Available online at www.sciencedirect.com
SCIENCE DIRECT®
Forensic Science International 153 (2005) 208–212
Forensic Science International
www.elsevier.com/locate/forsciint

The application of Kvaal's dental age calculation technique on panoramic dental radiographs

Nathalie Bosmans[a], Peirs Ann[b], Medhat Aly[a], Guy Willems[a,*]

[a]*Department of Forensic Odontology, School of Dentistry, Oral Pathology and Maxillo-Facial Surgery, Faculty of Medicine, Katholieke Universiteit Leuven, Kapucijnenvoer 7, B-3000 Leuven, Belgium*
[b]*University Centre for Statistics, Katholieke Universiteit Leuven, Leuven, Belgium*

Received 16 February 2004; accepted 24 August 2004
Available online 6 November 2004

Abstract

Introduction: Literature reports on a method for dental age calculation which is based only on radiological measurements on periapical dental radiographs: the relationship between chronological age and the two-dimensional dental pulpal size was analysed by means of multiple regression analyses.

The purpose of the present study was to evaluate whether this approach could be feasible and could lead to statistically sound results with adequate repeatability when applied on panoramic radiographs.

Materials and methods: One hundred and ninety seven panoramic radiographs were collected at random from patients of whom the age ranged from 19 to 75 years. According to the reported technique, six teeth were selected on the panoramic radiograph: in the maxilla the central and lateral incisor and second bicuspid, and in the mandibula the lateral incisor, cuspid and first bicuspid. The same exclusion criteria as in the original paper were respected. Statistical analysis was carried out in order to spot significant differences between the chronological age and the calculated age.

Results: When the age was calculated based on measurements of all six teeth or of all three mandibular teeth, no significant differences were found between the real age and the calculated one. In all other instances using the individual teeth separately or using all three maxillary teeth statistical analysis revealed significant differences.

Conclusion: There appears to be no significant difference between applying the original technique on standard long-cone periapical radiographs or on orthopantomograms, especially when carrying out measurements on all six selected teeth.

Keywords: Forensic odontology; Dental age calculation; Panoramic radiographs

1. Introduction

Age calculation has become increasingly important in forensic sciences. This is certainly true for unidentified corpses but also for living individuals. Especially in a multicultural society where legal and illegal immigration is rising, an increasing demand exists for age calculation in living persons.

Several authors have reported different techniques for dental age calculation in forensic literature. Among those are morphological and radiological techniques. Most commonly used morphological techniques are based on the length of the apical translucent zone [1], and on the evaluation of age related criteria such as attrition, secondary dentin, periodontal attachment, translucent apical zone, cementum

* Corresponding author. Tel.: +32 16 33 24 59; fax: +32 16 33 24 35.
E-mail address: guy.willems@med.kuleuven.ac.be (G. Willems).

0379-0738/$ – see front matter
doi:10.1016/j.forsciint.2004.08.017

apposition and root resorption [2]. In 1993 Solheim [3] also reported on a morphological technique which until today seems to be the most elaborated and statistically sound technique for dental age calculation.

All these methods require extraction, and most of the time preparation of microscopic sections of at least one tooth from each individual. These methods cannot be used in living individuals and in cases where it is not acceptable to extract teeth for ethical, religious, cultural, or scientific reasons.

In 1994 Kvaal and Solheim [4] presented a method which combines radiological and morphological measurements, and therefore extraction was still required. At least for some teeth regression formulas were calculated omitting the use of morphological parameters. As a continuation of this method Kvaal et al. [5] reported a method which is based on radiological measurements only. They investigated periapical radiographs by examining the relationship between chronological age and the two-dimensional dental pulp size in individuals older than 20 years of age. In order to do so, length and width measurements of tooth and dental pulp were analysed stereomicroscopically on apical radiographs of six teeth: maxillary central (Max1) and lateral incisors (Max2) and second bicuspids (Max5) and mandibular lateral incisors (Man2), canines (Man3) and first bicuspids (Man4). Ratios between the length and width measurements of the same tooth were calculated in order to avoid measurement errors due to differences in magnification of the image on the radiograph. Such ratios were: pulp/root length (*P*), pulp/tooth length (*R*), tooth/root length (*T*) and pulp/root width at three different levels: at the enamel–cementum junction (ECJ; *A*), at the midroot length (*C*) and at the midpoint between the ECJ and midroot level (*B*). Regression formulas were calculated for dental age estimation based on the analysis of either all six teeth (maxilla + mandibula), or the three maxillary teeth only (maxilla), or the three mandibular teeth only (mandibula) or each individual tooth only.

