Int J Legal Med (2012) 126:883–887
DOI 10.1007/s00414-012-0755-x

ORIGINAL ARTICLE

Human dental age estimation combining third molar(s) development and tooth morphological age predictors

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Received: 22 May 2012 / Accepted: 31 July 2012 / Published online: 12 August 2012

Abstract In the subadult age group, third molar development, as well as age-related morphological tooth information can be observed on panoramic radiographs. The aim of present study was to combine, in subadults, panoramic radiographic data based on developmental stages of third molar(s) and morphological measurements from permanent teeth, in order to evaluate its added age-predicting performances. In the age range between 15 and 23 years, 25 gender-specific radiographs were collected within each age category of 1 year. Third molar development was classified and registered according the 10-point staging and scoring technique proposed by Gleiser and Hunt (1955), modified by Köhler (1994). The Kvaal (1995) measuring technique was applied on the indicated teeth from the individuals' left side. Linear regression models with age as response and third molar-scored stages as explanatory variables were developed, and morphological measurements from permanent teeth were added. From the models, determination coefficients (R^2) and root-mean-square errors (RMSE) were calculated. Maximal-added age information was reported as a 6 % R^2 increase and a 0.10-year decrease of RMSE. Forensic dental age estimations on panoramic radiographic data in the subadult group (15–23 year) should only be based on third molar development.

Keywords Forensic science · Forensic odontology · Age determination by teeth · Third molars · Secondary dentine · Kvaal method

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Introduction

Dental age estimation performed in the subadult age group is mainly based on third molar(s) development observed in panoramic radiographs [1–10]. Additionally, these radiographs contain morphological age-related dental information. In fact, all permanent teeth are mature in the period of late third molar development, implicating that they have closed apices [11] and per definition signifying that secondary dentine formation started [12–15]. The amount of secondary dentine apposition was observed, measured, and quantified in periapical [16–18] as well as in panoramic radiographs [19–23]. The quantifications were related to age and modeled for age estimation purposes by Kvaal et al. [15]. These findings allow combining different dental variables observed on a single diagnostic tool for the purpose of age estimation.

Since age estimations based on third molar development only generate the widest prediction intervals compared to dental age estimations based on all maturing teeth except third molars [9], age estimation methods combining third molar development and other age predictors were studied [24–26] in an attempt to improve the accuracy of the age estimates.

The aim of this study was to analyze, in the subadult group, the age-predicting performances of adding tooth morphological measurements from permanent teeth to developmental stages of third molar(s) as evaluated on panoramic radiographic data.

Materials and methods

Four hundred fifty digital panoramic radiographs, from different individuals, were retrospectively collected from the dental clinic files of the Katholieke Universiteit Leuven, Belgium. The selected individuals had a Belgian nationality and were of Caucasian origin. For each gender, 25 radiographs were collected within each age category of 1 year in the range between 15 and 23 years. On each selected panoramic radiograph, at least one third molar was present, and the image quality allowed performing length and width measurements of the monoradicular teeth and their related pulp chambers. Furthermore, the selected individuals had no medical history possibly influencing tooth development and no history of tooth extraction.

The development of all available third molars was classified and registered according to the 10-point staging and scoring technique proposed by Gleiser and Hunt [1], modified by Köhler [2]. The Kvaal measuring technique [15] was applied on teeth from the left side. In particular, the upper central and lateral incisor and the second premolar, as well as the lower lateral incisor, the canine, and the first premolar were considered. If, due to tooth positioning, tilting, or overlapping, insufficient tooth information was available, the corresponding tooth at the right side was measured. Lengths and widths of tooth and pulp were measured. Their ratios, mean ratios (M, W, L), and difference of ratios (W−L) were calculated separately for each tooth, for all upper, for all lower, and for all six teeth [16]. The staging and measuring was performed in image enhancement software (Adobe Photoshop CS4, Adobe Systems Incorporated, San Jose, CA, USA) (Fig. 1).

All the radiographs were staged and measured by one observer. After 1 month, 20 radiographs were randomly selected from the sample and reevaluated by the same as well as a second observer.

Linear regression models with age as response and third molar scored developmental stages as explanatory variables were developed. To these models, M and W−L measurement ratios were added for the six teeth separately, the upper, the lower, and all six teeth together. From the models, determination coefficients (R^2) and root-mean-square errors (RMSE) were calculated. The R^2 calculation indicates the predictive value of the set of explanatory variables; the higher R^2, the more variance in age is explained by these variables. Smaller RMSEs denote minor differences between predicted and chronological age. Moreover, RMSEs give (compared to mean absolute errors) a relatively high weight to large errors since the errors are squared over the sample and the square root is taken from the mean of these square errors.

