). The accuracy of the models is

Table 2
Correlation coefficient measurements CBCT.

Tooth number	CBCT		i-CAT		CBCT & i-CAT	
	Coronal	Sagittal	Coronal	Sagittal	Coronal	Sagittal
11/21 A	−0.05 NS	−0.36*	−0.634**	−0.65**	−0.45**	−0.61**
11/21 B	−0.26 NS	−0.37*	−0.421**	−0.59**	−0.32*	−0.5**
11/21 C	−0.29 NS	−0.45**	−0.288*	−0.36*	−0.23*	−0.41**
12/22 A	−0.53**	−0.08 NS	−0.326*	−0.62**	−0.31*	−0.41**
12/22 B	−0.35*	−0.5**	−0.3*	−0.60**	−0.22*	−0.46**
12/22 C	−0.24 NS	−0.57**	−0.013 NS	−0.41**	−0.05 NS	−0.41**
13/23 A	−0.25 NS	−0.13 NS	−0.153 NS	−0.50**	−0.04 NS	−0.17 NS
13/23 B	−0.59**	−0.56**	−0.329*	−0.41*	−0.28**	−0.39**
13/23 C	−0.52**	−0.34**	−0.348*	−0.24 NS	−0.28**	−0.21*

*$p < 0.05$, **$p < 0.001$, NS = non-significant.

reported as the standard error of estimation (SEE).[11,13]

3. Results

Intra-observer error results were considered to be within acceptable range. (TEM <1.0 and the coefficient of reliability R>0.80%), regardless the tomograph source (Kodak or i-CAT) or whether the measurements were recorded in the bucco-lingual or mesio-distal view of the teeth. In terms of the relative technical error of measurement (rTEM), 72% of the observations scored <5% and 28% had a rTEM < 10%. It was also observed that the accuracy of the observer was better for the bucco-lingual measurements (sagittal view of the teeth) regardless the source of the tomography.

Pearson correlation coefficient test (r) demonstrated a stronger correlation between the pulp/tooth ratios and age for the bucco-lingual measurements (sagittal (s)) than for the mesio-distal measurements (coronal view (c)) (Table 2). Although there were differences between the correlation coefficients from the Kodak and i-CAT CBCT's, scatter-plots including the results of both sources do not show outliers associated with the specific use. There was a clear and significant negative correlation between age and pulp/tooth ratios in all the data sets. Correlation coefficient were calculated as follows: i) for the measurements obtained from the Kodak tomographs; ii) for the measurements recorded from the i-CAT tomographs; and iii) for the combination of both. The i-CAT tomographs showed the strongest correlation to age, especially for the upper central incisor ($r = -0.65$), followed by the combination of the Kodak & i-CAT data sets ($r = -0.61$). The correlation coefficients obtained from the Kodak, although statistically significant, were lower than that obtained from the i-CAT and combined Kodak & i-CAT (Table 2).

In relation to the accuracy of the different linear regression models, it was observed that all the estimates were over the threshold generally accepted for forensic application (SEE ±10 years),[14] however the SEE is reduced when both data-sets are combined into a linear regression model (Table 3). There was only one equation with an acceptable level of predictive accuracy (SEE 10.58 years ($n = 72$, $r = 0.59$, $r^2 = 0.56$)):

$$\text{Age} = 101.46 + 734.74\,(\text{Ac}) - 374.81\,(\text{Ac}_{(\text{Cent-Lat})}) - 1075.18\,(\text{Csc}) + 327.07\,(\text{Bc}) + 310\,(\text{Cc}_{(\text{Cent-Lat})}) - 159.25\,(11/21\ \text{As})$$

Abbreviations: Ac: average of the pulp/tooth ratio in the coronal view at level A from the three teeth. $\text{Ac}_{(\text{Cent-Lat})}$: average of the pulp/tooth ratios from the lateral and central incisors. Csc: average of the pulp/tooth ratio at level C from the sagittal and coronal views (sc) from all teeth. Bc: average of the pulp tooth ratio at the level B from all the teeth in the coronal view. ($\text{Cc}_{(\text{Cent-Lat})}$): average of the pulp/tooth ratios at the level C from the lateral and central incisor in the coronal view. 11/21 As: pulp/tooth ratio at the level A from the central incisor in the sagittal view.

The most accurate linear regression models obtained from the individual analysis of the bucco-lingual measurements were as follows: the central incisor at level A (Age = 84.059−191.003 (11/21 As), $r^2 = 0.37$, SEE = ±12.84), the average of the bucco-lingual measurements from the central incisor and lateral incisor at the level A, B and C (Age = 102.08−157.94 (As) −73.0 (Bs) −36.81 (Cs), $r^2 = 0.39$, SEE = ±12.73 years).

