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Third molar development: measurements versus scores as age predictor

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ABSTRACT

Human third molar development is widely used to predict chronological age of sub adult individuals with unknown or doubted age. For these predictions, classically, the radiologically observed third molar growth and maturation is registered using a staging and related scoring technique. Measures of lengths and widths of the developing wisdom tooth and its adjacent second molar can be considered as an alternative registration. The aim of this study was to verify relations between mandibular third molar developmental stages or measurements of mandibular second molar and third molars and age. Age related performance of stages and measurements were compared to assess if measurements added information to age predictions from third molar formation stage. The sample was 340 orthopantomograms (170 females, 170 males) of individuals homogenously distributed in age between 7 and 24 years. Mandibular lower right, third and second molars, were staged following Gleiser and Hunt, length and width measurements were registered, and various ratios of these measurements were calculated. Univariable regression models with age as response and third molar stage, measurements and ratios of second and third molars as predictors, were considered. Multivariable regression models assessed if measurements or ratios added information to age prediction from third molar stage. Coefficients of determination (R^2) and root mean squared errors (RMSE) obtained from all regression models were compared. The univariable regression model using stages as predictor yielded most accurate age predictions (males: R^2 0.85, RMSE between 0.85 and 1.22 year; females: R^2 0.77, RMSE between 1.19 and 2.11 year) compared to all models including measurements and ratios. The multivariable regression models indicated that measurements and ratios added no clinical relevant information to the age prediction from third molar stage. Ratios and measurements of second and third molars are less accurate age predictors than stages of developing third molars.

1. Introduction

Age estimation methods based on third molar growth are modelled on data registering and classifying a radiologically observed degree of third molar development. Third molar growth starts with the initial mineralisation of a cusp tip and stops at the end of root growth with closure of the apices. The intermediate tooth development can be assessed in different stages of growth. Accordingly multiple tooth staging and related scoring techniques were developed.[1–8] These techni-

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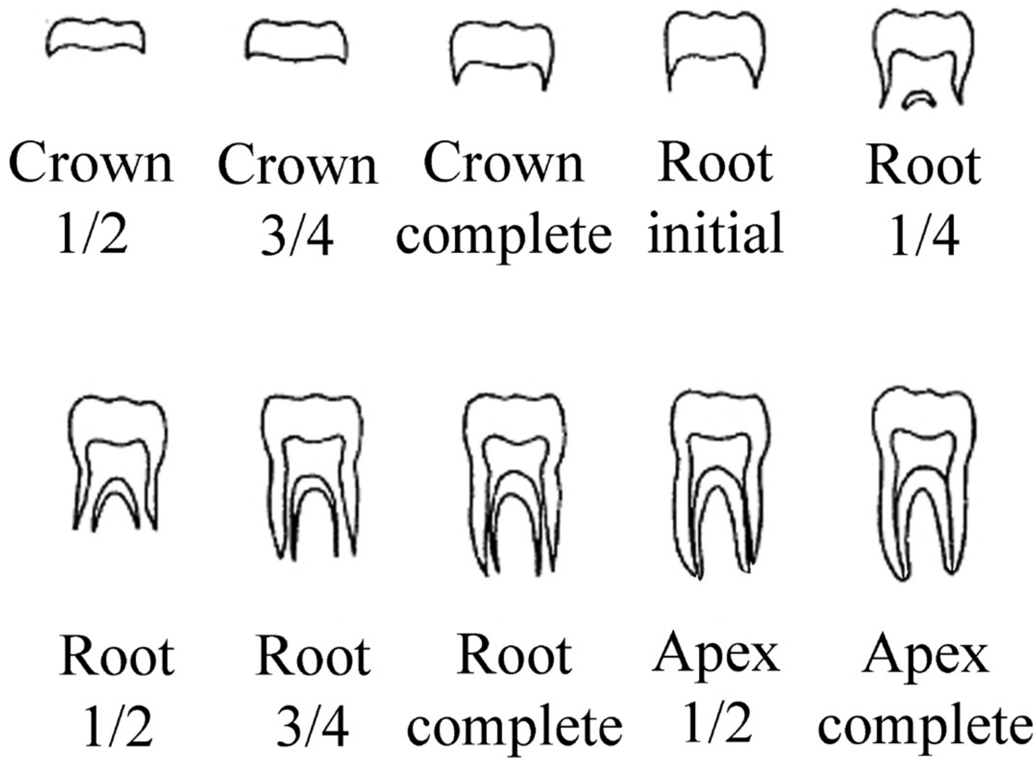