The analyses were performed on the entire group and separately for males and females. Pearson correlation between the four third molar stages showed strong correlations [0.86–0.93]. This relation was strongest between the molars

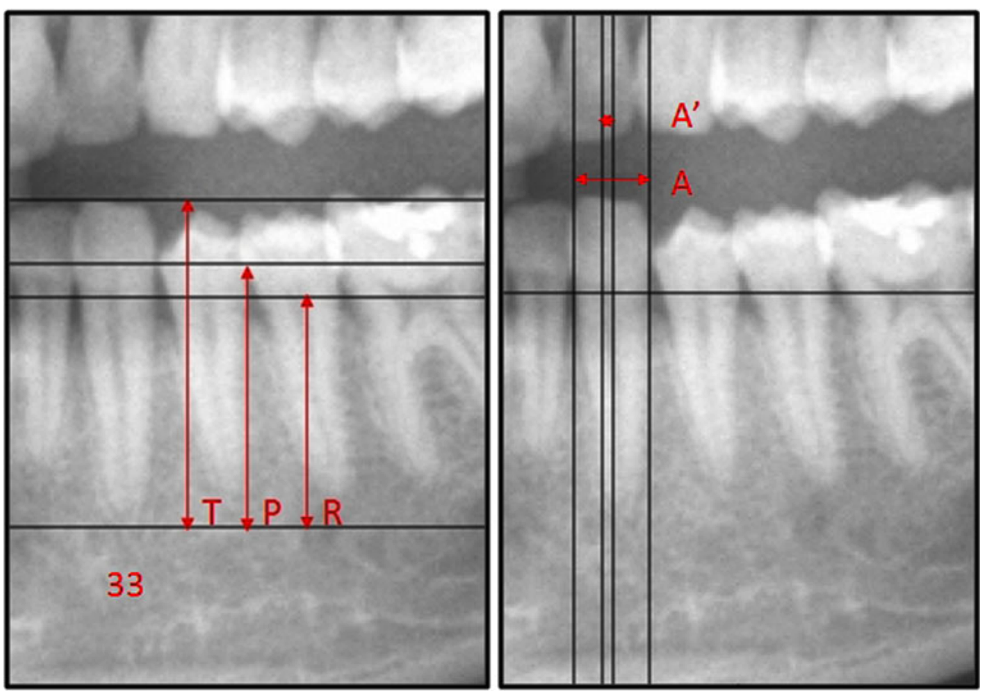

Fig. 1 Measurements according the Kvaal technique performed in image improvement software. To obtain optimal measurements, the panoramic radiographs were imported in Adobe Photoshop CS4®. The images were zoomed 300 % and arbitrary rotated to be parallel to the left (or right) working canvas side, guides were dragged at the selected tooth points, and measurements were performed using the measure tool snapped to the guides. The *left panel* illustrates the horizontal guides placed for the length measurements of tooth #33: *T* total tooth length, *P* pulp length, and *R* root length. The *right panel* illustrates the vertical guides placed for the width measurements at the level of the cementum enamel junction of tooth #33: *A* root width, *A′* pulp width

of the same arch (Table 2). Therefore, multicollinearity problems in the regression models were reduced using third molar stages of one side. For standardization, the left side was chosen. In case a left third molar was missing, the score of the corresponding right third molar was used. All analyses were done using the SAS software, version 9.2 of the SAS system for windows (SAS statistical software, SAS Institute, Cary, NC, USA).

Results

High intra and inter observer reliabilities were obtained for both the third molar staging (84 % perfect agreement) as well as the tooth measurements (maximal difference 2 %).

For the combined female and male sample, the regression model including only third molar stages provided an R^2 of 60 % and a RMSE of 1.63 years (Table 1). Adding to this model, Kvaal ratios (M, W−L) of one tooth maximally increased R^2 with 1 % (tooth #22, 61 %) and maximally decreased RMSE with 0.02 years (tooth #22, 1.61 years). Adding to the same model, Kvaal ratios of the upper or lower teeth increased R^2 maximally 1 % (uppers, 61 %) and decreased RMSE maximally 0.01 years (uppers, 1.62 years). Added information of all six teeth increased R^2 with 1 % (61 %) and a decreased RMSE with 0.02 years (1.61 years) (Table 1).

