



Human dental age estimation using third molar developmental stages: Accuracy of age predictions not using country specific information

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ABSTRACT

Unquestionable forensic age investigations are based on statistical models constructed on a sample containing subjects of identical origin as the examined individual. In cases where corresponding models are unavailable, the established report has to describe the possible effects of this unrelated information on the predicted age outcome. The aim of this study is to collect country specific databases of third molar development and to verify how the related dental age estimations are influenced if we were to use dental developmental information only from Belgium or from all collected countries together.

Data containing third molar developmental stages scored following Gleiser and Hunt (modified by Köhler) were collected from 9 country specific populations (Belgium, China, Japan, Korea, Poland, Thailand, Turkey, Saudi-Arabia and South-India). Age predictions were obtained from a training dataset and validated on a test dataset. Bayes rule using the repeated third molar scores is applied to get age predictions and prediction intervals. Three age predictions were compared for males and females separately. For the first prediction, the training dataset contains only Belgian subjects. For the second prediction, the training dataset for each country consists only of subjects of the country itself. For the final prediction, subjects from all countries are pooled into one common training dataset. Besides the (absolute) difference between the chronological age and the predicted age, specific interest lies in the juvenile–adult distinction.

In the age range from 16 to 22 years 6982 subjects (3189 male and 3793 female) were analyzed.

Using information on third molar development from Belgium compared to information from the country specific databases hardly increased the mean absolute differences (MAD) and mean squared errors (MSE): the MAD and MSE increased on average with 0.5 and 2.5 months with maximal increases of, respectively 1.6 and 7.3 months.

Using information from all countries pooled compared to country specific information provided even on average negligible increases (0.05 and 0.2 months for MAD and MSE, respectively). For the juvenile–adult discrimination, using information from all countries instead of country specific information yielded comparable performances. Using Belgium instead of country specific information increased the percentage of correctly identified juveniles, but decreased the percentage of correctly identified adults.

The adult–juvenile discrimination based on information used from Belgium provides judicially the best applied reference.

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1. Introduction

Forensic age estimations on living individuals are requisitioned to verify the chronological age of individuals who are, willfully or not, unable to deliver documentary evidence about

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their birth date or who's provided age related documents and statements are of doubtfully legitimacy [1–4]. The chronological age of these individuals is of legal pertinence in civil, criminal and asylum proceedings. Age authentication is established, using methodologies based on scientifically accepted research and contemporarily prescribed legal requirements symbiotically together [5]. These legal prerequisites oblige the investigator to apply the existing law regulations and to consider all requirements for indisputable investigation. Specifically in asylum procedures of unaccompanied young individuals the attainment of the age of majority, lawful in the country in which the asylum is requested, has to be considered. For this age threshold, dental age estimation methodology is modeled on retrospectively collected third molar developmental data. An undisputed dental age assessment requires a forensic investigation based on a sample of the same origin as the examined individual. If not, scientifically based information should be provided about the consequences of using unlike information on the validity of the reported age prediction.

The aim of this study is to collect country specific databases of third molar development to establish dental age predictions for the sub-adult group. Next will be verified how the use of third molar developmental information from specifically Belgium or from all collected countries pooled, influences the accuracy of the established dental age predictions.

2. Materials and methods

Archived panoramic radiographs, used for diagnosis and treatment planning were collected within 9 country specific populations. For each radiograph nationality, birth date and gender of the related individual was verified by use of the official birth certificate and (or) the identity card. The date of radiographic exposure was registered. It was checked if all included subjects lived a whole lifetime in their native country and if all individuals within a sample originated from the same biological group. In this ongoing data collection, actually, information from populations of Belgium (Be), China (Ch), Japan (Ja), Korea (Ko), Poland (Po), Thailand (Th), Turkey (Tu), Saudi-Arabia (Sa) and South-India (In) was assembled. The choice for country specific data collection allowed to discriminate socio-geographical as well as pure ethnical influences. In each of the samples, subjects in the age range between 16 and 22 years were retained for analysis and divided at random but stratified on age in a training and a test dataset. The test dataset was used to evaluate the performance of the model developed on the subjects in a training dataset. Additionally, from each country specific training dataset 100 male and 100 female subjects were randomly selected (given the differences in age distribution between the countries, a stratification on age was not feasible) and pooled. This pooled dataset will be denoted the total training set in the remainder. The total test set assembled all subjects from the country specific test datasets. On all the selected radiographs at least one third molar was present and subjects with a history of third molar extraction were excluded. Every available third molar was scored following the 10 point scoring system described by Gleiser and Hunt [6] and modified by Köhler et al. [7]. In case of doubt between two adjacent stages the corresponding radiograph was imported into image enhancement software (Adobe® Photoshop®, Adobe Systems Incorporated, San José, CA, USA) to compare the lengths of the concerned third molar and its preceding second molar [8]. Missing third molars received no value. Nine different observers scored the radiographs of an assigned country. Additionally in each country 10% of the

Table 1

Number of female and male subjects used in each country specific and total analysis and their partition in a training and a test dataset specified for each year interval in the range between 16 and 22 years.

