Forensic Science International 201 (2010) 86–94

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

A comparative study of two different regression methods for radiographs in Polish youngsters estimating chronological age on third molars

M. Van Vlierberghe [a], E. Bołtacz-Rzepkowska [b], L. Van Langenhove [c], J. Łaszkiewicz [b], B. Wyns [d], D. Devlaminck [d], L. Boullart [d], P. Thevissen [a], G. Willems [a,*]

[a] School of Dentistry, Oral Pathology and Maxillo-Facial Surgery, Department of Forensic Odontology, Katholieke Universiteit Leuven, Kapucijnenvoer 7, B 3000 Leuven, Belgium

[b] Department of Conservative Dentistry, Endodontics and Periodontology, Medical University of Łódź, 92-216 Łódź, Pomorska 251, Poland

[c] Department of Textiles, Ghent University, Technologiepark 907, 9052 Zwijnaarde, Belgium

[d] Department of Electrical Energy, Systems and Automation, Ghent University, Technologiepark 913, 9052 Zwijnaarde, Belgium

ARTICLE INFO

Article history:
Received 16 March 2010
Accepted 11 April 2010
Available online 7 May 2010

Keywords:
Gleiser and Hunt
Age estimation
Polish population
Third molar development
Orthopantomogram
Regression formulae

ABSTRACT

Aim: The aim of this study was to establish a third molar developmental database to model dental age of Polish youngsters, to investigate the rating level of the scores when dividing a year interval into a quarter of a year and to examine sex differences, left-right and upper-lower jaw asymmetry.

Material and methods: A cross-sectional sample of 1048 orthopantomograms of 644 females and 404 males aged between 12 and 26 years was investigated using the scoring system of Gleiser and Hunt modified by Köhler. Reference tables according to age were split in a whole year and in quarters of a year using descriptive statistics. The various developmental stages between males and females were analyzed with a paired *t*-test and the cusum method. Differences in mineralization between the quadrants were analyzed with a two-factor ANOVA and the Duncan post hoc test. The single quadratic and support vector regression were performed to describe the relationship between score and age.

Results: Dividing age classes in quarters of a year discriminated better between individuals provided that there is a sufficient sampling size for all age classes. The mineralization tempo occurred significantly at a faster rate in males. The maturational events in the upper arch developed significantly at earlier ages for both genders. Obtained chronological age had nearly the same standard error of estimate when calculated with both regression methods.

Discussion and conclusion: Comparing the results of the present study with those of other population groups suggests that there are differences in the ageing process of the wisdom tooth. This is the first database of Polish youngsters (15–24 years) with their respective regression equations to yield age estimations.

1. Introduction

Nowadays there is an increasing number of youngsters of approximately 18 years of age from different countries in the world with whom the Belgian judicial system has to deal. Judicial agencies retain forensic experts for age estimation of living adolescents and young adults with regard to criminal activities, asylum seekers, illegal immigrants and unaccompanied minors. The physiological age of a person is determined by the degree of maturation of different tissue systems. The recommendations of "The international interdisciplinary Study Group on Forensic Age Diagnostics" [1] state that dental age diagnosis includes a clinical dental observation and a radiological investigation. During the transitional period from adolescence to adulthood, the only dental biological variable consists of the crown and root development of the wisdom teeth [2–5]. Individuals of the same chronological age can demonstrate different degrees of dental maturation. Analyzing populations from various genetic backgrounds suggests substantial inter-population differences [6–31]. Until now no dental database is available of Polish youngsters originating from the same biological nationality. Besides those dental observations forensic age estimation should also include a physical inspection for signs of sexual maturity and any age-relevant developmental disorders, X-ray examination of the non-dominant hand and wrist [32–34] and eventually an X-ray examination of the medial clavicular epiphyseal cartilage [3,35–41]. The drawback of the ossification of ephiphysis and diaphysis in hand and wrist is that it is completed around the age of 18 while the third molar development continues until the early twenties.

* Corresponding author. Tel.: +32 16332459; fax: +32 16337578.
E-mail address: guy.willems@med.kuleuven.be (G. Willems).