Analogous analyses performed on the male sample resulted in similar increases of the R^2 and alike decreases of the RMSE values (Table 1).

The largest added value of age-predicting information was detected in the regression analyses performed on the female sample. In fact, adding the Kvaal ratios of all six teeth increased R^2 with 6 % (58 %) and decreased RMSE with 0.10 years (1.68 years) (Table 1).

R^2 and RMSE values from the regression models including only Kvaal ratios ranged between 0.1 and 29 % and 2.21 and 2.60 years, respectively (Table 2).

Discussion

In present study, models combining third molar(s) developmental information with morphological dental variables resulted in a maximal increase of explained variance in age of 6 % and a maximal decrease of 0.1 year in RMSE compared to models based only on third molar(s) development. On average, the nine studied models combining developmental and morphological variables disclosed ignorable and clinically insignificant differences with the corresponding third molar models. This finding reflects the poor age-related morphological information available in the studied age range. Indeed, the explained variance in age detected in the models based on tooth morphology varied between 0.1 and 29 %, and the RMSE were between 2.21 and 2.60 years (Table 2). The cause of these inferior age-related performances could be explained by the lack of ample amounts of secondary dentine formed in this age category. Indeed, Philippas et al. [13] studied secondary dentine formation in 14 age groups of 5 years, starting at the age of 6 years, and concluded that with beginning of the 21- to 25-year group, there was a gradual increase in the amount of irregular secondary dentine formation, attaining a pronounced increase in the 46- to 50-year group. Moreover, the teeth considered by Philippas et al. were upper central incisors. From all developing permanent monoradicular teeth, incisors are maturing earliest and thus are advanced in secondary dentine formation. In the current study, beside incisors, canines and premolars were measured, implicating that within this group of

Table 1 R^2 and RMSE calculated from the third molar regression model without and with added Kvaal information

Regression model	Males+Females		Males		Females	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
TM	0.60	1.63	0.70	1.43	0.52	1.78
TM+21	0.60	1.64	0.70	1.43	0.53	1.78
TM+22	0.61	1.61	0.71	1.42	0.56	1.71
TM+25	0.61	1.62	0.70	1.43	0.56	1.72
TM+34	0.61	1.63	0.70	1.43	0.54	1.76
TM+33	0.60	1.63	0.70	1.43	0.54	1.76
TM+32	0.61	1.63	0.70	1.43	0.56	1.73
TM+U	0.61	1.62	0.70	1.43	0.57	1.69
TM+L	0.61	1.62	0.70	1.43	0.56	1.72
TM+U+L	0.61	1.62	0.70	1.43	0.58	1.68

TM third molar model; 21, 22, 25, 34, 33, 32, U, L, and U+L are Kvaal ratios of tooth/teeth 21, 22, 25, 34, 33, 32, 21+22+25, 34+33+32, and 21+22+25+34+33+32, respectively

Table 2 Determination coefficient (R^2) and root-mean-square error calculated from the third molar regression model and the Kvaal regression models

Regression model	Males+Females		Males		Females	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
TM	0.60	1.63	0.70	1.43	0.52	1.78
21	0.03	2.57	0.001	2.60	0.09	2.50
22	0.06	2.53	0.02	2.58	0.15	2.40
25	0.10	2.47	0.05	2.55	0.19	2.36
34	0.06	2.54	0.03	2.57	0.13	2.45
33	0.06	2.53	0.02	2.58	0.16	2.41
32	0.04	2.56	0.01	2.59	0.14	2.43
U	0.11	2.46	0.03	2.57	0.25	2.26
L	0.09	2.50	0.03	2.57	0.24	2.29
U+L	0.13	2.44	0.05	2.55	0.29	2.21

TM third molar model; 21, 22, 25, 34, 33, 32, U, L, and U+L are Kvaal model containing calculated measures of tooth/teeth 21, 22, 25, 34, 33, 32, 21+22+25, 34+33+32, and 21+22+25+34+33+32, respectively

combined tooth types, the mean threshold of beginning gradual increase of secondary dentine formation has to be set at older ages (>21- to 25-year group). Furthermore, one has to take into consideration that in the Phillippas et al. study, secondary dentine formation was microscopically evaluated on sectioned teeth with magnifications up to 200 times. In the present study, this initial secondary dentine formation was measured on panoramic radiographs magnified three times in Adobe Photoshop CS4®, (Adobe Systems Incorporated, San Jose, CA, USA). Associated with the knowledge that no distinction can be made between primary and secondary dentine on radiographs, it has to be concluded that, certainly, initial secondary dentine formation is hardly or even not measurable when evaluating ratios of tooth lengths and root-pulp widths on panoramic radiographs.

