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PAPER

ODONTOLOGY

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Orthodontic Treatment: Real Risk for Dental Age Estimation in Adults?

ABSTRACT: Dental age estimation becomes a challenge once the root formation is concluded. In living adults, one dental age indicator is the formation of secondary dentine, also associated with orthodontic treatment as well as root shortening. The aim of this study was to establish whether these secondary effects of orthodontic treatment could generate a statistically significant difference in dental age estimations when using Kvaal's method. The study sample included 34 pairs of pre- and postorthodontic panoramic radiographs, from different individuals with exactly the same age and sex distribution. Females 65%, median age 17.5 years, and males 35%, median age 22.5 years, were included. After data collection, dental age was estimated per tooth using formulae previously published. The risk of obtaining over-estimation of age was calculated. (RR = 1.007). The changes caused by orthodontic treatment do not have any significant effect on age estimation when Kvaal et al.'s method is applied on panoramic radiographs.

KEYWORDS: forensic science, dental age estimation, secondary dentin formation, adults, orthodontic treatment, root resorption

The analysis of teeth for age estimation has been scientifically reported since the early 1800's (1). Methods based on tooth formation in juveniles have shown high reliability (2–4). Once the root formation has finished (generally at the age of 14 years, excluding the third molar) (5), dental age estimation becomes a challenge, partly as a result greater variability in the development of third molar (6). The most reported noninvasive methods for dental age estimation are based on the formation of secondary dentine and the decrease in pulp chamber dimensions. These features are measurable in periapical radiographs (7,8), panoramic radiographs (9,10), micro-focus-computed tomographs (11), computed tomographs (12), and cone beam-computed tomographs (13). These methods proposed different formulae to be used in specific populations. An important characteristic of these studies is that in their analysis, they only included totally sound teeth.

It is well known that orthodontic forces generate irreversible changes on tooth structure, such as root shortening (14) and secondary dentine formation (15). These two biological changes in tooth structure may directly affect the features used for dental age estimation in adults, especially the method proposed by Kvaal et al (7). This method is based on the measurement of tooth/pulp length, root canal, and root width at different levels, followed by ratio calculations and linear regression analysis for dental age estimation. It would be expected that with the mentioned changes, secondary to orthodontic treatment, age estimation in participants' postorthodontic treatment would show a higher estimation error and higher over-estimation, compared to that of nontreated participants. If that were to be the case, it would be necessary to develop specific standards for orthodontically treated participants, not only for the Kvaal et al.'s method (7), but for any method based on secondary dentine formation and the variation of pulp/tooth dimensions with age. In the event of the results being different to the expected, it would mean that the Kvaal's method could be used despite the evidence of anatomic changes related to orthodontic treatment. The aim of this study was to establish whether orthodontic treatment would generate changes in dental age estimations at the tooth level when the Kvaal et al.'s (7) method is applied per individual tooth.

Materials and Methods

Ethics approval was obtained from the Human Research Ethics Committee of The University of Western Australia (Ref: RA/4/1/6797) prior to commencement.

Panoramic Radiographs, Orthodontics, and Dental Age Estimation

Initially, the Kvaal et al.'s (7) method was proposed to be used on periapical radiographs. However, recent studies have also applied this method on panoramic radiographs (9,10). Panoramic radiographs have more image distortion than periapical radiographs, but it has been reported that when root resorption associated with orthodontic treatment is measured on panoramic radiographs, it is significantly higher than when measured on periapical radiographs (16). This study presents the first

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study to see the effect of orthodontic-related changes on age estimation, and therefore, no power calculation was achievable. However, based on the size of previous research assessing pulpal changes associated with orthodontic treatment (17), a sample size in a similar range was deemed appropriate.

Sample Selection

The study cohort consisted of a series of participants who consecutively presented for orthodontic treatment at a private specialist orthodontic clinic (SV). The initial sample for this study was 91 participants from a Western Australia population, who had a pre- and post-treatment panoramic radiograph. From the initial sample, a total of 34 pre- and 34 postorthodontic treatment panoramic radiographs were selected, resulting in a final sample of 34 pairs of panoramic radiographs (n = 68). Sample size reduction corresponded to the need of age and sex matching between the different individuals in each pair, one of them without orthodontic treatment and the other one with a concluded treatment. Female 65% (n = 22, for both groups), age range 15–50 years old, median 17.5. Male 35% (n = 12, for both groups) age range 16–37 years old, median 22.5. The minimum length treatment was 1.2 years, the maximum 3.6 years, and median 2.1 years.

Intra-observer calibration was performed to test the repeatability and reliability of the main observer (TM). All the measurements were completed by a single observer (TM), and the analysis was completed with Image J software (version 1.48 19 April 2014—National Institute of Health, Bethesda, Maryland). All data were collated using Excel (version 2013 Microsoft, Redmond, WA), and statistical analysis was completed using the program 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/).

Inclusion Criteria

All participants who had a recorded panoramic radiograph of high quality with respect to factors of image brightness, contrast, and sharpness were included. In addition, all teeth included in the analysis were clinically sound with completed root formation and in functional occlusion.