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doi:10.1016/j.forsciint.2010.04.019

Research reports variable opinions about the role of gender [6,7,9,10,21,23,28,42]. In the literature contradiction exists whether there is a left-right asymmetry in the developmental formation of the wisdom teeth. Investigations shows that formation stages of the third molars are more advanced in the upper then in the lower jaw [6,7,9,10,23,31]. All these aforementioned statements claim that specific reference tables for both sexes are much-needed for estimating dental age of Polish individuals. To realize the present study orthopantomograms were gathered from Polish youngsters. Deciding on whether the person is an adolescent or an adult pertains to the judicial agencies. The task of the forensic expert includes the application of the latest and scientific based methods with appropriate statistical significance tests and their limits.

The aim of this paper was first to develop a database for Polish youngsters for dental age estimation. The second aim was to examine the degree of refinement in age estimation when delimiting age intervals to quarter of a year instead of year interval. Thirdly differences in genders and between quadrants were investigated. Finally besides the single quadratic regression analysis a second order polynomial regression model has been established to figure out the smallest standard error of estimate. Because the last technique has limitations in that the form of the model has to be fixed in advance, support vector regression (a black box method) was carried out as well.

2. Materials and methods

The sample consisted of orthopantomograms of Polish individuals of whom the age and sex were known. Some radiographs were digitally generated on a Orthorolix 9200 (Gendex, IL, USA). They were stored as TIF files. The remaining X-rays were acquired a on conventional manner using a Planmeca Proline XC (Planmeca Oy, Helsinki, Finland). The manually generated radiographs were scanned with a SNAP SCAN 1236 AFGA, Gevaert NV, Moortsel, Belgium. The scanned orthopantomograms were stored as JPEG file. All the X-rays were compiled in Lodz, Poland, from the Institute of Dentistry and private practices of two co-authors. The social background of the persons from the Institute was from lower and middle class. Those derived from the private practices came from wealthy families. Age was calculated on information from identity cards and converted to a decimal value. In total 1048 orthopantomograms were analyzed. The age ranged from 12.0 to 26.0 years. The data set included 644 females and 404 males with an original Polish background.

Table 1 displays the age and sex distribution and percentage of each population age category. Females represent a larger group than males because they are more concerned about their general health and dental status. The clinical records reported no history of medical disease or surgery that could affect the presence and development of third molars.

Radiological third molar development was scored following the 10 point scoring classification designed by Gleiser and Hunt [43] and modified by Köhler [44] (MG&H). On multi-rooted third molars the least developed side was scored. Image quality improving software tools were used to adjust gray scale, brightness and contrast or for conversion into a negative image.

For detection of intra-operator variation a repeated third molar scoring of 173 third molars was performed after one month and assessed with ANOVA.

The whole data set was elaborated using descriptive statistics. The different scores corresponding to the mean ages were devised for both genders and for the four quadrants.

An ANOVA was used to split out variation of scores between and within age categories (classes). Between class variability corresponded to the development stages depending on age.

This effect was minimal for within class variability. The share of each component depended on the test set up, i.e. on the selection of class limits. On the one hand the size of divided age classes should not be too broad as this means that the share of within class variation becomes too big, moreover a sufficient number of classes should be maintained. On the other hand the number of cases per class should be high enough for statistic reliability. Interclass comparison was performed between the age classes of one year and a quarter of a year (3 months). MG&H upper right for female has been chosen as an example. Each age class was described by its centre. This means that age class 18 included patients with ages between 17.5 and 18.5 (classes of 1 year) and between 17.875 and 18.125 (classes of a quarter of a year) excluding the lower limit and including the upper limit.

A paired *t*-test analyzed the differences in average scores per age classes between males and females and each quadrant. The assumed difference was zero. The cusum method [45,46] was used to analyze trends (development in age evolution) in

Table 1
Number of individuals categorized by age and gender.

Age	12–12.99	13–13.99	14–14.99	15–15.99	16–16.99	17–17.99	18–18.99	19–19.99	20–20.99	21–21.99	22–22.99	23–23.99	24–24.99	25–25.99	26–26.99
Male	0	1	3	40	53	51	42	35	40	35	39	41	20	3	1
Female	2	1	2	48	67	62	57	52	68	76	88	77	38	6	0
Total (%)	0.3	0.4	1	17.4	23.5	22.2	19.3	16.8	20.5	20.5	23.4	22.1	10.9	1.6	0.2

differences between variables of both genders. This technique allows to prove small but persistent differences.