Fig. 1 – Developmental stages according to the 10 point scoring system developed by Gleiser and Hunt and modified by Köhler (GH). Stages "Crown complete", "Root initial" and "Apex complete" were based on objective anatomical descriptions. The other stages depended on subjective predictions of unknown tooth dimensions. Each developmental stage received a corresponding score classified from 1 to 10, starting with "Crown complete" and ending at "Apex complete".

ques provide ordinal data and describe anatomic tooth features or predictions of future tooth part dimensions as reference points for identification of the used stages .The "complete calcification of the tooth crown" is an example of an anatomical borderline between two stages, "root half completed" indentifies a reference point without knowing the final root length once the specific tooth has stopped growing [Fig. 1]. The subjective approach in the second example is a drawback to use this scoring technique for age estimations. Furthermore the degree of third molar development between equally scored subjects can differ. The difference is maximally between subjects with features allowing them to be classified with a third molar development just passing the lowest threshold of a specific stage and subjects with a degree of third molar development classified just before the highest threshold of the same stage. Regardless the amount of stages described in the applied technique these differences remain. Both disadvantages could be avoided by measuring the lengths of the developing third molar on the obtained radiographs. These measurements provide continuous data and an objective, precise and highly reproducible tool of registration.[9–11] Moreover these measurements allow to correct certain features. Geometric deformations inherent to radiographical set-ups, could be circumvented by calculating tooth measurement ratios.[12,13] Some deformations due to a tilted cheek position of the measured tooth could be detected and corrected. Taking into account dimensions of the second molar enables to diminish the variability in tooth size between individuals.

The aim of this study was to measure dimensions of third and preceding second molars on orthopantograms and to verify the significance of possible relations between these measurements and age. Furthermore whether measurements add information to age prediction once scoring of third molar development is performed, will be checked.

2. Materials and methods

In the age range between 7 and 24 year, 340 (170 female and 170 male) panoramic radiographs, taken with a Veraviewepocs 2D unit (J. Morita Inc., Irvine California, USA) were retrospectively selected. More specific in each age category of 0.1 year, starting at 7 year, a female and male subject was randomly picked from the dental clinic files of the Katholieke Universiteit Leuven. To collect indices on all present lower right third (Fédération dentaire international (FDI) #48) and second molars (FDI #47) the radiographs were imported in Adobe® Photoshop® (Adobe Systems Incorporated, San José California, United States America).

Firstly both molars were scored following the 10 point scoring system developed by Gleiser and Hunt and modified by Köhler (GH)[1] [Fig. 1].

Table 1 – Overview of abbreviations and descriptions of collected indices.

Indices group	Abbreviation	Description
Tooth length	TTL[a]	Tooth length from most occlusal till most apical calcified tooth point
	OPL[a]	Tooth length from occlusal plane till most apical calcified tooth point
	PHL[a]	Tooth length from occlusal plane till most occlusal pulp horn point
	CEJL[a]	Tooth length from occlusal plane till cement enamel junction
Tooth width	CW[a]	Maximal crown width
	CEJW[a]	Crown width at cement enamel junction
Ratio	R1	TTL^{48}/TTL^{47}
	R2	OTL^{48}/OTL^{47}
	$R3^{48}$	TTL/CW on third molar
	$R3^{47}$	TTL/CW on second molar
	$R4^{48}$	TTL/CEJW on third molar
	$R4^{47}$	TTL/CEJW on second molar
	$R5^{48}$	TTL/PHL on third molar
	$R5^{47}$	TTL/PHL on second molar
	$R6^{48}$	TTL/CEJL on third molar
	$R6^{47}$	TTL/CEJL on second molar
	$R7^{48}$	TTL^{48}/OPL^{48}
Ratio of ratio's	R3	$R3^{48}/R3^{47}$
	R4	$R4^{48}/R4^{47}$
	R5	$R5^{48}/R5^{47}$
	R6	$R6^{48}/R6^{47}$
Score	GH[a]	Developmental score following Gleiser and Hunt modified
	PC	The score on the first principal component

