ORIGINAL ARTICLE

Application of the method of Kvaal et al. to digital orthopantomograms

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Abstract Estimation of age in individuals has received considerable attention in the forensic literature. The reduction of size of dental pulp cavity as a result of secondary dentin deposit with increasing age could be used as an indicator of age. This regression change, apart from morphological techniques, can also be analysed by radiological techniques. In 1995, Kvaal et al. reported a new method for estimating the chronological age of adults based on the relationship between age and the pulp size on periapical dental radiographs. In 2005, Paewinsky et al. reported specific regression formulae for dental age calculation. The aim of this work was to evaluate the reproducibility of the original method of Kvaal et al. on digital panoramic radiographs as well as to analyse the application of age-estimation formulae reported in the literature. Orthopantomograms (OPGs) of 100 patients aged between 14 and 60 years old from a private radiology department in Bilbao were selected at random. According to the reported technique, three mandibular teeth were evaluated in each orthopantomogram. The results showed that the method reported by Kvaal at al. cannot be applied to direct digital OPGs. The values of age estimation obtained using regression formulae analysed on digital images were so distant from the real ages that this method must be discouraged as being a reliable one to estimate age on a direct digital OPGs sample.

Keywords Age estimation · Dental orthopantomograms · Digital radiology · Secondary dentin

Introduction

The use of dentition for the assessment of age appears to date back to the early years of the nineteenth century. In 1889, Laccasagne was first to use changes in teeth of adults to estimate age. Later, Bodecker, in 1925, pointed out that some morphological changes in teeth could be related to increasing age. Since the publication of these works, a great number of studies have analysed the different structural age-related changes in fully developed teeth [1].

In 1950, Gustafson [2] provided the first scientific method for determining the age of an individual by means of examination of teeth. Six features were examined: secondary dentin deposition, attrition, periodontosis, cementum apposition, root resorption and transparency of the root. Afterwards, there have been numerous publications on each of the six regressive changes, however, most of the age-estimation methods published show a destructive approach and require teeth extraction which may in many circumstances be considered as unacceptable for a variety of reasons, especially in living persons.

Authors like Benzer [3], Philippas and Applebaum [4], Moore [5] and Solheim [6] focused their research on the phenomenon of secondary dentin formation, which is a slow process that progresses throughout life and gradually

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reduces pulp cavity dimensions. Therefore, measurements of the length and width of the pulp cavity may be taken as an indirect expression of the amount of secondary dentin [6].

This parameter for age estimation, apart from morphological techniques, can also be analysed by several radiological techniques as length and width measurements of teeth and dental pulp cavities can be carried out on radiological images. Therefore, these values provide information about the reduction of size of pulp cavity as a result of secondary dentin deposit with increasing age, whose quantification could be used as an age indicator. Radiological techniques are a non-invasive and simple dental age calculation method and can therefore be used in living or dead individuals as well as in skeletal remains.

Philippas [7] was one of the first authors to use the radiographic method to determine the influence of age on the formation of dentin. Shaw and Jones [8], Woods et al. [9] and Prapanpoch et al. [10], when continuing this line of research, obtained contradictory results. Other authors analysed the reduction of root canals (Morse et al. [11]) and the tooth coronal index (Drusini [12] , Drusini et al. [13] and Igbigbi and Nyrenda [14]) with advancing age by means of radiographic techniques.

In 1995, Kvaal et al. [15] developed a new method for estimating the chronological age of an adult based on the relationship between age and the pulp size on periapical dental radiographs. One hundred radiographs collected from a Norwegian sample with an individual age ranging from 20 to 87 years were analysed. Correlation coefficients between age and most of the calculated ratios were negative and significant. The coefficient of determination obtained ($r^2 = 0.76$) was stronger when the ratio from all six types of teeth was employed for the age estimation. Likewise, regression formulae for estimating chronological age were presented.

Following the recommendations of these authors, several works have been performed to test the reproducibility of this method on independent samples using different radiological techniques. Bosmans et al. [16] applied the technique of Kvaal et al. on digital orthopantomograms and obtained age estimations comparable to those based on the original technique. Paewinsky et al. [17] also tested the method of Kvaal et al. on digital panoramic radiographs but specific regression formulae were developed by these authors for their sample. According to these equations, a linear correlation coefficient $r = -0.95$ with a standard deviation of 5.6 years was calculated when the width ratios from all teeth were included. Recently, in 2007, Meinl et al. [18] evaluated the use of the regression formulae proposed by Kvaal et al. [15] and Paewinsky et al. [17] in forensic age estimation. Cameriere et al. published a method for assessing chronological age based on the relationship between age and measurement of the pulp/tooth area ratio [19, 20].

Apart from the above-mentioned techniques, in the last decades, numerous age-estimation methods have been described in the literature. Recently, several articles about the need for accurate techniques for age estimation has been published [21–23].