The aim of the present study was to apply Kvaal's technique [5] on digital orthopantomographs of adults and evaluate whether this approach leads to statistically comparable and reproducible results.

2. Materials and methods

One hundred and ninety seven orthopantomographs of digital origin were collected from three Belgian dental practices and delivered on CD-ROM. The radiographs were from 197 Caucasian individuals with an age ranging from 19 to 75 years (mean age: 34.7 years; number of females: 95; number of males: 102; Table 1). Each file was numbered consecutively from 1 to 197 being part of a blind set-up. When analysing the radiographs the observer had no idea about the chronological age of the individuals examined.

Table 1
Age and gender distribution of the population studied

Years	Male	Female	Total
<29	37	44	81
30–39	37	26	63
40–49	18	17	35
50–59	6	6	12
60–69	3	1	4
>70	1	1	2
Total	102	95	197

On each of the orthopantomographs the original six teeth were selected as described in literature [5]. For the original method no significant differences between teeth from the left and the right side of the jaw were found. This provided the opportunity to choose the teeth that were best presented on the orthopantomograph and thus most suited for measurement. The same exclusion criteria were used: impacted teeth, teeth with vestibular radioopaque fillings, crowns, pathological processes in the apical bone visible on the radiograph and teeth with root-canal treatment were not selected. Orthopantomograms showing badly rotated teeth or teeth with large areas of enamel overlap between neighbouring teeth were also excluded.

The following measurements were carried out on the orthopantomographs for all six types of teeth with the aid of the computer program Adobe Photoshop 6.0® (Adobe Systems Incorporated, San Jose, CA, USA): the maximum tooth length, the pulp length, the root length on the mesial surface from the ECJ to the root apex, the root and pulp width at levels *A*, *B*, and *C*. The obtained measurements were transferred to the Dental Age Estimation® software version 2.0 for automatic calculation of dental age [6].

The unmodified orthopantomographs were entered as 1024 × 768 pixel digital images. With the Adobe Photoshop 6.0®-computer program the brightness and contrast of the images could be adjusted and enlarged. Using the mouse-driven cursor, the reference points on the images of the teeth were defined and the number of pixels within the defined line was given.

All measurements were performed by a single observer and 30 orthopantomographs were revaluated after 1 month in order to obtain an idea of the intra-observer agreement.

Statistical analysis. All measurements together with known chronological ages and calculated dental ages according to the formulas developed on the original technique were statistically analysed by means of a SAS-univariate procedure (SAS statistical software, SAS Institute, Cary, NC, USA). Differences between chronological and calculated ages were analysed using the Student's *t*-test and the standard error of the estimated age was calculated. Finally, Pearson correlation coefficients between chronological age and the obtained ratios were calculated.

Table 2
Pearson correlation coefficients (r) and concordance correlation coefficients (cc) between measurements 1 (M1) and 2 (M2), and between both measurements and the real age (RA)

Pearson correlation coefficient	
r(M1, M2)	0.94
r(M1, RA)	0.91
r(M2, RA)	0.84
Concordance correlation coefficient	
cc(M1, M2)	0.93
cc(M1, RA)	0.90
cc(M2, RA)	0.82

3. Results

No significant intra-observer effects were found between measurements 1 and 2 as depicted by the high concordance correlation coefficient (Table 2). High concordance correlation values of 0.82 and 0.90 were also obtained between the calculated age and the chronological age for both the first and the second measurements, respectively. This does not only mean that both measurements are nearly the same, but also that the technique is reproducible on orthopantomogram (Table 2).

A Student's t-test with alpha set at 0.05 was performed in order to find out whether significant differences exist between the chronological and the calculated age and this in relation to the number of teeth used for age calculation. Results of the t-test analysis performed for each group of teeth or for each individual tooth are displayed in Table 3. No significant differences were found between chronological age and calculated age for the results obtained based on the original regression formulas including all six teeth or including the three mandibular teeth only. Using any other possible combination of teeth for age calculation resulted after statistical analysis in significant differences between the calculated and the real age (Table 3).