Exclusion Criteria

Radiographs with observable failings (image distortion, poor contrast, superposition of tooth structure, or improper positioning) were excluded. Teeth with pulpal or periodontal pathologies and endodontic treatment and/or restorations, incomplete root formation, dilacerations, or rotations were excluded. Teeth with developmental abnormalities in size, shape and tooth structure, or large areas of enamel overlap between neighboring teeth were also excluded in this study.

Teeth Analyzed

The purpose of this study was to assess the biologic variation effects of orthodontic treatment at the tooth level. Therefore, the tooth-by-tooth formulae for the Kvaal method were applied (10,18).

Following the parameters as provided by Kvaal et al. (7), three upper and three lower single-rooted teeth were included: one maxillary central incisor (with Federation Dentaire Internationale (FDI) notation 11 or 21), one maxillary lateral incisors (FDI notation 12 or 22), and one maxillary second premolar (FDI notation 15 or 25), mandibular lateral incisors (FDI notation 32 or 42), one mandibular canine tooth (FDI notation 33 or 43), and one first premolar teeth (FDI notation 34 or 44). In accordance with the study by Karkhanis et al. (10), panoramic radiographs that presented any combination of the required teeth were included. There is no evidence claiming that the accuracy of the results had varied depending on the use of left or right teeth. Consequently, in the absence of one of the teeth the contralateral was used, as long as they met the inclusion criteria.

Measurements

All the panoramic radiographs were obtained in digital format, and the measurements were performed using the software Image J software (developed by the National Institute of Health, USA). According to Kvaal et al. (7), the following measurements were recorded: tooth, pulp, and root length, as well as the pulp and tooth width at three different levels: A (cemento–enamel junction on the mesial surface of the roots), B (midpoint between the points A and C), and C (midpoint between the cemento–enamel junction and root apex). All the measurements were recorded before the sample was categorized into two groups: group *pre* for panoramic radiographs obtained from nontreated participants and group *post* for treated participants, to avoid observation bias. Following the recording of measurements, a series of length and width ratios were calculated: tooth/root length; pulp/tooth length, and root width/ pulp width ratio at levels A, B, and C. These ratio calculations were proposed by Kvaal et al. (7) as it reduces the effect of magnification and angulation inherent in most radiographs (7,19). The different mean values from the ratios were used to obtain age estimation predictors. (M: mean value all five ratios, W: mean value of width ratios at level B and C, L: mean value of length ratios P and R, W-L: difference between W-L) (7). The predictors M and W-L were later used to estimate the age of all the participants.

Five randomly selected panoramic radiographs from the final study sample were used to estimate intra-observer calibration. These panoramic radiographs were measured on five different days with at least one-day interval. With the aim to avoid the recall of the measurements and landmarks, five new panoramic radiographs were also measured on each occasion. Three estimates of precision were calculated to quantify intra-observer measurement error and precision: the technical error of measurement (TEM), relative technical error of measurement (rTEM), and coefficient of reliability (20).

Statistical Analysis

After the completion of the measurements, dental age estimations were calculated using the age estimation equations from individual teeth. In participants aged 30 years or older, the equations used were those reported by Karkhanis et al. (10) And for participants 29 years or younger, the used equations were obtained from a different group of nontreated participants (n = 74 aged 12–28 years). Both sets of equations were obtained from a Western Australian population.

Results

For the estimation of intra-observer error, the obtained values were within acceptable standards for all the measurements. The

TABLE 1—*Comparison of over- and under-estimates obtained per tooth before and after orthodontic treatment. And reported standard estimation error SEE per individual tooth, for participants younger than 30 years (SEE ± years (<30 years)) and over 30 years of age (SEE ± years (>30 years)).*

	Tooth	11/21	12/22	15/25	32/42	33/43	34/44
Over-estimation	Pretreatment	39% (n = 13)	50% (n = 16)	52% (n = 17)	47% (n = 16)	54% (n = 13)	47% (n = 15)
	Post-treatment	38% (n = 13)	45% (n = 15)	48% (n = 16)	44% (n = 15)	61% (n = 20)	52% (n = 15)
Under-Estimation	Pretreatment	61% (n = 20)	50% (n = 16)	48% (n = 16)	53% (n = 18)	46% (n = 11)	53% (n = 17)
	Post-treatment	62% (n = 21)	55% (n = 18)	52% (n = 17)	56% (n = 19)	39% (n = 13)	48% (n = 14)
SEE ± years (<30 years)		4.344	4.258	4.536	4.465	3.708	3.709
SEE ± years (>30 years)		9.367	9.648	9.525	10.222	10.903	10.534

intra-observer results were as follows: TEM < 1.0 (0.92), rTEM < 5% (2.99%), and $R > 0.75$ (0.95).

After age estimation per individual tooth, there were a total of 189 age estimates for group *pre* and 196 estimates for group *post*. The age estimates obtained were then compared between participants with exactly the same age and sex in group *pre* and group *post*. In this way, 183 pairs of age estimates were obtained and compared 1 to 1.