The main purpose of this project was to test the reproducibility of the original method for age estimation developed by Kvaal et al. [15] on direct digital orthopantomograms and to evaluate the application of regression formulae reported by Kvaal et al. [15] and Paewinsky et al. [17] on the values from the sample studied.

Materials and methods

Digital orthopantomograms from 100 Caucasian patients with an age ranging from 14 to 60 years (mean age 36 years old), 50 males and 50 females, were selected at random from a private radiology department in Bilbao. The radiographs were obtained directly from digital radiological technology and collected during the year 2006. The gender and age distribution of the patients are shown in Table 1.
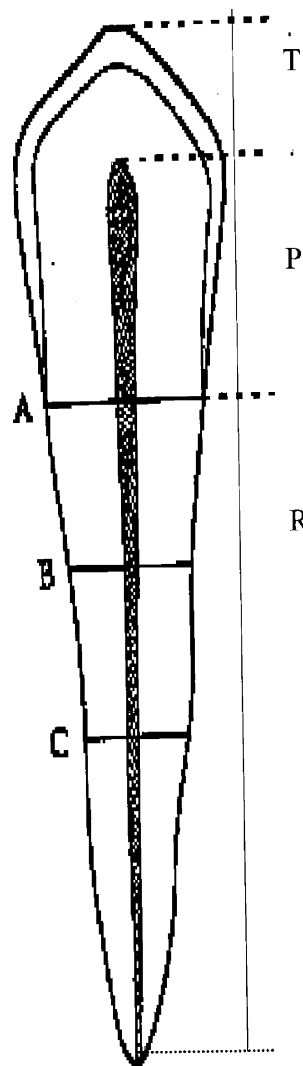
Although the original method of Kvaal et al. [15] included the analysis of six teeth (three maxillary and three mandibular teeth), it was not possible to study the maxillary teeth in the present research due to the fact that the digital radiographic images did not meet quality criteria, mainly because of overlap adjacent tissues and the lack of sharpness of the images. These limitations led to a reduction of this research to analyse three mandibular teeth (lateral incisors, canines and first premolars) and the left or right tooth was selected depending on the sharpness of the images. Impacted or rotated teeth and teeth with treatment or pathological processes that could interfere with the appropriate assessment of dental radiological images were excluded.

On all 100 digital panoramic radiographs, length and width measurements of teeth and dental pulp cavities were carried out according to the method of Kvaal et al. [15] under blinded conditions to evaluate the reproducibility of this technique (Fig. 1): maximum tooth length (T), the maximum pulp length (P), root length on the mesial surface from the enamel–cementum junction (ECJ) to the root apex (R) and the root and tooth width both at the ECJ (level A),

Table 1 Age and gender distribution of the population studied

Age (years)	Males	Females	Total
0–20	10	10	20
21–30	10	10	20
31–40	10	10	20
41–50	10	10	20
51–60	10	10	20
Total	50	50	100

Fig. 1 Diagram showing the measurements made on the radiographs according to Kvaal et al. (1995) [15]: *T* maximum tooth length, *R* root length on the mesial surface, *P* maximum pulp length; *A* root and pulp width at enamel–cementum junction (ECJ), *B* root and pulp width midway between measurements levels A and C; *C* root and pulp width midway between apex and ECJ

free software program permits not only to view and manipulate digital X-rays but also to obtain the quantification of relative distance in number of pixels between two different reference points after defining their relative position in X and Y axis on the digital image.

All measurements were performed by a single observer. The reproducibility of the method was checked by repeating the measurements by the same observer on ten randomly selected panoramic radiographs 4 weeks after the first evaluation.

Statistical analysis was performed by means of SPSS program (13.0 version; SPSS Inc. 1989–2004). Pearson correlation coefficients between chronological age and the ratios were calculated. Intraobserver correlation was assessed by intraclass correlation coefficient (ICC).

Results

Intraclass correlation coefficient (ICC) showed values higher than 0.75 for canines [33/43], for first premolars [34/44] and for the three mandibular teeth valued altogether. These results suggested an excellent intraobserver correlation. However, the revaluation carried out on lateral incisor teeth [32/42] showed lower correlation values.

Correlation coefficients between age and the calculated ratios and their mean values from each tooth calculated according to the method of Kvaal et al. [15] are specified in Table 2. In general, the Pearson correlation coefficients obtained in this study based on length and width measure-

at the midroot level (level C) and at midpoint between the ECJ and midroot level (level B).

To compensate for differences in magnification and angulation on the panoramic radiographs, the following ratios were calculated: pulp/root length (*P*), pulp/tooth length (*R*) and pulp/root width at the three levels (A, B and C).