In order to test whether the development of the third molars depended on the quadrant, a two-factor ANOVA was carried out with factors "quadrant" and "orthopantomogram (individual)". The development differed amongst individuals and by adding the OPG as a factor this parameter can be extracted. The analysis was performed in two steps. First of all it was investigated whether there was a difference between quadrants and secondly, if such differences would exist, which ones were significantly different. A Duncan post hoc test was carried out to identify homogeneous subsets. Homogeneous subsets are subgroups of quadrants that are statistically equal whereas the subgroups themselves are statistically different. Quadrants can be part of more than one subgroup.

Finally a regression analysis was performed in order to model the relationship between chronological age (dependent variable) and score (independent variable) using a classical statistical regression and a support vector regression (nonlinear machine learning approach) [47,48] allowing to seek for the smallest standard error of estimate. For each subject the developmental third molar score in each quadrant and separately the minimum value of the four scores was considered.

Statistical analysis was carried out with SPSS version 17, Chicago USA.

3. Results

3.1. Intra-operator variation

Table 2 reflects the frequency of differences found between repeated scores. Calculated with ANOVA no significant difference between repeated scores was detected ($p > 0.05$).

The average of the difference between repeated scores was 0.46 with a standard deviation of 0.323 which confirmed that the majority of scores deviated not more than 1 class.

3.2. Descriptive statistics of age categories

In this cross-sectional investigation 3937 third molars were scored. 43 radiographs from 13 males and 30 females were excluded because of erroneous exposure, unclear radiographs and horizontal impaction of M3 in bucco-lingual direction. Table 3 illustrates the different scores corresponding to the mean ages for both genders and for the four quadrants. The means, the minimum and maximum chronological ages, the standard deviations, the age ranges and counts are recorded. For both genders the development of the crown encompassed an average of 3 years and the formation of the root length extended to an average of 7 years. When score 10 is reached or "the apices are closed" further age estimation depending on tooth development included no more significance.

Table 4 and Fig. 1 show the distribution for mean third molar scores per quarter of a year and per year related to the wisdom tooth in the upper right female quadrant. There was a noticeable distinction between the scores of the quarters within one year.

Secondly within class variation was reflected by the range (maximum–minimum value per class) which is smallest for quarter year classes.

Thirdly the standard deviation was maximum around the age of 18 (1.93 resp. versus the average of 1.68 resp. 1.64).

Table 2
Frequencies of the differences between repeated measurements.

Difference	Frequency	%
−2	2	1.2
−1	8	4.6
0	143	82.7
1	20	11.6
2	0	0
Total	173	100

Frequency: number of different measured scores; Difference: differences between repeated scores of each third molar; %: relative frequencies of different measured scores.

3.3. Comparison male–female and the differences between the quadrants

The results of the paired *t*-test for each of the quadrants revealed that the differences were highly significant (different from zero). The difference was positive explaining that males have a higher score for the same age than females. Although the score was different for males and females the evolution of development as a function of age (trend) seemed to be similar.

The cusum technique applied on the data set of differences between scores per age demonstrated that the difference in the scores between female and male was age dependent (Fig. 2). For each of the quadrants a clear trend could be distinguished indicated by the S shaped curve. In the age zone ranging from 15 up to approximately 17.5 years the cusum was decreasing indicating the difference tended to be smaller than average. From approximately 17.5 till 21 years the cusum was increasing indicating the difference tended to be bigger in this period than average. In the age zone ranging from 21 years onwards the cusum was decreasing indicating the difference tended to be smaller than average.

The two-factor ANOVA showed that tooth development varied between quadrants. The Duncan post hoc test pointed out those differences by listing the quadrants, number of measurements and average value per quadrant (Table 5). This table displays the homogeneous subsets for both genders. Upper and lower jaws were different for both genders. Indeed the tooth development was significantly faster in the upper jaw in contrast to the lower jaw. Given the same score in the four quadrants the corresponding ages were lower in the upper jaw than in the lower jaw. In the upper jaws the right side seemed to have a higher score than the left side but this difference was only significant for males In the lower jaw the left side indicated the highest scores but the difference was not significant both for males and females. As the trends were the same for male and female although not always significant one could assume that the development between left and right side was different but more data would be required to confirm this.