^{48} indices on lower right third molar, ^{47} indices on lower right second molar.
[a] To specify the measured or scored tooth the indices receive an additional indication of the corresponding tooth number (e.g. TTL measured on lower right third molar = TTL^{48}).

Secondly 4 tooth lengths: total tooth length (TTL), occlusal plane length (OPL), pulp horn length (PHL) and cement enamel junction length (CEJL); and 2 tooth widths: crown width (CW) and cement enamel junction width (CEJW) were measured. The properties of these measurements were described in detail in Table 1 [Table 1, Fig. 2]. To perform optimal measurements the radiographs were zoomed at 300% and rotated arbitrary parallel to the occlusal plane of the measured tooth, guides were dragged at the selected tooth marks, measurements were performed using the measure tool snapped to the guides. The occlusal plane was defined as the line connecting the tips of a mesial and distal cusp radiologically superimposed on other tooth material. Above settings were installed separately for the length and the width measurements of each measured tooth (FDI #47, #48).

Thirdly ratios of these measurements and fourthly ratios of these ratios were calculated and described in detail in Table 1 [Table 1]. Ratios of tooth lengths and (or) tooth widths from the

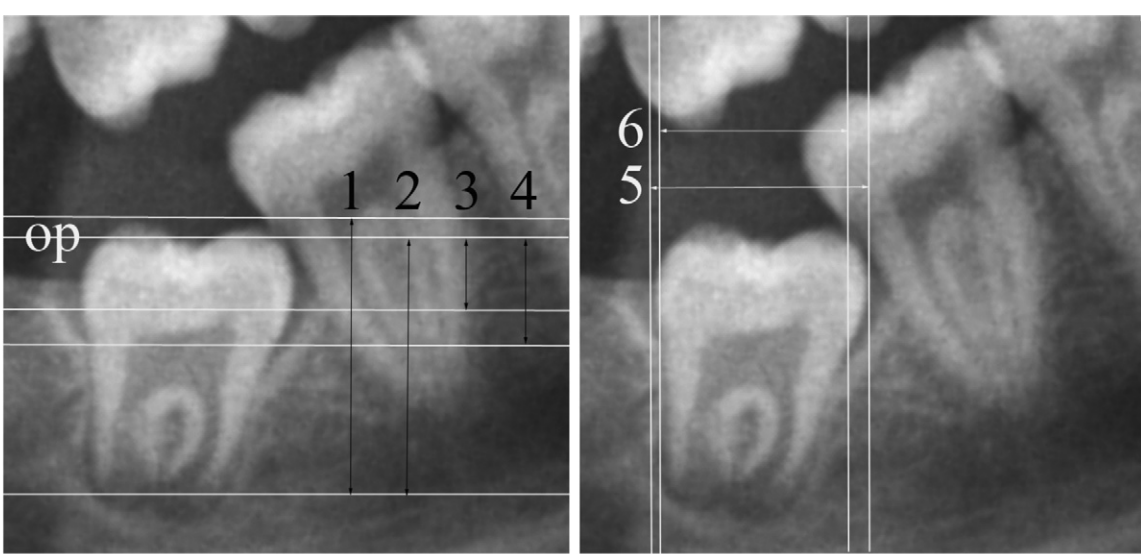

Fig. 2 – Illustration of performed tooth dimension measurements. op = occlusal plane. On the left panel the four length measures of tooth #48 are illustrated: 1 = TTL, 2 = OPL, 3 = PHL, 4 = CEJL [Table 1]. In cases where the cement enamel junction on the mesial and distal side was not at the same horizontal level, the mean height between the two points was considered. On the right panel the two width measures of tooth #48 are indicated: 5 = CW, 6 = CEJW [Table 1].