		Age distribution											Total	
		Female						Male						
		16*	17*	18*	19*	20*	21*	16*	17*	18*	19*	20*		21*
Be	an	159	162	191	211	249	307	125	103	146	158	174	218	2203
	tr	80	81	96	106	125	154	63	52	74	79	87	109	1106
	te	79	81	95	105	124	153	62	51	72	79	87	109	1097
Ch	an	51	48	47	50	46	53	46	51	37	42	40	32	543
	tr	26	25	24	25	24	27	24	26	19	22	21	17	280
	te	25	23	23	25	22	26	22	25	18	20	19	15	263
Sa	an	52	59	44	62	59	54	54	51	48	58	58	51	650
	tr	26	30	23	31	30	27	28	26	25	30	30	26	332
	te	26	29	21	31	29	27	26	25	23	28	28	25	318
Th	an	68	62	82	68	70	69	65	64	66	76	68	63	821
	tr	34	31	42	34	36	35	33	32	34	38	35	32	416
	te	34	31	40	34	34	34	32	32	32	38	33	31	405
Tu	an	50	49	50	50	51	49	50	48	49	51	50	50	597
	tr	25	25	25	26	26	25	25	24	25	26	25	25	302
	te	25	24	25	24	25	24	25	24	24	25	25	25	295
Ko	an	54	54	55	57	53	57	52	53	63	57	55	50	660
	tr	28	28	28	29	27	29	27	27	32	29	28	25	337
	te	26	26	27	28	26	28	25	26	31	28	27	25	323
Po	an	50	46	48	44	70	84	36	45	35	25	39	30	552
	tr	26	24	25	23	36	42	18	23	18	13	20	16	284
	te	24	22	23	21	34	42	18	22	17	12	19	14	268
Ja	an	52	39	48	41	37	44	39	52	49	46	40	39	526
	tr	27	20	25	21	19	23	20	27	25	24	20	20	271
	te	25	19	23	20	18	21	19	25	24	22	20	19	255
So	an	44	50	53	48	27	16	37	39	32	43	25	16	430
	tr	22	26	27	25	14	8	19	20	17	22	13	9	222
	te	22	24	26	23	13	8	18	19	15	21	12	7	208
To	an	434	421	457	454	484	517	397	410	403	433	427	395	5232
	tr	148	142	154	143	159	154	150	161	147	160	157	125	1800
	te	286	279	303	311	325	363	247	249	256	273	270	270	3432

Be: Belgium, Ch: China, Ja: Japan, Ko: Korea, Po: Poland, Th: Thailand, Tu: Turkey, Sa: Saudi-Arabia, In: South-India, To: Total dataset, an: analyzed dataset, tr: training dataset, te: test dataset, 16* includes all individuals aged 16.00–16.99 years etc.

subjects were randomly selected and scored by a tenth investigator. All examiners repeated their scoring after 1 month.

Bayes' rule was applied to obtain age predictions for each possible combination of the four third molar scores. Details of this approach can be found in an earlier research [9]. Briefly, interest is in the distribution of age given a specific pattern of scores, the so-called *posterior distribution*. To obtain this distribution, one needs to specify the multivariate distribution of the ordinal scores given age (the *conditional distribution*) and the distribution of age (the *prior distribution*). For the conditional distribution of the scores given age, a generalized linear mixed model for multivariate ordinal data is used in each training dataset. A uniform distribution within the age range 16–22 years is used as prior distribution. The 50th percentile of the posterior distribution is used as point prediction.

The difference between observed and predicted age was calculated in each test dataset and mean absolute difference (MAD) as well as mean squared error (MSE) were used to quantify the performance. To understand the difference between both quantifications, note that larger differences receive relatively more weight in the MSE than in the MAD. All analyses were performed for female and male subjects separately.

The juvenile and adult distinction (set at the threshold of 18 years), was studied by calculation of the percentages of correctly identified adults, correctly identified juveniles and correctly identified subjects. Exact McNemar tests were used to compare these percentages between the various approaches.

All analyses were 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).

3. Results

Within the age range from 16 to 22 years 6982 subjects (3189 male and 3793 female) were included for analysis. 25277 third

molars were scored, implying that 9.5% third molars were absent. The number of female and male subjects included for each country and the total dataset were listed, separately for every training and test dataset per 1 year age range (Table 1). Kappa statistics revealed no significant intra- or inter-observer effects.

The MAD obtained with the use of country specific information, information from Belgium and information from the total dataset varied, respectively between 0.92 and 1.24 years, 0.89 and 1.29 years, and 0.87 and 1.24 years. For the MSE, these ranges were, respectively 1.24–2.30 years, 1.28–2.68 years and 1.29–2.32 years (Fig. 1).

Information from Belgium compared to information used from the specific country increased the MAD on average only with 0.5 month, with a maximal MAD increase of 1.6 months observed for females in Poland and males in India. For some countries, the MAD even decreased. The MSE was increased on average with 2.5 months.