3.4. Regression analysis

Single quadratic regression equations and support vector regression were worked out to seek for the smallest standard error of estimate. Table 6 shows regression coefficients for both genders. Four different equations can be used in case where only one third molar is present. The minimum relates to the minimum score of the four given scores in the same individual provided that all third molars are present. The latter could give better results as in many cases some scores reached a maximum although not all of them did. All regression coefficients are highly significant for males. For females either the linear or the quadratic coefficient are highly significant. In case one or more molars were missing the OPG was not considered. The resulting single quadratic regression model is of the following form based on gender, on the number and the location of the third molar(s) present on the orthopantomogram. Five formulae were obtained.

$$\text{Age} = \text{const} + \text{Bi} \times \text{score\_}\{\text{UR or UL or LL or LR orminscore}\} + \text{Bi}^2 \times \text{score}^2\text{\_}\{\text{UR or UL or LL or LR orminscore}\}.$$

SVR is a black box modeling technique. So the form of the model cannot be described. Because of the nature of the SVR model such regression coefficients cannot be derived.

The correlation coefficient and the standard error of estimates for models based on single quadratic regression equations and support vector regression are listed for males and females (Table 7). All models are significant but the correlation is not

Table 3
Relations between the scores of MG&H in all the quadrants and ages in years for males and females.

Score	Males						Females					
	Mean	Min	Max	SD	Range	count	Mean	Min	Max	SD	Range	Count
UR quadrant												
2	15	14.78	15.21	0,3	0.43	2	15.21	14	17	0.94	3	1
3	16.57	15.03	19	1.6	3.97	6	16.06	13	22	1.92	9	6
4	16.01	15	18.14	1.05	3.14	10	16.43	14	21	1.46	7	13
5	15.8	14.32	18.16	0.8	3.84	33	16.67	12	20	1.42	8	34
6	16.6	14.01	21.81	1.45	7.8	52	17.41	15	24	2.07	9	46
7	17.19	12.69	20.97	1.48	8.28	56	18.57	15	24	2.02	9	79
8	17.89	15.07	20	1.6	4.93	9	19.78	17	23	1.79	6	79
9	19.12	14.89	23.72	2.22	8.83	34	20.46	15	24	1.98	9	22
10	21.31	16.39	26.47	1.9	10.07	176	21.77	12	25	1.79	13	72
UL quadrant												
2	15.69	14.78	18.14	1.39	3.36	5	15.70	14.75	18.00	1.12	3.25	10
3	16.1	15.03	17.34	1.09	2.31	6	15.82	13.00	18.75	1.39	5.75	18
4	15.93	15	18.58	1.12	3.58	10	16.23	14.00	21.50	1.68	7.50	24
5	16.05	14.32	18.99	0.94	4.67	33	16.51	12.25	20.00	1.47	7.75	46
6	16.37	14.01	21.81	1.45	7.8	53	17.21	14.75	21.75	1.74	7.00	71
7	17.32	12.69	23.55	1.63	10.86	58	18.27	15.00	23.50	1.98	8.50	81
8	18.01	15.07	21.93	1.81	6.86	10	18.97	16.50	21.00	1.50	4.50	23
9	18.86	14.89	21.39	1.67	6.5	28	20.50	15.25	23.75	1.86	8.50	81
10	21.26	15.92	26.47	1.99	10.55	185	21.82	12.00	25.00	1.79	13.00	251
LL quadrant												
1							15.50	15.00	16.50	0.87	1.50	3
2	15.26	14.78	16.42	0.78	1.64	4	15.79	14.25	18.75	1.40	4.50	12
3	16.18	14.92	19	1.27	4.08	13	15.92	13.00	18.50	1.25	5.50	19
4	16.02	14.32	18.58	1.11	4.26	19	16.70	14.00	20.75	1.52	6.75	50
5	16.28	14.01	20.01	1.29	6	57	17.22	12.25	22.50	1.96	10.25	71
6	17.13	12.69	23.55	1.64	10.86	74	18.52	14.75	23.50	2.23	8.75	89
7	18.39	14.89	23.04	1.7	8.15	36	19.43	15.25	24.50	2.08	9.25	65
8	18.65	17.67	19.63	1.39	1.96	2	20.14	15.25	23.75	2.22	8.50	14
9	20.31	16.75	24.52	1.62	7.76	69	21.12	12.00	24.75	1.88	12.75	119
10	22.1	17.29	26.47	1.63	9.17	114	22.19	15.75	25.00	1.52	9.25	147
LR quadrant												
1							15.75	15.00	16.50	0.87	1.50	4
2	15.51	14.78	17.25	0.94	2.47	6	15.32	13.00	17.50	1.17	4.50	11
3	15.73	14.32	17.91	1.07	3.59	15	16.25	14.00	19.50	1.40	5.50	29
4	16.38	14.98	19.56	1.2	4.58	19	16.54	14.75	19.75	1.34	5.00	44
5	16.25	14.01	18.99	1.17	4.98	60	17.18	12.25	22.50	1.88	10.25	77
6	17.48	12.69	23.55	1.69	10.86	76	18.97	14.75	23.50	2.13	8.75	93
7	18.2	14.89	21.93	1.87	7.04	25	19.79	15.25	24.75	2.22	9.50	70
8	19.16	17.45	21.48	1.48	4.04	5	19.30	15.25	21.75	2.06	6.50	11
9	20.36	16.75	24.52	1.73	7.76	66	21.25	15.25	24.00	1.74	8.75	123
10	22.09	17.39	26.47	1.57	9.08	116	22.21	12.00	25.00	1.68	13.00	144