same tooth ($R3^{48}$, $R3^{47}$, $R4^{48}$, $R4^{47}$, $R5^{48}$, $R5^{47}$, $R6^{48}$, $R6^{47}$, $R7^{48}$) were considered to correct radiographical deformations. Ratios of corresponding tooth lengths obtained on the third and second molar (R1, R2) and ratios of ratios obtained on the third and second molar (R3, R4, R5, R6) were calculated in an attempt to diminish the effect of variability in tooth size. Specially for evaluation of this effect the original sample was divided in individuals having a fully developed second molar ($GH^{47} = 10$) and individuals with a calcifying second molar ($GH^{47} < 10$). The ratio between TTL^{48} and OPL^{48} ($R7^{48}$) could give an indication of the degree of bucco-palatal inclination of the third molar (ratio = 1 is no inclination).

To quantify differences in amounts of information between various age related indices, coefficients of determination (R^2) and root mean squared errors (RMSE) are reported from regression models with age as response. A model is used for each index separately. Nonlinearity in the relation between the index and age is allowed by the use of restricted cubic splines.[14] The development status of the second molar (fully developed versus not fully developed) is included as a binary factor, and the relation between the index and age is allowed to differ as a function of this status (by including the interaction between index and status). Multivariable regression models were used to check if the other indices added information to age prediction once GH^{48} was used and to explore if combining indices reduced the RMSE.

A principal component analysis was performed on all length or width measurements and ratios. The scores of the subjects on the first principal component (explaining 79.1% of the variability) can be interpreted as an index of development. This score (PC) is a weighted average of all included indices, and was used as an alternative predictor for age estimation.

Since there is no crown information yet at younger age, the absence of information of GH, PHL, CEJL, CW, CEJW is related with age. Therefore, a variable with two levels (0 = no information missing, 1 = information missing) is added as an additional predictor in all regression models using GH, PHL, CEJL, CW or CEJW to predict age''.

Exploring the regression models revealed that the variance of age was not constant. To handle this, the variance was allowed to be specific for 3 GH^{48} categories, namely for GH^{48}smaller than 5, GH^{48} between 5 and 9 and GH^{48} equal to 10. Models were fitted separately for girls and boys. All analyses have been performed using SAS software, version 9.2 of the SAS System for Windows. Copyright© 2002 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA. The procedure PROC MIXED is used to fit models with non-constant variance.

3. Results

55.6% (189/340) and 17.77% (60/340) of respectively the second and the third molars are fully developed. For 53.9% (151/280) of the third molars who are not fully developed, the corresponding second molar did not reach the final developmental stage. For males and females, the latter percentage equals respectively 56.1% (78/139) and 51.8% (73/141).

The regression models for each index separately revealed that using GH^{48} will yield most accurate age predictions compared to all other indices. Indeed, systematically the R^2 for the model using GH^{48} is highest and the RMSE is lowest at each of the variance specific levels. The performance of GH was better (higher R^2, lower RMSE) for males compared to females.

Table 2 – List of coefficients of determination (R^2) and root mean squared errors (RMSE) calculated from index-specific regression models with age as response.

