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TECHNICAL NOTE

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On the Applicability of Secondary Dentin Formation to Radiological Age Estimation in Young Adults

ABSTRACT: The literature provides linear regression formulas for dental age estimation that is based on radiological two-dimensional measurements of the pulp size. The aim of the present study was to explore whether the previously presented regression formulas could lead to statistically sound results and to appropriate repeatability when applied to young individuals. Orthopantomograms (OPGs) of 44 Austrian individuals, aged between 13 and 24 years, were selected at random. In accordance with the reported method, six teeth on each OPG were chosen to carry out the measurements. Statistical analysis was performed in order to assess the difference between the estimated and the true chronological age.The regression formulas reported by Kvaal et al. (1995) led to a consistent underestimation; the regression formulas reported by Paewinsky et al. (2005) resulted in a constant overestimation of age. The statistical analysis of intraobserver and interobserver variation revealed a variation width below 2%, respectively.

KEYWORDS: forensic science, forensic odontology, dental age estimation, secondary dentin, orthopantomogram

The accuracy and precision of dental age estimation do depend on the age of the examined individual. Best results can be achieved when the individual growth is fast and there are a number of teeth in development. Dental age estimation of individuals who are older than 14 years of age constitutes a great challenge. All permanent teeth, except the third molars (if present), have finished their development in this age group (1).

Up to now, a multiplicity of methods have been applied on this problem. Best results were provided by the analysis of tooth cementum annulations (2) as well as the determination of the degree of aspartic acid racemization, (3,4) which can be correlated with chronological age.

These methods are invasive; hence, they cannot be used in living individuals and in cases where it is not acceptable to extract teeth for ethical, cultural, or religious reasons. Kvaal et al. (5) presented a method, that is based on radiological measurements and does not require extraction. The authors were able to demonstrate the negative correlation of a composition of different rations of the two-dimensional pulp size, which depends on the amount of secondary dentin, and chronological age.

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Secondary dentin formation is initiated after dentinogenesis (6). The odontoblasts lining the pulp cavity continuously form layers of secondary dentin deposited along the wall of the dental pulp chamber. In 1925, Bodecker (7) established that the apposition of secondary dentin was correlated to age. Secondary dentin is built up throughout life and laid down on the pulpal surface of the primary dentin. This process leads to a continuous decrease in the size of the pulp cavity (8–14). As a consequence of this deposition, there is a tendency towards pulp obliteration. The pattern for the secondary dentin formation varies among the different tooth types. In maxillary anterior teeth, the greatest dentin deposition occurs on the palatal wall of the pulp chamber with subsequent deposition in the incisal tip and the remaining walls. In molars, the greatest dentin deposition is on the floor of the pulp chamber; lesser amounts are deposited on the occlusal and lateral walls (13,15,16).

Secondary dentin deposition was introduced for age estimation in the method by Gustafson (10), where secondary dentin is one parameter in addition to attrition, periodontal recession, cementum apposition, apical translucency, and external root resorption.

In 1993, Drusini published a study that confirmed the negative correlation between the Coronal Index after Ikeda et al. (17) and the actual age of individuals using soft X-ray photos of intact adult teeth (18). The author was able to show that the correlation coefficients range from -0.73 (female molars) to -0.89 (female premolars).

The method by Kvaal et al. (5) represents an independent procedure to examine the relationship between pulpal size and chronological age. Based on the investigation of periapical radiographs, from individuals older than 20 years of age, it was shown that Pearson's correlation coefficient between age and the different size ratios for each type of tooth was significant. When six teeth of each individual were included, a coefficient of determination (r^2) for the estimation of 0.76 was calculated.

Paewinsky et al. (19) verified the applicability of this method to orthopantomograms (OPGs). They used a sample consisting of 168 individuals between the ages of 14 and 81 years. A significant negative correlation between the width ratios of the pulp cavity and chronological age was shown. The authors presented linear regression formulas, although the same study found a higher coefficient of determination in upper lateral incisors when a cubic or logistic regression model was constructed.