Min: minimum chronological age; Max: maximum chronological age; Range: difference between minimum and maximum age; SD: standard deviation.

Table 4
Comparison of the mean MG&H scores of the upper right quadrant in females between age classes of 3 months and of 1 year.

Middle age value	CLASSES OF 3 MONTHS								CLASSES OF 1 YEAR							
	Count	Mean	Median	SD	Min	Max	Range	Average SD/year of quartiles	Middle age value	Count	Mean	Median	SD	Min	Max	Range
16.00	14	5.36	6	1.34	3	7	4	1.53	16	63	5.41	6	1.46	3	10	7
16.25	12	4.83	5	1.40	3	7	4									
16.50	21	6.33	6	1.46	3	10	7									
16.75	13	6.00	6	1.92	2	9	7									
17.00	14	6.23	6	2.05	3	10	7	1.66	17	58	6.22	6	1.60	2	10	8
17.25	15	6.20	6	1.15	4	8	4									
17.50	17	6.24	7	1.30	4	9	5									
17.75	14	7.00	7	2.15	4	10	6									
18.00	14	6.71	6.5	1.68	4	10	6	1.93	18	54	6.87	7	1.90	4	10	6
18.25	7	6.00	6	2.08	4	9	5									
18.50	21	7.67	7	1.83	5	10	5									
18.75	9	7.56	9	2.13	4	10	6									
19.00	8	8.63	10	2.26	5	10	5	1.77	19	46	7.85	8	1.81	4	10	6
19.25	11	8.18	9	1.60	6	10	4									
19.50	13	8.08	8	1.55	6	10	4									
19.75	14	8.62	9	1.66	5	10	5									
20.00	13	8.21	8.5	1.37	6	10	4	1.52	20	62	8.73	9	1.42	5	10	5
20.25	20	9.05	10	1.36	6	10	4									
20.50	17	8.59	9	1.42	6	10	4									
20.75	16	8.50	9.5	1.93	4	10	6									
Total average				1.68				1.68					1.64			

Middle age value: centre of an age class; Mean: mean MG&H score; SD: standard deviation in function of age; Max: maximum MG&H score; Average SD/year of quartiles: average standard deviation of the quartiles in one year; Count: number of given scores; Median: median MG&H score; Min: minimum MG&H score; Range: difference between minimum and maximum MG&H score.

very high (around 0.76). The differences between quadrants and both methods are very small and no trend can be seen. The min scores do not lead to better values for both single quadratic equations and for the support vector regression model. Only in males the best values were found in the minimum scores and in the lower quadrants. All models had similar predictive values for females.

Unfortunately the accuracy of predictions for both models was low as the error on predictions was at least 1.5 year. All model types give comparable results. Although the support vector regression is a very powerful technique it does not lead to a significant improvement of the models.