Indices	Females (N = 170)					Males (N = 170)				
	N	R^2	RMSE $GH^{48} < 5$	RMSE $5 \leq GH^{48} < 10$	RMSE $GH^{48} = 10$	N	R^2	RMSE $GH^{48} < 5$	RMSE $5 \leq GH^{48} < 10$	RMSE $GH^{48} = 10$
GH^{48}	132	0.78	1.65	2.12	1.20	130	0.86	1.20	1.47	1.39
TTL^{48}	133	0.72	1.58	2.20	1.91	135	0.72	1.48	2.37	1.82
OPL^{48}	133	0.73	1.59	2.13	1.97	135	0.75	1.31	2.17	2.00
PHL^{48}	116	0.51	2.04	2.36	4.24	113	0.59	1.70	2.40	3.46
$CEJL^{48}$	111	0.56	1.67	2.41	4.28	113	0.59	1.63	2.59	3.07
CW^{48}	131	0.46	2.16	2.42	4.50	134	0.54	1.61	2.64	3.87
$CEJW^{48}$	110	0.56	1.75	2.33	4.29	111	0.58	1.52	2.42	4.02
R1		0.70	1.73	2.67	1.35		0.72	1.57	2.31	1.82
R2		0.70	1.73	2.55	1.54		0.74	1.38	2.12	2.06
$R3^{48}$		0.74	1.50	2.14	2.01		0.74	1.37	2.40	1.77
R3		0.69	1.67	2.62	1.69		0.69	1.59	2.52	1.85
$R4^{48}$		0.73	1.45	2.60	1.60		0.76	1.12	2.36	2.05
R4		0.70	1.51	2.76	1.62		0.74	1.19	2.38	2.03
$R5^{48}$		0.70	1.71	2.16	2.17		0.67	1.39	2.22	3.23
R5		0.62	1.76	2.56	2.25		0.64	1.56	2.20	3.40
$R6^{48}$		0.69	1.84	1.96	2.50		0.65	1.50	2.28	3.16
R6		0.62	1.79	2.44	2.75		0.64	1.60	2.25	3.09
$R7^{48}$		0.58	1.82	2.36	3.55		0.62	1.62	2.47	2.86
PC		0.76	1.47	2.42	1.29		0.73	1.28	2.21	2.41

N = number of subjects with information on the index. For each model, three RMSEs are reported since a model with non-constant variance was needed. Note that the regression models are always based on N = 170 (see statistical methodology).

There was no indication that indices based on ratios would yield better age predictions than indices based on full length measurements (TTL, OPL) [Table 2].

None of the other indices added significantly information to age prediction once GH^{48} was used, independent of the calcification status of the second molar (results not shown). An exception was found for females where adding PC or $R6^{48}$ provided a statistical significant but clinical small gain of information. The increase in R^2 was maximally 2% and in both cases the RMSE, calculated for the three variance specific levels, changed hardly.

Multivariable regression models revealed that a combination of the best performing length index (OPL) with indices based on ratios does not yield a better age prediction than the use of only GH^{48}. For example, for males the highest R^2 was obtained with the combination of OPL, $R4^{48}$ ($R^2 = 0.76$) and OPL, R4 ($R^2 = 0.76$). Both combinations do not contain more information than GH^{48} ($R^2 = 0.77$)

4. Discussion

The age range of the subjects included in a study will bias the age predictions as soon as the age distribution conditional on predictors is truncated. A straightforward example of such bias would occur if the GH^{48} score is used for age prediction and the maximal age of subjects is restricted. In this situation, using the results of such study for future age predictions, will underestimate the age of subjects with a fully developed third molar. Similarly, if length measurements are used for prediction, the age might be overestimated for subjects with lower values if the minimal age to enter the study is chosen inappropriately. In the current study, 10 males and 10 females were included within each age range of 1 year. The maximal age was set at the age range where all 10 included subjects had during the random selection a fully developed third molar (i.e. 24 years), avoiding (right) truncation of the age distribution. The minimal age was set at 7 years. For this age category all 10 included male subjects had during the random selection no calcifying third molars. For girls this was the case for all subjects in the age categories below 10 years. For 2 boys in the 9–10 years range a GH^{48} was available and for only 1 boy in the 8–9 years range length measurements (TTL^{48}, OPL^{48}) were obtained. As such (left) truncation of the age distribution is unlikely for the subjects in the earliest stages of third molar development.

The results related to TTL^{48} were in agreement with findings detected by Liversidge et al.[10] Firstly, these authors have found an S shaped relation between tooth length and age. Also in our study, nonlinear terms were needed to describe the relation between TTL^{48} and age (results not shown). Secondly Liversidge et al. detected for third molars an RMSE value (1.478 years) comparable with our results. It has to be noticed that the composition of the sample used by Liversidge et al. focused on lower ages, therefore their recommendation to use preferably information from other teeth for age prediction, just holds for these young ages ($\leq$5 year).