The objective of the present study was to apply Kvaal's method to digital OPGs of Austrian juveniles and to evaluate whether the linear regression formulas of Kvaal et al. (5) and Paewinsky et al. (19) could yield feasible and reproducible results, which would legitimate their use in forensic age estimation.

Material and Methods

OPGs from 44 individuals with known age and gender were selected for the study (mean age: 19.2 years; 18 males; 26 females; Table 1). OPGs were taken in the period between 2002 and 2004 at the Bernhard Gottlieb University School of Dentistry, Vienna. Individuals with foreign surnames were avoided in order to obtain a homogenous Austrian sample.

OPGs showing pathological processes in the apical bone, rotated, or overlying teeth were not chosen. The examined teeth had to be in normal functional occlusion and free from any manifestations of traumatic insults. Furthermore, teeth with fillings, crowns, and carious lesions were excluded from the evaluation.

From each OPG, three digital pictures with different exposure times were made to compensate for the unequal brightness of the radiographs.

The measurements were carried out on six teeth as described previously (5): one maxillary central incisor (tooth 11 or 21), one maxillary lateral incisor (tooth 12 or 22), one maxillary second premolar (tooth 15 or 25), one mandibular lateral incisor (tooth 32 or 42), one mandibular canine (tooth 33 or 43), and one mandibular first premolar (tooth 34 or 44). Owing to the fact that Kvaal et al. (5) did not find significant differences between teeth from the left and the right side of the jaw, the teeth were selected from the left or the right side, depending on the sharpness and quality of the OPG in the respective region.

The maximum tooth length, the pulp length, the root length on the mesial surface from the enamel–cementum junction (ECJ) to the root apex, and the root and pulp width at the levels A, B, and C

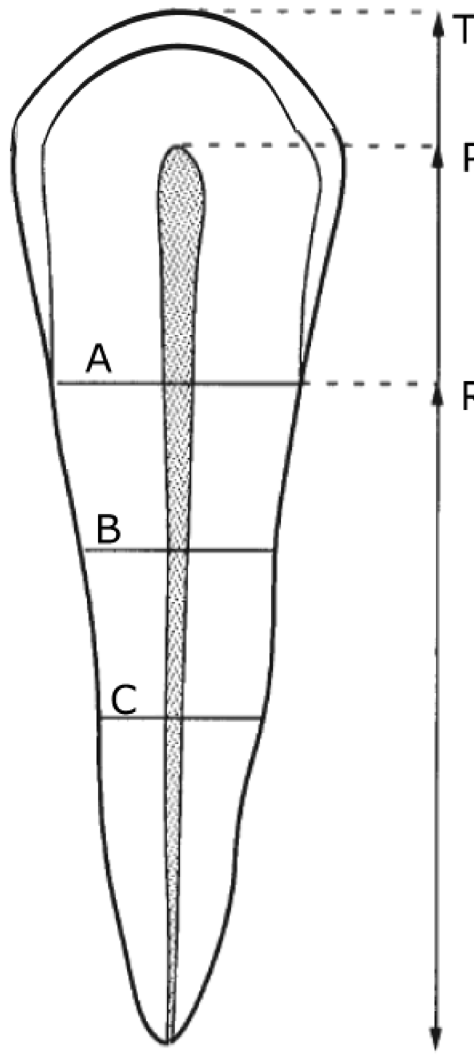

FIG. 1—*Diagram showing the measurements made according to Kvaal et al. (5): maximum tooth length (T); root length on the mesial surface (R); maximum pulp length (P); root and pulp width at the enamel–cementum junction (ECJ) (A); root and pulp width midway between measurements levels A and C (B); root and pulp width midway between apex and ECJ (C).*

were measured according to Kvaal et al. (5) (Fig. 1) using Adobe Photoshop 6.0® (Adobe Systems Incorporated, San Jose, CA). The following ratios were calculated: the ratio between the length of pulp and root, the ratio between the length of tooth and root, the ratio between the length of pulp and tooth, the ratio between the width of pulp and root at ECJ (level A), the ratio between the width of pulp and root at midpoint between levels C and A (level B), and the ratio between the width of pulp and root at the midroot level (level C).