Table 3
Results of t-test analysis (alpha = 0.05) for all of the teeth combinations possible (mean: mean difference between chronological age and calculated age in years; S.D.: standard deviation of this mean difference in years, S.E.M.: standard error of the mean in years; * significant difference between calculated age and mean age; ns: no significant difference)

	Mean	S.D.	S.E.M.	t-Test
Maxilla + mandibula (six teeth)	−0.49	5.41	0.39	ns
Maxilla (three teeth)	−1.87	6.43	0.46	*
Mandibula (three teeth)	0.37	6.15	0.44	ns
Max1	−6.08	7.24	0.52	*
Max2	−2.63	8.66	0.62	*
Max5	3.01	8.47	0.60	*
Man2	−7.21	8.35	0.60	*
Man3	−3.44	7.91	0.56	*
Man4	1.37	8.95	0.64	*

The Pearson correlation coefficients between chronological age and the different ratios (P, T, R, A, B, C) calculated based on length and width measurements directly on the orthopantomographs are displayed in Table 4. All correlation coefficients noted in Table 4 were significant. Especially the correlations between the chronological age and ratio T were not significant for the different combinations of teeth. The coefficients of the difference between W (the mean value of width ratios from levels B and C) and L (the mean value of the length ratios P and R) were also not significant.

Based on the measurements made in this study and related to the calculation of age, statistical analysis also revealed the standard error of the calculated ages. Table 5 reports these standard error of the estimates (S.E.E.) as well

Table 4
Pearson correlation coefficients between the real age and the calculated ratios for all the teeth combinations possible

Ratio	Max1	Max2	Max5	Man2	Man3	Man4	Mandibula	Maxilla	Maxilla + mandibula
P	−0.56	−0.47	−0.27	−0.60	−0.42	−0.45	nc	nc	nc
T	ns	ns	ns	−0.25	ns	−0.17	nc	nc	nc
R	−0.53	−0.38	−0.25	−0.42	−0.30	−0.24	nc	nc	nc
A	−0.70	−0.64	−0.52	−0.65	−0.54	−0.58	nc	nc	nc
B	−0.62	−0.58	−0.48	−0.54	−0.56	−0.47	nc	nc	nc
C	−0.58	−0.28	−0.48	−0.48	−0.54	−0.43	nc	nc	nc
M	−0.76	−0.69	−0.65	−0.73	−0.69	−0.66	−0.82	−0.81	−0.87
W	−0.64	−0.48	−0.54	−0.55	−0.62	−0.52	−0.72	−0.70	−0.79
L	−0.59	−0.50	−0.30	−0.58	−0.43	−0.41	−0.62	−0.62	−0.70
$W - L$	ns	ns	ns	0.20	ns	ns	ns	ns	ns

P: ratio between length of pulp and root; T: ratio between length of tooth and root; R: ratio between length of pulp and tooth; A: ratio between width of pulp and root at enamel–cementum junction (level A); B: ratio between width of pulp and root at midpoint between level C and A (level B); C: ratio between width of pulp and root at midroot level (level C); M: mean value of all ratios except ratio T; 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; nc: not calculated; ns: not significant.

Table 5
Standard error of the estimate in years for all teeth combinations possible compared to the S.E.E. obtained on the original sample

Teeth	S.E.E.	S.E.E. [5]
Maxilla + mandibula (six teeth)	9.5	8.6
Maxilla (three teeth)	9.2	8.9
Mandibula (three teeth)	9.9	9.4
Max1	9.7	9.5
Max2	9.8	10.0
Max5	9.3	11.0
Man2	11.6	11.5
Man3	8.2	11.5
Man4	8.1	10.5

as the S.E.E. obtained with the original technique [5]. Both values seem to be relatively comparable.