The R^2 values reported in the Kvaal et al. study [16] were outperforming (56 %<R^2<76 %) compared to the obtained R^2 values evaluating the tooth morphological variables in current study (0.1<R^2<29 %) (Table 2). The major difference in research set up between both studies concerns the age range and distribution of the investigated sample. The age range of the reference sample in the current study was restricted to young individuals (15–23 years). In the Kvaal study, adult individuals (20–87 years) were sampled. Although a bigger sample size with a more homogenous gender and age distribution was used in the present study, this could not compensate for the poor variance in age explained by the considered tooth morphological variables. Meinl et al. [19] reported similar poor age-predicting performances when validating the Kvaal method on a sample of individuals between 13 and 24 years. Further, the contrasting performance between the young and adult age groups, applying the Kvaal method, was reported in the Paewinsky et al. [20] study. The results were plotted as relation between pulp-root width ratios and age and fitted as well as linear, cubic and logistic functions. For each of the fitted curves, the young individuals (between 14 and 20 years) could be considered as outliers. Hereby, again a marked deviation from the performance of the adult part of the considered sample (between 20 and 81 years) was expressed.

Erbudak et al. [21] reported as main disadvantage for the application of the Kvaal method on panoramic radiographs that these images do not display the fine anatomic details available on periapical radiographs. Landa et al. [22] had to exclude measurements of all indicated upper teeth due to overlap and the lack of sharpness in their selected panoramic radiographs. It has to be denoted that the potency to perform the secondary dentin measurements on all tooth positions indicated in the Kvaal method indeed greatly depended on the image quality of the selected panoramic radiographs. However, the described differences in performance between the Kvaal et al. [16] and the current study were not related to the better image quality found on periapical x-rays. Indeed, in the Bosmans et al. [23] study, panoramic radiographs were evaluated on an adult age group. It was concluded that no significant differences were detected comparing the results based on periapical versus panoramic radiographic data. Therefore, in the Bosmans et al. study, the sampled reference data were selected on criteria requiring good quality panoramic radiographs with clear radiological image. It was not quantified how many panoramic radiographs had to be eliminated from sampling. In the current study, strict image quality selection criteria were used based on criteria that allow performing optimal variable measurements on each indicated tooth. Therefore, on average, 80 % of the archived radiographs had to be excluded. The use of the image-ameliorating tools in Adobe Photoshop CS4® did not narrow the obtained exclusion result. Moreover, in the current study, it was aimed to measure the teeth on the left side. Due to the altering image quality according to specific tooth positions, at least one contralateral tooth was chosen to enable optimal variable measurements for that particular tooth position in almost every selected panoramic radiograph. In forensic practice, it is impermissible to apply a method only applicable on 20 % of the population.

The poor age-predicting performance of the models based on morphological tooth/teeth information indicate that the use of Kvaal measurements on all related permanent teeth is not a good alternative to perform (dental) age estimations in subadult individuals (between 15 and 23 years) who are missing all four third molars. In these cases, specific dental age estimations can just be performed if other permanent teeth are still maturing. If all teeth are fully developed, the only dental age prediction that can be reported is that the investigated individual is at least 16 year of age [11]. To determine whether individuals with unknown age have passed the subadult age category, besides dental development, skeletal maturation has to be considered. More specifically, the ossification of the hand wrist bones and the medial part of the clavicles provide relevant added information [27]. If all these dental and skeletal parameters are mature, the individual has to be considered as an adult. In the adult age category, the Kvaal technique can provide more accurate age estimates, under condition that the method is applied as originally designed, implicating that periapical x-rays (preferably taken with the parallel technique) need to be examined.

Conclusion

Due to the inherent image quality of panoramic radiographs, the Kvaal measurements could only be achieved on a restricted sample. Clinically, the gain in age prediction accuracy was neglectable when adding the time consuming tooth morphological measurements to the staged third molar(s) development. On panoramic radiographs, forensic dental age estimations in the subadult group should consider third molar development as only reliable age predictor.

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