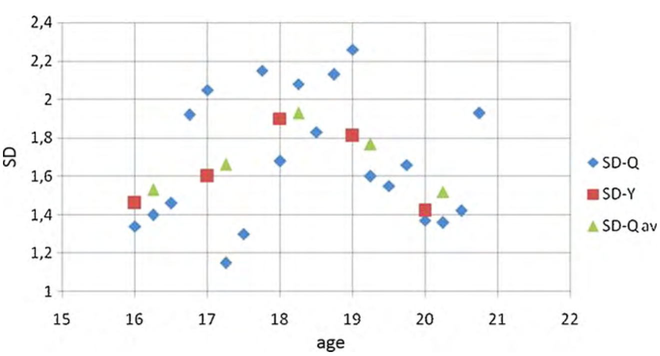

Fig. 1. Comparison of the standard deviation of the MG&H scores of the upper right quadrant in females between age classes of 3 months and of 1 year. SD-Q: standard deviation per quartiles; SD-Qav: standard deviation per quartile averaged per year; SD-Y: standard deviation per year.

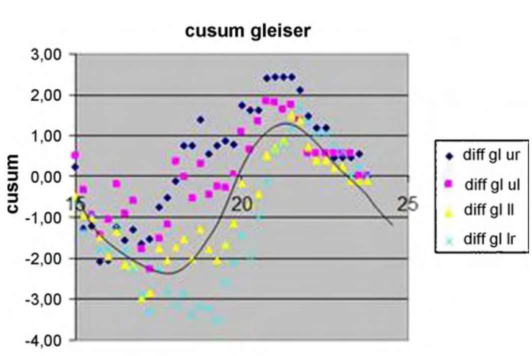

Fig. 2. Cusum outcomes related to age for each third molar score.

Table 5
Gender specific Duncan post hoc test on third molar scores and related tooth position.

Quadrant	*N* males	Subset			*N* females	Subset	
		1	2	3		1	2
LR	400	7.12			606	7.19	
LL	399	7.22			589	7.27	
UL	401		7.83		596		7.90
UR	379			8.10	606		7.95

LR: lower right; LL: lower left; *N*: number of scores; UL: upper left; UR: upper right.

Table 6
Regression coefficients for quadratic regression models for both genders.

	Males			Females		
	Const	Bi	Bi^2	Const	Bi	Bi^2
UR	17.822	−1.093*	0.143*	15.2	0.018	0.064*
UL	18.008	−1.14*	0.146*	16	−0.33	0.091*
LL	16.43	−0.553*	0.111*	14.3	0.511*	0.028
LR	15.971	−0.373*	0.098*	13.7	0.754*	0.01
Min	15.953	−0.361*	0.098*	14.24	0.661*	0.015

Bi^2: regression coefficient for quadratic term; Bi: regression coefficient for linear term; UR: upper right; UL: upper left; Min: minimum score; Const: constant; LL: lower left; LR: lower right.
* $p < 0.01$.

Table 7
Performance of the different regression models for both genders.

	Males				Females			
	Single quadratic regression		SVR		Single quadratic regression		SVR	
	R	SE	*R*	SE	*R*	SE	*R*	SE
UR	0.79	1.74	0.79	1.73	0.76	1.83	0.76	1.83
UL	0.79	1.74	0.79	1.74	0.79	1.75	0.79	1.75
LL	0.84	1.55	0.84	1.55	0.76	1.84	0.76	1.84
LR	0.84	1.55	0.84	1.54	0.76	1.84	0.75	1.86
Min	0.85	1.51	0.85	1.49	0.75	1.85	0.76	1.83

R: correlation coefficient; UR: upper right; UL: upper left; SVR: support vector regression; SE: standard error of estimate in years; LL: lower left; LR: lower right.

4. Discussion

4.1. Applying the MG&H scoring system

Numerous studies have documented various maturation stages of wisdom teeth. They differ with regard to the number of stages, the definitions of each stage, its presentation and the part of third molar development used for analysis [6,10,20,22,31,42,44,49–56]. In this study archived cross-sectional dental radiographs of Polish youngsters are used to evaluate the developmental sequence of the wisdom teeth starting from 12 to 26 years. Until now no database has been established from this specific biological and age group. Because of the worldwide travelling of individuals every forensic odontologist can take benefit from these reference tables to estimate age for legal issues. The most critical age with judicial relevance for the Belgian court is 18 years. Around this age interval there is a high probability that the crown of the third molar is fully developed and that root formation is going on. The seven distinct root scores of MG&H signify a reliable and useful value during this large age span of the root development. In accordance to the present investigation no significant intra- and inter observer effects were found in other studies using this modified scoring system [10,20,23]. Defining fewer scores is synonym of leaving more time (age) between the different formation rates. This means failing to reach the forensic purpose which aim is to optimize precision of the age estimation.