4. Discussion

The orthopantomographs examined in this study were collected from three Belgian dental practices. The major reason why it seemed so difficult to find suitable radiographs in the older age category was the specific selection criterium that at least all six type of teeth that needed to be examined should be present. Further exclusion criteria like the presence of impacted teeth or teeth with vestibular radio-opaque fillings and crowns, pathological processes in the apical bone visible on the radiograph, or teeth with endodontic treatment did not facilitate the selection procedure. Nevertheless this study ended up selecting twice as much individual orthopantomographs compared to the original study [5]. Medical history of the patients was not taken into account when selecting the radiographs.

Some questions concerning precision and accuracy of the measurements have been reported in literature when using digital measurements. Some authors [7] have looked at different methods of measuring morphological parameters on dental radiographs like image analysis and manual measurements. When comparing both methods they concluded that ratios calculated from the linear measurements of the tooth/pulp showed a weaker correlation with age when an image analysis program was employed than did ratios based on conventional measurements of the same parameters. The main source of errors in measurement seemed to be difficulties in recognition of the reference points on the radiographs when viewed on the monitor, and therefore in defining the line to be measured. In 1999 Schulze et al. [8] investigated the precision and accuracy of measurements in digital panoramic radiographs. They reported that vertical measurements were less reproducible and less accurate than horizontal. On the other hand the results of the present study have shown a very high degree of intra-observer agreement indicating a high reproducibility of the measurements. In addition the calculated age did come very near to the chronological age. Especially in those conditions where either all six teeth or all three mandibular teeth participated in the age calculation no significant difference was found between the real age of the individual and the calculated age based on the orthopantomograph.

Kvaal's original technique [5] requires that standard apical radiographs are taken of the selected teeth. When using panoramic dental radiographs instead other disadvantages have to be taken into account. Patients that are badly positioned relatively in relation to the X-ray tube of the machine while taking the radiograph, give rise to obvious distortion of the teeth on the orthopantomograph and unsharpness of the image. This in turn may affect the quality of the measurements performed and thus the accuracy of the calculated age. Careful management of the specific operating instructions related to patient positioning is a must.

As in the original work this study also reports a non-significant correlation for most of the teeth examined between the chronological age and ratio T, being the ratio of tooth to root length. This may give an indication that attrition in the present population sample may not—or at least not significantly—be related with chronological age. The knowledge that the Central European diet is far less abrasive compared to some cultures even nowadays may support these findings.

Table 5 presents data on the standard error of the estimate (S.E.E.). Some precaution should be taken when interpreting these data. Although both S.E.E. reported seem to be comparable, further conclusions based on this fact may not be made for the reason that actually two different population samples were examined, the original Norwegian and the present Belgian Caucasian population. This makes strict comparison impossible. On the other hand one could argue that both are from Caucasian origin and therefore the spread of the chronological age of both subpopulations might not be so different.

5. Conclusion

From the results of this study it can be concluded that the use of Kvaal's technique [5] in adults and the application of the original regression formulas on data obtained from panoramic radiographs instead from the typical apical radiographs as originally described, may lead to age estimations that are comparable to those based on the original technique if at least the selection criteria are respected and good quality orthopantomographs with clear radiological image are used.

References

[1] G. Bang, E. Ramm, Determination of age in humans from root dentin transparency, Acta Odontol. Scand. 28 (1970) 3–35.
[2] G. Johanson, Age determination from teeth, Odontol. Revy 22 (1971) 1–126.

[3] T. Solheim, A new method for dental age estimation in adults, Forensic Sci. Int. 59 (1993) 137–147.
[4] S.I. Kvaal, T. Solheim, A non-destructive dental method for age estimation, J. Forensic Odontostomatol. 12 (1994) 6–11.
[5] S.I. Kvaal, K.M. Kollveit, I.O. Thompsen, T. Solheim, Age estimation of adults from dental radiographs, Forensic Sci. Int. 74 (1995) 175–185.
[6] G. Willems, A review of commonly used dental age estimation techniques, J. Forensic Odontostomatol. 19 (2001) 9–17.
[7] L. Kullman, G. Tronje, A. Teivens, A. Lundholm, Methods of reducing observer variation in age estimation from panoramic radiographs, Dentomaxillofac. Radiol. 25 (4) (1996) 173–178.
[8] R. Schulze, F. Krummenauer, F. Schalldach, B. d'Hoedt, Precision and accuracy of measurements in digital panoramic radiography, Dentomaxillofac. Radiol. 29 (2000) 52–56.