GH^{48} yields most accurate age predictions compared to all other indices. More specific the continuous data from the raw total third molar length measurements (TTL^{48}, OPL^{48}) are not providing extra age related information compared to the categorical data according to the ordinal (10 levels) GH^{48} stages. All ratios between tooth lengths and tooth widths from the same tooth ($R3^{48}$, $R3^{47}$, $R4^{48}$, $R4^{47}$, $R5^{48}$, $R5^{47}$, $R6^{48}$, $R6^{47}$, $R7^{48}$), used to eliminate radiographic distortions, are less informative than the raw third molar length measurements. Ratios normalizing the raw third molar length measurements on corresponding second molar length measurements (R1, R2, R5, R6) were used in an attempt to reduce the influence of tooth size. Especially for individuals with a fully developed second molar ($GH^{47} = 10$). But these ratios are not yielding better age predictions compared to the raw third molar length measurements. Even the PC score, which reflects information from all included indices, did not outperform the GH^{48}. Probably human variability in tooth size is the major cause of these findings. In this study the variability of third molar size can be derived from the TTL^{48} and OPL^{48} measurements on all fully developed third molars ($GH^{48} = 10$, $N = 60$) having ranges of 2.3–3.4 cm and 2–3.2 cm respectively. On all fully developed second molars ($GH^{47} = 10$, $N = 189$) the ranges for both measurements were respectively 2.4–4.1 cm and 2.3–3.9 cm. Moreover a human variability in difference between third and second molar size has to be taken into account. The ranges for the difference in length between the second and third molar were −0.02 cm to 1.01 cm and −0.08 cm to 1.33 cm for respectively TTL and OPL measurements. Note that for TTL and OPL, systematically larger measurements were obtained for the second molar. Using length indices of developing teeth as information for age estimation embodies previous variability's and results in extra loss of age related information. Scoring third molar development is independent from tooth size variability under condition that the observed third molar calcification information is used as standard. Based on this standard, predictions of future third molar lengths have to be made and these predictions allow to categorise the developing wisdom tooth regardless existing tooth size variability's. This implicates that scorings have to rely on the highest intra and inter observer reliability to prevent subjective operator influences. Moreover predictions of third molar lengths should not be based on (or compared with) the dimensions of neighbouring teeth.

Using combined length measurements of the second and third molar (R1, R2, R3, R4, R5, R6) does not result in a gain of age related information compared to the raw third molar length measurements (TTL^{48}, OPL^{48}). Most likely this can be explained by the fact that second and third molars are developing simultaneously during a long period. In the studied data all second molars achieved complete development at the age of 19 year. More specific 73 females and 78 males had GH^{47} lower than 10, meaning that only 55,6% of all second molars were fully developed ($GH^{47} = 10$) and not in developmental overlap with corresponding third molars. An alternative explanation would be that the measurement error in the measurements is too high, hereby attenuating the relations with age. To obtain an indication for the amount of the measurement error, intra-observer reliability was evaluated. Therefore the measurements of 10% of the male individuals (at random chosen) were measured again by the same observer. The results on the standard error of measurement (SEM), also expressed relative to the mean value (within-subject coefficient of variation = WSCV) revealed a high level of intra-observer agreement for all measurements (SEM [0.006–0.022], WSCV [0.3–1.5%]). This result indicates that the measurement errors cannot be considered as a cause of the lack of gain in age related information.

In further research models with combinations of indices other than evaluated in this study could be explored. They are expected to be less informative about age than scorings and care has to be taken not to overfit the data.

5. Conclusions

Third molar scorings (categorical data) were best related to age and provided the most accurate age predictions compared to all collected tooth measurements and ratios of tooth measurements (continuous data). Combining the third molar scorings with tooth measurements or ratios did not contribute to a clinical relevant information gain for age prediction. Therefore the method of third molar staging and related scoring has to be recommended over complicated dimensions measurements or ratio calculations of second and/or third molars for the purpose of age estimations.

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Conflict of interest: None declared.

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