When both data-sets were combined (Table 3) the highest accuracy was achieved from: the average of the bucco-lingual (s) plus the average of the mesio-distal (c) measurements at level A, (SEE ±12.17 years); the average of the bucco-lingual and mesio-distal measurements at level A from the central and lateral incisors, (SEE ±12.76); and the average of the bucco-lingual and mesio-distal measurements from the central and lateral incisors at level A, plus level B, plus level C, (SEE ±12.7). The linear regression models generated by the inclusion from only the mesio-distal (c) measurements did not result in an SEE lower than ±14 years, and therefore these results are not included.

4. Discussion

This is the first study testing the Kvaal et al. method exclusively in tomographs, and also the first one applying Kvaal et al.'s. pulp/tooth width ratio calculations in the bucco-lingual aspect of the teeth. Computer tomography is increasingly being used in dental practice and provides three-dimensional information about any area of interest, in a relatively quick and cost-effective manner.[15] In this study it was expected that application of the Kvaal et al. method using CBCT diagnostic images would increase the array of methods available for the forensic profiling of living and deceased individuals. Until now, there has only been one other study proposing a similar method for adult dental age estimation, based on the assessment of the pulp/tooth bucco-lingual dimensions (area) in canines.[16] Although the results of the latter study were satisfactory (Mean prediction error, ME ±2.8 years at best), this method required extracted teeth, and thus has restricted application in a forensic context. The use of tomographs overcomes issues related to the requirement for tooth extraction, and also permits the analysis of multiple teeth with less radiation exposure.

Although, in this study, the number of individuals was small in certain age intervals, there are well documented biological age related changes in the human dentition, which have allowed forensic dentists to propose and use different methods for dental age estimation.[17] In previous publications applying the Kvaal et al. method for dental age estimation in adults, it has been noted that one of the principal limitations is the absence of a clear limit between the dentine and the pulp camber,[11] which is observed as a

Table 3
Linear regression analysis, linear regression formulae, correlation coefficient (r) between age and the ratios of bucco-lingual and mesio-distal width measurements from CBCT & i-CAT.

Sagittal and coronal					
Age predictors	n	Linear regression formulae	r	r^2	SEE
11/21 A sc	86	Age = 99.74−72.07(11Ac)−161.63(11As)	0.4	0.4	**12.2**
11/21 B sc	86	Age = 81.82−35.031(11Bc)−147.14(11As)	0.26	0.24	14
11/21 C sc	86	Age = 71.92−29.16(11Cc)−134.69(11Cs)	0.17	0.15	14.9
12/22 A sc	89	Age = 87.43−68.05(12Ac)−129.37(12As)	0.21	0.19	14.5
12/22 B sc	89	Age = 73.98−24.34(12Cb)−127.46(12Bs)	0.21	0.19	14.5
12/22 C sc	89	Age = 57.56 + 37.84(12Cc)−148.22(12 cs)	0.18	0.17	14.7
13/23 A sc	95	Age = 51.14−5.4(13Ac)−47.192(13As)	0.03	0.01	15.4
13/23 B sc	95	Age = 69.51−47.15(13Bc)−70.44(13Bs)	0.17	0.15	14.2
13/23 C sc	95	Age = 60.81−78.34(13Cc)−34.37(13Sc)	0.09	0.08	14.9
A sc	78	Age = 100.41−33.11(Ac)−206.40(As)	0.34	0.33	13.5
B sc	78	Age = 89.22−20.54(Bc)−178.29(Bs)	0.31	0.29	13.9
C sc	78	Age = 69.46 + 16.4(Cc)−174.42(Cs)	0.17	0.15	15.2
A sc Cent/Lat	83	Age = 105.42−72.96(Ac1/2)−187.22(As1/2)	0.4	0.38	**12.8**
B sc Cent/Lat	83	Age = 86.31−19.86(Bc1/2)−180.19(Bs1/2)	0.29	0.27	13.9
C sc Cent/Lat	83	Age = 70.41 + 42.09(Cc1/2)-206.7(Cs1/2)	0.23	0.21	14.4
Asc + Bsc + Csc	74	Age = 104.09−17.65 (Ac)−135.48 (AS)−38.18(Bc)−105.54(Bs)+40.87(Cc)+10.93 (Cs)	0.4	0.35	13.3
Asc + Bsc + Csc Lat/Cent	82	Age = 106.25−180.14(Asc1/2)−135.83(Bsc1/2)+51.73(Ccs1/2)	0.4	0.39	**12.7**