Correlation coefficients between age and the calculated ratios and their mean values from each tooth were calculated according to the method of Kvaal et al. [15]. Then, according to the study of Meinl et al. [18], the regression formulae reported by Kvaal et al. [15] and Paewinsky et al. [17] were applied to values obtained from our sample for age estimation. Following this study, the mean difference between real age and estimated age was calculated after applying the regression formulae reported by both authors [15, 17].

Direct digital orthopantomograms, originally obtained in DICOM format, were saved as JPG files (2,370 × 1,770 pixels) and were analysed using the Image-J program. This

Table 2 Pearson correlation coefficients between chronological age and ratios of measurements from the digital orthopantomograms and the mean of the ratios from each tooth ($n=100$)

Ratios	Tooth 32/42	Tooth 33/43	Tooth 34/44
P	−0.177	−0.010	−0.001
R	0.183	0.022	0.179
A	−0.080	−0.052	−0.421[a]
B	−0.134	−0.310[a]	−0.478[a]
C	−0.088	−0.311[a]	−0.302[a]
M	−0.124	−0.208[b]	−0.385[a]
W	−0.126	−0.350[a]	−0.467[a]
L	−0.060	0.002	0.076
W−L	−0.016	−0.195	−0.371[a]

[a] Two-tailed significance test ($p<0.01$)
[b] Two-tailed significance test ($p<0.05$)
P Ratio between length of pulp and root, *R* ratio between length of pulp and tooth, *A* ratio between width of pulp and root at enamel–cementum junction (level A), *B* ratio between width of pulp and root at midpoint between level A and C (level B), *C* ratio between width of pulp and root at midroot level (level C), *M* mean value of all ratios, *W* mean value of width ratios of levels B and C, *L* mean value of the length ratios *P* and *R*, *W−L*, difference between *W* and *L*.

ments on digital orthopantomograms were significantly lower than the results originally reported by Kvaal et al. [15] for mandibular teeth. The best correlation was observed for ratio B (ratio between width of pulp and root at level B) from the first premolar teeth [34/44] in both gender samples (−0.478); lower than the value reported by the method of Kvaal et al. [15] for this ratio (−0.62).

As regards to the formulae reported by Kvaal et al. [15], the mean differences between real age and estimated age, both for the ratio of single teeth and for the equation for three mandibular teeth, after applying the regression formulae reported by these authors are shown in Table 3. These results showed a negative value and demonstrate that age calculated by means of these formulae was overestimated.

Likewise, the mean difference between real and estimated age for the three types of evaluated teeth after applying dental age equations published by Paewinsky et al. [17], showed negative results and, therefore, these values showed a consistent overestimation These results are displayed in Table 4.

Just like in the study by Meinl et al. [18], the mean differences between real age and estimated age based on specific equations reported by Paewinsky et al. [17] and developed for the width pulp and root ratios at the three levels evaluated (level A, B and C) also reflected values quite different from the real age and very similar to those obtained in the sample of Meinl et al. These results can be observed in Table 5.

Discussion

The main purpose of this research was to analyse both the validity of original method for dental age calculation published by Kvaal et al. [15] and the method modified by Paewinsky et al. [17] in 2005 on digital orthopantomograms collected from a Spanish population sample.

Significant differences were observed between results reported by Kvaal et al. [15] and Paewinsky et al. [17] and those obtained in the present study based on direct digital radiology.

Previous works with the aim to evaluate the reproducibility of the method developed by Kvaal et al. [15] showed contradictory results. Bosmans et al. [16] found no

significant differences between chronological age and estimated age calculated from orthopantomograms when all six teeth or all three mandibular teeth were included. These authors used orthopantomograms instead of apical radiographs as originally described, despite the fact that they pointed out inherent technical limitations of using panoramic radiographs. Factors like the distortion of teeth in the orthopantomograms as a result of the patient being inadequately positioned in relation to the machine and the unsharpness of the images may affect the precision of the measurements.

In this respect, the study of Paewinsky et al. [17] revealed that width ratios at different root levels showed significant correlations with chronological age. Although this investigation consisted in the application of the method of Kvaal et al. [15] on panoramic radiographs, results were calculated according to specific equations developed by these same authors for their sample.

In clear contrast to these studies, some previous articles showed absolutely different results from those mentioned above. Prapanpoch et al. [10] found no significant correlation between the age of an individual and the width and height of the pulp chamber evaluated on dental radiographs, and suggested that these measurements should not be used as a reliable method of age determination. Meinl et al. [18] evaluated whether the regression formulae reported by Kvaal et al. [15] and Paewinsky et al. [18] could lead to similar results when applied to digital OPGs collected from Austrian juveniles (age ranging from 13 to 24 years old). The age estimations were far from the real chronological age, so these results clearly proved the inapplicability of these regression equations on their sample. The use of the formulae reported by Kvaal et al. [15] resulted in a constant underestimation with a mean difference between chronological and estimated age of 31.44 years for the ratio of single teeth, 47.10 years for three mandibular teeth and 46.04 years for the equation that included all six teeth. However, those published by Paewinsky et al. [17] led to a consistent overestimation and showed a mean difference between chronological and estimated age of −20.88 years when the ratio between the width of pulp and root at level A was employed, −22.01 years using the equation at root level B and −31.92 years for the ratio at root level C.