For 79% (n = 145) of the total observations, the fluctuation of the data was the same, regardless whether there was over- or under-estimation of the age. In terms of over-estimation, in 47% of these observations, the over-estimation was higher after the orthodontic treatment.

The fluctuation of the data with regard to the chronological age of the individual was analyzed per individual tooth (Table 1), showing that there was no significant difference in the percentages of over- and under-estimation between both groups (Pearson's correlation coefficient $r = 0.78$).

Although the fluctuation of the data was the same in both groups, pre and post, there was a clear difference between the ages. It was observed that before the age of 25, the large majority of results showed a slight over-estimation of age which did not exceed the reported SEE. In contrast, the majority of age estimation data obtained from older participants showed under-estimation of the age that notably exceeded the reported SEE.

A contingency table (Table 2) was developed to test whether the secondary effects of orthodontic treatment were a real *risk* to produce over-estimation of the age when the Kvaal et al.'s method is applied. The relative risk calculated was RR = 1.0071 (low risk)

Discussion

The reliability of dental age estimation in adults, based on the formation of secondary dentine, has shown superior accuracy to other methods, based on the analysis of other age-related dental or osseous changes (8,10). However, teeth are subjected to different changes through life related to pathology as well as biological, chemical, or mechanical trauma or dental procedures.

TABLE 2—*Contingency table to estimate whether orthodontic treatment was a causal of over-estimation, when the Kvaal et al.'s method is used to age estimation.*

Orthodontic treatment	Over-estimation	Under-estimation	Total
YES	48%	52%	n = 196
Post-treatment	n = 94	n = 102	
NO	48%	52%	n = 189
Pretreatment	n = 184	n = 99	
Total	n = 184	n = 201	n = 385

Incidence over-estimation group A = 47.9%. Incidence under-estimation group B = 47.6%. Relative risk of presenting over-estimation owed to orthodontic treatment secondary effects when Kvaal et al.'s method is used for dental age estimation: RR = 1.0071 (No or low risk).

It has been reported that orthodontic treatment causes mechanical trauma to the periodontal ligament and induces pulpal reactions (21). The most frequently reported side effect is external root resorption, a process characterized by the destruction of root structure (21), with the subsequent diminution of root length (mean reported value of 1.42 ± 0.44 mm) (22). Another side effect is the reduction in pulp chamber dimensions, owing to secondary dentine formation (15). With these changes, it was expected to obtain significant differences between group *pre* and *post*, with higher percentages of over-estimates of age in treated participants. The analysis of the obtained data facilitated the calculation of the potential risk of having over-estimation in participants after finishing the orthodontic treatment (Table 1). After calculating the incidence of over-estimation in groups *pre* and *post*, there was no evidence of association between over-estimation of age and orthodontic treatment (RR = 1.0071). However, it is necessary to mention that in this study none of the tested teeth showed signs of severe apical root resorption.

According to previous studies, it was found that maxillary teeth are more affected by root shortening due to orthodontic treatment, specially lateral and central incisors (23,24). In this study, they also presented the higher percentage of under-estimates of age for both groups, followed by the mandibular lateral incisor. In the case of under-estimation, it was observed in a higher percentage in lower canines for *group pre* and *group post*, 54% and 61%, respectively.

Previous studies using the Kvaal et al.'s method and her proposed formulae reported a constant under-estimation of age, from 18 to 20 years (19) up to 47.10 years (25). These studies did not use population-specific formulae. In this study, the formulae used were obtained from the same Western Australian population. There was a clear-cut line (24 years for both groups) where the estimates would notably exceed the reported SEE (1–5 years), having statistically significant under-estimates. It is necessary to determine in future studies whether this finding could be related to the fact that the apposition of secondary dentine does not occur in a linear manner through life (25), causing a larger decrease in pulp dimensions between 20 and 40 years of age, than between 40 and 60 years of age (26). A limiting factor to clearly examine this relation in the current study was the lack of individual over 40 years of age.

As the main objective of this study was to establish whether orthodontic treatment would generate changes in dental age estimation, and as each type of tooth is affected by different degrees of severity, in this study we used previously published formulae for dental age estimation for individual teeth rather than per set of teeth or per individual. The use of Kvaal et al.'s (7) individual teeth formulae to estimate dental age has been reported on extracted teeth (27). In the same way, there are other methods based on the assessment of a single tooth per individual to generate dental age estimation models with acceptable results in a forensic framework (5,7,13).

Conclusion

In our study, orthodontic treatment did not affect the final results when the Kvaal et al.'s method was used for dental age estimation. Although it has been previously established that, to use the pulp complex as a biomarker for general aging, the analyzed teeth have to fulfill the requirements of being in normal and functional occlusion, totally sound and free from dental procedures (7), the real effect of this conditions on methods based on the formation of secondary dentine, for dental age estimation, has not been tested. The results of our study allow forensic dentists to use the Kvaal et al.'s method in participants who have had previous orthodontic treatment, when there are no signs of severe apical root resorption.

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