Abbreviations: Tooth number (11/21, 12/22 and 13/23) with Asc, Bsc or Csc = pulp/tooth ratio at the levels A, B or C in the sagittal and coronal view (sc) calculated per tooth. Asc, Bsc or Csc: average of the pulp/tooth ratio at the respective level, from all the teeth. Asc, Bsc or Csc with Lat/Cent: average of the pulp/tooth ratio only from central and lateral incisors. Asc + Bsc + Csc = average from the pulp/tooth ratio from all the teeth at the respective level. Asc + Bsc + Csc = average from the pulp/tooth ratio from all the teeth at the respective level including only lateral and central teeth. SEE: Standard error of estimation in ± years. Best results in bold.

grey zone instead of a distinct line.[6] This affects the accuracy of the measurements and intra/inter-observer agreement. In the present study it was observed that neither Kodak nor i-CAT tomographs were exempt from this issue. In certain cases, the border between the pulp chamber and dentine, or tooth and bone are also more blurred than in periapical radiographs. It is true that dental Kodak tomographs may have higher resolution than i-CAT tomographs. However, in the present study it was observed that the data obtained from the i-CAT had a higher correlation to age compared to the Kodak scans (Table 2). Similarly, the bucco-lingual width ratios had a higher correlation to age than the mesio-distal width ratios (with the latter measurable in periapical radiographs).

It has previously been reported that Kvaal et al. length measurements are both difficult to register and do not provide significant information to the final equation.[5,18] It is important to note that in the tomographs analysed in the present study, it was even more difficult to observe the root apex compared to periapical radiographs. The only length measurement registered was the root length from the CEJ towards the apex to locate points A, B and C. In this way only pulp/tooth width and ratios were used as the only age predictors. The exclusive use of pulp/tooth ratios proposed by Kvaal et al. has previously been documented[18] on panoramic radiographs, showing more accurate results (SEE = ±10.02 years) than those obtained in this study. (SEE = ±10.58 years at best). In a previous study that analysed the odontometric age-related changes in different teeth, it was found that the rate of secondary dentine formation varied depending on tooth type: in canines the increase of coronal dentinal thickness was not as high as it was for the incisor and premolars.[19] In the present study it was similarly observed that although the correlation coefficient between pulp/tooth ratios and age were significant, the exclusion of canine ratios when the linear regression models were generated, improved their accuracy.

On the other hand, this is also the first study documenting the inclusion of teeth with small crown fillings in the sample to generate linear regression formulae, in contrast to previous publications using the Kvaal et al. method,[5] where one of the inclusion criteria was to use only totally clinically sound teeth. It was observed that there were no statistically significant differences caused by inclusion of these teeth. This may relate to the nature of the formation of tertiary dentine or reactionary dentine to external threats. It has been reported that tertiary dentine formation is highly dependent on the stimulus, and that caries mediators induce a focal dentine production,[19–21] with a rate formation of about 3 μm per day.[22]

Regression analysis, has been chosen for age estimation due to its simplicity.[23] Nevertheless, it is necessary to note the limitations of the use of linear regression models for dental age estimation; for example, the higher standard deviations when the original formulae of Kvaal et al. are applied in populations of different ethnic backgrounds.[24] The latter necessitates the need for population specific formulae. Also, it assumes that formation of secondary dentine is a linear process, when it is more similar to a curve.[25]

Additionally, it was observed that, although using tomography result in obtaining more odontometric data from the same teeth (mesio-distal and bucco-lingual measurements), this apparent advantage over the use of dental radiographs, did not improve the final outcome. Also, the need to properly align the teeth in the sagittal and coronal plane demands more time than the traditional Kvaal et al. approach in dental radiographs.

Finally, it is necessary to mention that CBCT is not exempt of artefacts intrinsic to the process of image acquisition.[26] This could explain, not only the high SEE obtained in this study, but also the poor accuracy of those methods based on pulp/tooth volume calculation,[9,10] when compared with more simple approaches such as the measurement of pulp/tooth area on dental radiographs (Cameriere et al. method, with a SEE = ±3.27 years).[16]

5. Conclusion

Radiological assessment of dental age-related changes is a valid tool for age estimation. It is true that new diagnostic technologies provide the practitioners and forensic researchers new opportunities to use and propose new methods for dental age estimation. However, the use of tomographs in this study, applying the Kvaal et al. method, did not improve the results. It is recommended to also include teeth with small fillings in studies based on pulp/tooth dimension ratios, as long as the pulp chamber is not compromised. The aim of this is to further investigate the application of these different methods on those individuals who do not have totally sound dentitions.

Conflict of interest

None of the authors have any conflict of interest associated with this study.

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Ethics approval

Ethics approval for this study was obtained from the Human Research Ethics Committee of the University of Western Australia (Ref: RA/4/1/6797). Permission was also granted by the University of Keibangsaan Malaysia. The design of the study, data collection, and analyses have been performed in accordance with the ethical standards set forth in the 1964 Declaration of Helsinki.

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