All measurements were made by the same observer (A.M.). Repetitive measurements were performed under blinded conditions after several weeks to evaluate the intraobserver variation. Interobserver variation was checked by recruiting a second observer (C.F.), who passed an initial training and measured the same OPGs like the first observer.

The previously published regression formulas of Kvaal et al. (5) and Paewinsky et al. (19) were used for age estimation.

Statistical analysis was performed using SAS 9.1 for Windows (SAS statistical software, SAS Institute, Cary, NC) in order to assess the difference between the estimated and the true chronological age.

TABLE 1—*Age distribution of the individuals studied.*

Age (Years)	No. of Orthopantomograms (OPGs)
13	2
14	3
15	4
16	7
17	3
18	1
19	3
20	4
21	5
22	4
23	5
24	3
Total	44

TABLE 2—*Mean estimated age and mean difference between chronological and estimated age in years based on regression formulas reported by Kvaal et al. (5).*

	N	Mean	Standard Deviation	Minimum	Maximum
Estimated age—single teeth	44	– 12.06	13.91	– 74.48	16.15
Difference between chronological and estimated age—single teeth	44	31.44	13.45	8.01	89.78
Estimated age—three maxillary teeth	44	– 18.84	7.27	– 34.47	– 0.27
Difference between chronological and estimated age—three maxillary teeth	44	38.21	5.98	24.43	49.77
Estimated age—three mandibular teeth	44	– 27.72	8.84	– 48.78	– 8.07
Difference between chronological and estimated age—three mandibular teeth	44	47.10	7.58	32.23	65.17
Estimated age—six teeth from both jaws	44	– 26.67	7.39	– 41.48	– 6.38
Difference between chronological and estimated age—six teeth from both jaws	44	46.04	5.84	30.54	56.23

Estimated ages were calculated using the formulas reported by Kvaal et al. (5).

Results

A random sample of ten OPGs was selected and repetitive measurements by the same observer on the ten OPGs were performed. The variation width due to two measurements was below 2%. The intraobserver variation was small and is negligible. Most variation is due to interindividual difference and type of teeth.

Additionally, a second observer made the same measurements on the 10 selected OPGs. The variation width of the measurements due to two different observers was below 2%. The interobserver variation was small and is negligible. Most variation is due to interindividual difference and type of teeth.

SAS 9.1 (PROC VARCOMP) was used to estimate variance components.

Tables 2 and 3 detail the results of the calculations carried out using the formulas reported by Kvaal et al. (5) and Paewinsky et al. (19), respectively.

The results were expressed as mean estimated age with standard deviation, minimum and maximum as well as mean difference between the chronological and estimated age with standard deviation, minimum, and maximum.

A positive result (of the mean difference between the chronological and estimated age) indicates the number of years that the age was underestimated.

A negative result (of the mean difference between the chronological and estimated age) indicates the number of years that the age was overestimated.

Age estimation performed with the formulas reported by Kvaal et al. (5) for the ratio of single teeth resulted in a mean underestimation of 31.44 years. If age estimation was carried out with the help of the equation for three maxillary teeth, the chronological age was underestimated approximately 38.21 years. The use of the formula for three mandibular teeth led to a mean underestimation of 47.10 years. If the measurements of all six teeth from both jaws were included in age estimation, the calculation resulted in a mean underestimation of 46.04 years.

The regression formulas reported by Paewinsky et al. (19), which use the ratio between the width of the pulp and the root at level A, yielded a mean overestimation of the real chronological age of 20.88 years. If the age was estimated with the equations that use the ratios at root level B, the overestimation became even higher, namely 22.01 years. The application of the calculation formulas, which uses the ratio between the width of the pulp and the root at level C, resulted in a mean overestimation of the chronological age of 31.92 years.