4.2. Age categories

The standard deviation was minimum for younger and older age categories. At young age the development of the third molar started only for few persons and after the age of 21 the third molar had fully developed for most people.

The literature denotes that the observed age ranges are lower for the earliest stages. Once the crown is fully developed the age interval for root formation increases as age proceeds. This is in accordance with the present study. In this study the age span can reach 3 years to mineralize the crown and seven years for root development in both genders.

Dividing a year into quarters of a year distinguishes better the differences in tempos of formation. This is caused by the limited number of samples in some classes. Standard deviation was generally underestimated when sampling size was small. An estimation of a standard deviation for 15 samples is approximately 10% lower than the SD calculated from a set of 50 samples. Following this one would expected the average SD of classes of 3 months to be approximately 10% lower than the SD calculated per year (for which the *t*-value will provide a correction). This was clearly not the case as average SD per year calculated from groups of 3 months are usually higher than the corresponding SD calculated for classes of 1 year.

One reason was that one exceptional value had a much bigger impact when the sampling size was small.

Secondly the variation consisted of the influence of age on score plus the variation of score for a specific age. When the age class was more narrow, the contribution of the influence of age was reduced as well. As a consequence the share of variation per age increased. This demonstrates it is worthwhile considering smaller classes only when a sufficient sampling size is available for all classes.

Refinement of age classes in quarters of year discriminated better individuals who reached just the beginning of that age span from those ones who are at the end of that age span.

4.3. Male/female/quadrant/ethnic comparison

Cross-sectional data of the literature report that males achieved most formation stages of the wisdom teeth in advance of females [6,7,9,12,14,16,18,31,42–44,50,52,56–59]. The present study reports a highly statistical sexual dimorphism when comparing the average scores in relation to the age. Males reach higher scores in each quadrant for the same age than females. The cusum method indicates that the difference is higher in the age interval from 17 until 21 years. On the contrary some investigations find no significant differences between both genders [15,60,61].

In the whole Polish data set tooth development is significantly higher in the upper jaw in contrast to the lower jaw. This observation was consistent with previous studies performed in different populations [6,7,9,10,23,31,53,55,62].

The Duncan post hoc test pointed out that in the upper arch a statistical difference in mineralization rate is only observed in males where the right quadrant has the highest score for the same given age. No significant differences in root formations are found in the mandible for both genders. Although in females the wisdom teeth of the lower right quadrant tend to achieve their maturity indicators later. Many authors observed no statistical differences between the development of left and right third molars in both jaws [6,7,9,10,23,28,31,42,44,55,56,60,61,63,64]. Knell [65] and Mincer [7] remarked a left-right asymmetry in root development in 14.9% respectively 26%. Results from other studies on the mandibular third molar corroborate with the present study where no side differences in mineralization are observed [9,10,14,23,55].

This MG&H method was compared per formation course with results published in several studies for the lower third molar for males respectively females (Table 8).

From score 3 to score 10 it can be seen from Table 8 that both Polish genders lag remarkable behind the mean ages of the white Caucasians of Canada [53] and London [22]. Comparison with results of studies on Spanish population from different geographic regions in the world demonstrates diverse mean ages for each developmental mineralization phase [6,14,15,57]. Similar effects were calculated from Turkish population [31,60]. Third molar development among the Turkish Caucasians appears at an earlier age than among Japanese [9,11] and American population [7]. The study of Olze [8,11] collates orthopantomograms between Germans, Japanese and South Africans. Findings indicated that Japanese lagged for Demirjian stages D–F on average 1–2 years

Table 8
Mean age in years in different white Caucasian populations based on MG&H.

Scores	Gender	Anderson [53]	Liversidge [22]	Present study
3	Males	13.3	14.23	15.96
	Females	12.8	14.21	16.10
4	Males	14.1	14.72	16.20
	Females	13.7	14.64	16.62
5	Males	14.80	15.09	16.27
	Females	14.50	15.21	17.20
6	Males	16.10	16.29	17.30
	Females	16.30	16.97	18.61
7	Males	16.80	16.99	18.30
	Females	17.30	17.70	19.61
8	Males	17.40	17.92	18.91
	Females	17.70	18.75	19.72
9	Males	18.02	18.33	20.34
	Females	18.02	19.62	21.19
10	Males	18.50	19.26	22.10
	Females	18.30	20.88	22.20

behind the Germans. South Africans reached on average Demirjian stage D–G 1–2 years before the German individuals.