Nevertheless, conclusions of both researches are in accordance with the results obtained from the measure-

Table 3 Statistical measures of difference between real age and estimated age based on regression equation reported by Kvaal et al. (1995) [15]

Tooth	Mean	Standard deviation	Median	Minimum	Maximum
32/42	−5.915491	14.9511873	−5.540654	−40.8580	34.9405
33/43	−6.760291	13.9634153	−8.977023	−29.5919	22.6276
34/44	−2.078521	12.5326159	−4.031539	−30.4604	33.0225
3 Mandibular teeth	−4.095060	14.8034270	−4.550278	−45.7453	36.5911

Table 4 Statistical measures of difference between real age and estimated age based on regression equation reported by Paewinsky et al. (2005) [17] for each tooth

Tooth	Mean	Standard deviation	Median	Minimum	Maximum
32/42	−33.471288	20.9218428	−33.532058	−84.2534	28.4655
33/43	−19.767661	14.7150299	−19.583001	−52.6067	17.3136
34/44	−23.716488	15.2969869	−23.231462	−73.1382	17.2434

ments performed on direct digital radiology carried out in the present study. Age estimations resulted from the application of both formulae on our series showed values quite different from chronological ages, so the dental variables analysed cannot be considered as appropriate parameters to obtain a reliable age calculation.

In the last decades, digital systems have improved considerably and nowadays are considered an acceptable and useful technology for clinical use in dentistry [24]. Bosman et al. [16] and Paewinsky et al. [17] described the use of indirect digital radiology. Both studies emphasized that the accuracy of this age-estimation method mainly depended on the precision of measurements performed on digital images and the quality and sharpness of the panoramic radiographs. Paewinsky et al. [17] suggested that the interobserver differences may be due to interpretation differences when it is necessary to define reference points for carrying out the measurements on the radiological image.

López Nicolás et al. [25] used a computerized image analysis system (Kontron IBAS-I) to study 19 morphological dental parameters and obtained much more accurate measurements of dental surfaces and distances analysed; therefore, this technique increased the precision of age prediction. Drusini et al. [26] reported that age estimations based on measurements performed with a computerized densitometric analyser (Kontron IBAS 2000) showed similar results to those obtained using the manual system when they studied root dentine transparency.

Kollveit et al. [27] found that the manual measurements of morphological parameters in dental radiographs showed a better correlation with chronological age than did the computer-assisted ones. Schulze et al. [28] evaluated the precision and accuracy of digital measurements in digital panoramic radiography and pointed out that the digital method evaluated may be considered as adequate for clinical applications, although it would be necessary to bear in mind the inherent errors due to the use of panoramic radiography when a reliable quantification of distances was required.

In our sample, the images analysed were obtained from direct digital radiological techniques. When using digital radiology, some previous authors pointed out the difficulties in identifying the reference points on digital images as viewed on the monitor screen, and therefore, defining the relative distance between two different points whose quantification in pixels is needed. This technical limitation might have reduced the precision of the measurements used for age estimation based on application of the regression formulae reported by Kvaal et al. [15] and Paewinsky et al. [17], and could explain the significantly lower results obtained on our sample than those published by previous authors.

Finally, based on the results of this study, it can be concluded that it is not possible to confirm the reproducibility of the original method reported by Kvaal et al. [15] on direct digital orthopantomograms. The parameters analysed on our digital images showed a low correlation with the chronological age, so these results suggest that this method could not be considered as a useful and reliable indicator for age estimation. In the same way, age estimation based on regression formulae reported by Kvaal et al. [15] and Paewinsky et al. [17] applied on our direct digital orthopantomograms sample showed values far from the real age. These results suggest that age prediction using regression equations tested in this study should not be considered as an appropriate age-estimation technique, and therefore, their application should not be recommended on direct digital OPGs.

Table 5 Statistical measures of difference between real age and estimated age based on specific equations for width pulp and root ratios at level A, B and C reported by Paewinsky et al. (2005) [17]

Level	Mean	Standard deviation	Median	Minimum	Maximum
A	−26.513830	18.3384503	−25.531945	−79.1169	24.0224
B	−28.949280	19.6570309	−28.905129	−92.2356	21.6944
C	−31.009704	19.6445208	−31.823645	−84.2534	28.4655

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