Discussion

Secondary dentin apposition occurs throughout life and leads to a reduction in the size of the pulp cavity. Presently, there is no evidence that this process occurs in a linear manner, or that every age group needs the same time span to present itself with a defined amount of secondary dentin. Although linear regression is widely used in forensics to provide the estimate of a measurement, for instance the age at death or the living stature, it should be kept in mind that human growth is a nonlinear process (20). Tooth development in its entirety underlies demonstrable chronological (21–23), environmental, hereditary (24,25), and sexual differences (26). Our results clearly indicate the inapplicability of the regression equations of Kvaal et al. (5) and Paewinsky et al. (19) on a young sample like ours. The age estimations were far away from the real chronological age. The use of the formulas reported by Paewinsky et al. (19) resulted in a consistent overestimation; the equations of Kvaal et al. (5) led to a constant underestimation. Kvaal and colleagues, who developed the original regression formulas for age estimation by means of secondary dentin, did this using a relative small, cross-sectional sample representing a large age span. It could not be ruled out that any possible influences of chronological or sexual differences were abolished by using a small sample size. Paewinsky et al. (19), who evaluated the applicability of Kvaal's method on OPGs, showed an increase of the coefficient of determination (r^2) of the maxillary lateral incisors when nonlinear regression models were used. The authors did not further explain why it was decided to present linear regression equations for the description of the correlation between chronological age and the width ratios of the pulp cavity. This finding is

TABLE 3—*Mean estimated age and mean difference between chronological and estimated age in years based on regression formulas reported by Paewinsky et al. (19).*

	N	Mean	Standard Deviation	Minimum	Maximum
Estimated age, width ratio at root level A	44	40.25	27.05	– 207.05	83.37
Difference between chronological and estimated age, width ratio at root level A	44	– 20.88	26.70	– 60.40	222.35
Estimated age, width ratio at root level B	44	41.39	17.57	– 7.80	96.88
Difference between chronological and estimated age, width ratio at root level B	44	– 22.01	16.39	– 72.27	20.83
Estimated age, width ratio at root level C	44	51.29	18.08	– 24.86	107.65
Difference between chronological and estimated age, width ratio at root level C	44	– 31.92	17.15	– 84.49	41.25

Estimated ages were calculated using the formulas reported by Paewinsky et al. (19).

in accordance with the results of Woods et al. (27), who concluded that the timing of secondary dentin formation is more closely fit by a curved than a straight line. Therefore, it could be possible that the formation rate of secondary dentin does underlie chronological differences, which, in turn, would imply the need for further research to provide sufficient data for age estimation.

Another study, which tested Kvaal's method on OPGs (28), also used a rather small-sized sample and found quite similar results when compared with the original publication. Kvaal et al. (5) and Bosmans et al. (28) expressed their results as a "standard error of the estimate" (SEE). Owing to the fact that this statistical value does not reflect the error in single cases, but only when applied a great number of times to normally distributed data, one should be aware of misinterpreting the results. As properly discussed in a paper by Snow and Luke (29), the authors faced the problem of estimating the stature of a female by constructing confidence intervals. In this approach, the confidence interval is about twice as large as the published value of the SEE. We do not support the application of the presented regression formulas for age estimation of living persons according to Kvaal and coworkers like others do (19). In our opinion, it should be verified that the presented equations do have comparable accuracy when applied to different age groups or different populations.

From the results of this study, it can be concluded that the regression equations reported in Paewinsky et al. (19) and Kvaal et al. (5) cannot be applied to a young sample like ours (13.03–24.61 years). The use of these formulas led to age estimations that are far away from the real chronological age. However, only limited conclusions can be drawn from a single study. Further research is required to assess whether secondary dentin deposition does underlie chronological or regional differences. The application of the regression formulas reported by Kvaal et al. (5) and Paewinsky et al. (19) to the age estimation of living people should only be performed when bearing in mind the limitations of this method.

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