Rozkovcová [66] investigated 1700 orthopantomograms of a Czech population residing in Prague from 5 to 21 years. She designed 7 developmental courses starting with dental follicle to convergent root canals. The seven stages are not purely delineated. Stage III is applied for advanced crown mineralization. The question rises if that means total crown formation. Stage V refers to divergent root canals. One cannot infer which length the root must have attained. An attempt is made to compare the scorings of stage IV and stage VII with the scores 5 and 10 of the MG&H in the present study on the lower third molar in males. Stage IV and VII in the Czech population refer respectively to incipient root mineralization and convergent root canals. The mean ages of Czech respectively of Polish males are recorded at 15.0 and 16. 3 years for stage IV. The study of Rozkovcová included individuals until 21 years of age. In about one third of the total population the apex was not fully closed. The present study finished at 25 years. The mean age for apex closed was 22.10 years.

Liversidge [22] and Harris [21] concluded that people of African descent tend to develop the third molar earlier than whites. All those previous reports must caution forensic odontologists about the possibility of an appreciable intergroup variability.

4.4. Relationship between age and scores

Several studies utilized regression equations to evaluate the relationship between age and dental maturity [7,10,13,20,23,63]. In the present study single quadratic regression equations and support vector regression were carried out. The minimum standard error of estimate in males and females are 1.51 respectively 1.75 years for classical regression methods and 1.49 respectively 1.75 for support vector regression. This statistical parameter has a lower value in males than in females because there is a more uniform pace in mineralization tempo. In females the various data of a same score have a higher variance.

Scoring the upper molars is sometimes difficult when the bottom of the maxillary sinus or the maxillary tuberosita eclipse the roots. To overcome this problem single quadratic regression formulas are devised including only the mandibular molars. For males the lower quadrants give slightly better predictions.

The different modeling techniques all are quite good at describing the average development of teeth as a function of age. However when it comes down to individuals this development is also largely influenced and this is clearly not covered by any of the models. It's inherent on the high human variability in third molar development. So all models have the same strength and weakness and it cannot be expected that further improvements can be made without adding information on geno- and phenotype factors.

Only applying descriptive statistics like the mean ages leads to false conclusions with regard to the medico-legal question whether an individual is at least 18 years of age.

4.5. Other considerations

From legal perspective the least developed wisdom tooth and above all the least developed root of a pluriradicular third molar has to be considered like the slogan claims ''in dubio pro reo''. A prerequisite implies that the image of the third molar on the radiograph is clearly perceptible to measure. Forensic odontologists must be warned that asymmetry in development is possible. Both sides should be independently evaluated. The forensic report is a legal document which is presented in the court proceedings. All statements need to be supported by scientific evidence together with the limitations of those procedures. References to the literature in relation to the used methods or age classification systems must be cited. Statistical outcomes with their respective significance parameters have to be noted too as well [39] even like the range of scatter in the reference population.

Further research involves establishing databases of the different mineralization stages of the third molar in both jaws derived from large sample populations with different ethnic origin. The scoring technique has to be well defined and delineated in order that it could be applied by forensic odontologists all over the world. The inferring regression equations need a low standard error of estimate and a high correlation coefficient. Maybe future research in age estimation in young adolescents lies in measuring the crowns and roots lengths by means of morphometric analysis and ratios.

The present study offers a database with their corresponding regression formulas derived from adolescents and young adults with original Polish background of Central Poland with different socio-economic status.

5. Conclusion

The relevant legal age range in Belgium courts hinges upon 18 years by which third molar root formation occurs with a high probability. The MG&H method delineates seven different scores for that specific developmental age span.

Finer differentiation of age classes in quarters of a year performs a better distinction between the scores of the individuals which can imply considerable medico-legal consequences.

There is a highly statistical significant difference in mineralization between both genders. Females mature at a slower rate than males. Third molars in the upper arch complete their root formation earlier than their antagonist.

Only in males a higher score in root development is reached in the upper right quadrants. In the lower jaw the antimeres are nearly equal in developmental rate for both genders.

Age estimation based on regression equations is more accurate in males.

Even the most powerful modeling technique for forensic age estimation is not accurate enough because of the high variable formation of third molars in individuals. Genetic and ethnic factors must be considered as elements affecting this developmental course.

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