Information used from all countries together compared to country specific information hardly changed on average the MAD (0.05 month) and MSE (0.2 month). Maximal increases were 0.7 and 2.7 months, respectively. Almost an equal number of situations were observed with decreases in MAD or MSE compared to increases.

The percentage correctly identified adults ranged between 72% and 93%, the percentage correctly identified juveniles between 33% and 87% and the percentage of correctly identified juveniles and

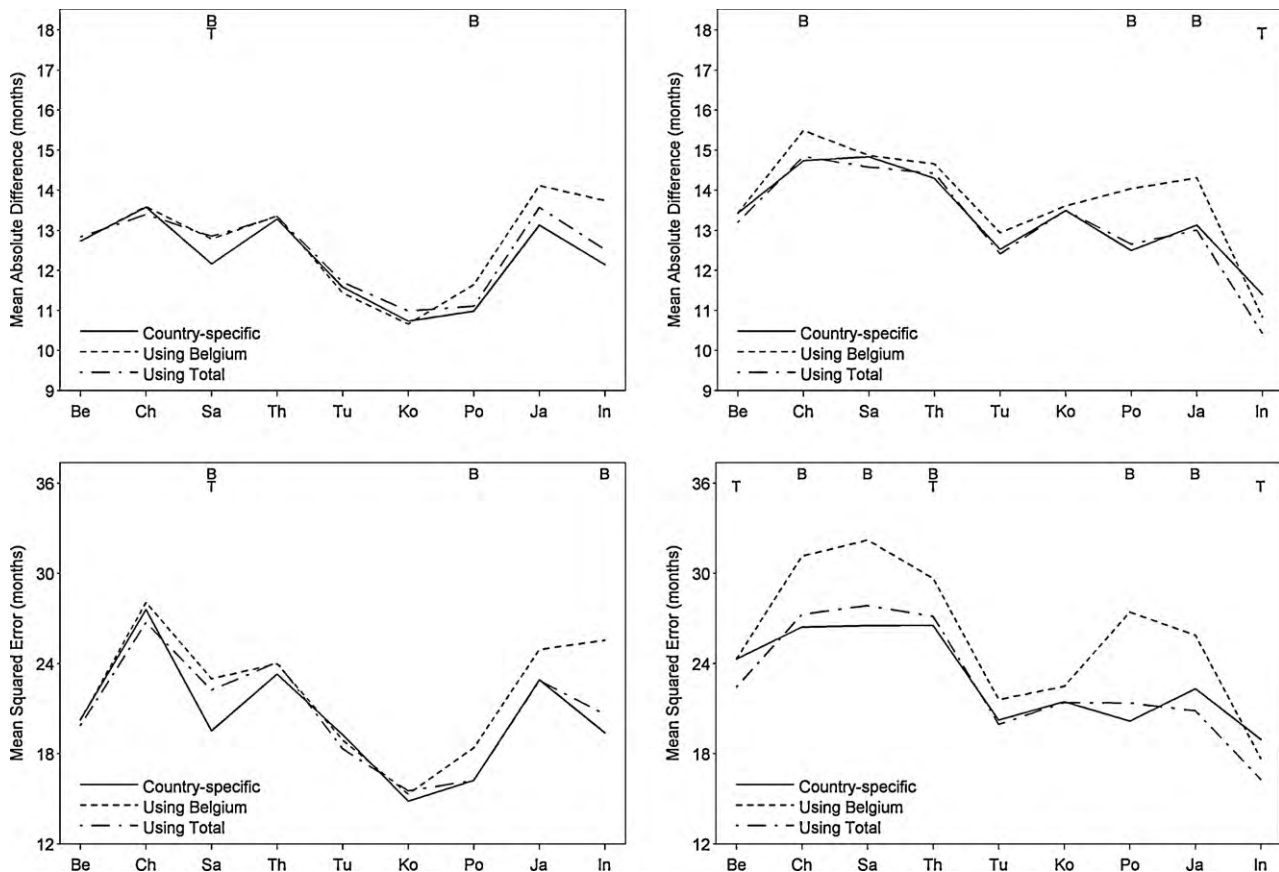


Fig. 1. Mean absolute difference and mean squared error, based on country specific information, information from Belgium and information from all countries pooled (total). Males (left panel) and females (right panel). Be: Belgium, Ch: China, Ja: Japan, Ko: Korea, Po: Poland, Th: Thailand, Tu: Turkey, Sa: Saudi-Arabia, In: South-India. T = significant ($p < 0.05$, paired t -tests) difference in mean absolute difference (MAD) or mean squared error (MSE) obtained when using total dataset compared to country specific information. B = significant ($p < 0.05$, paired t -test) difference in MAD or MSE obtained when using Belgian dataset compared to country specific information. The MAD obtained with information from Be is higher than the obtained country specific MAD, except for equal values found for Ch males and Sa females and lower values detected for In females together with Tu and Ko males. The MSE obtained with information from Be is higher than the obtained country specific MSE except for Tu males and In females. For both genders the MAD and MSE obtained with information from the total dataset is most alike to MAD and MSE values obtained with country specific information. Some differences in MAD or MSE are statistically significant but with low actual values.

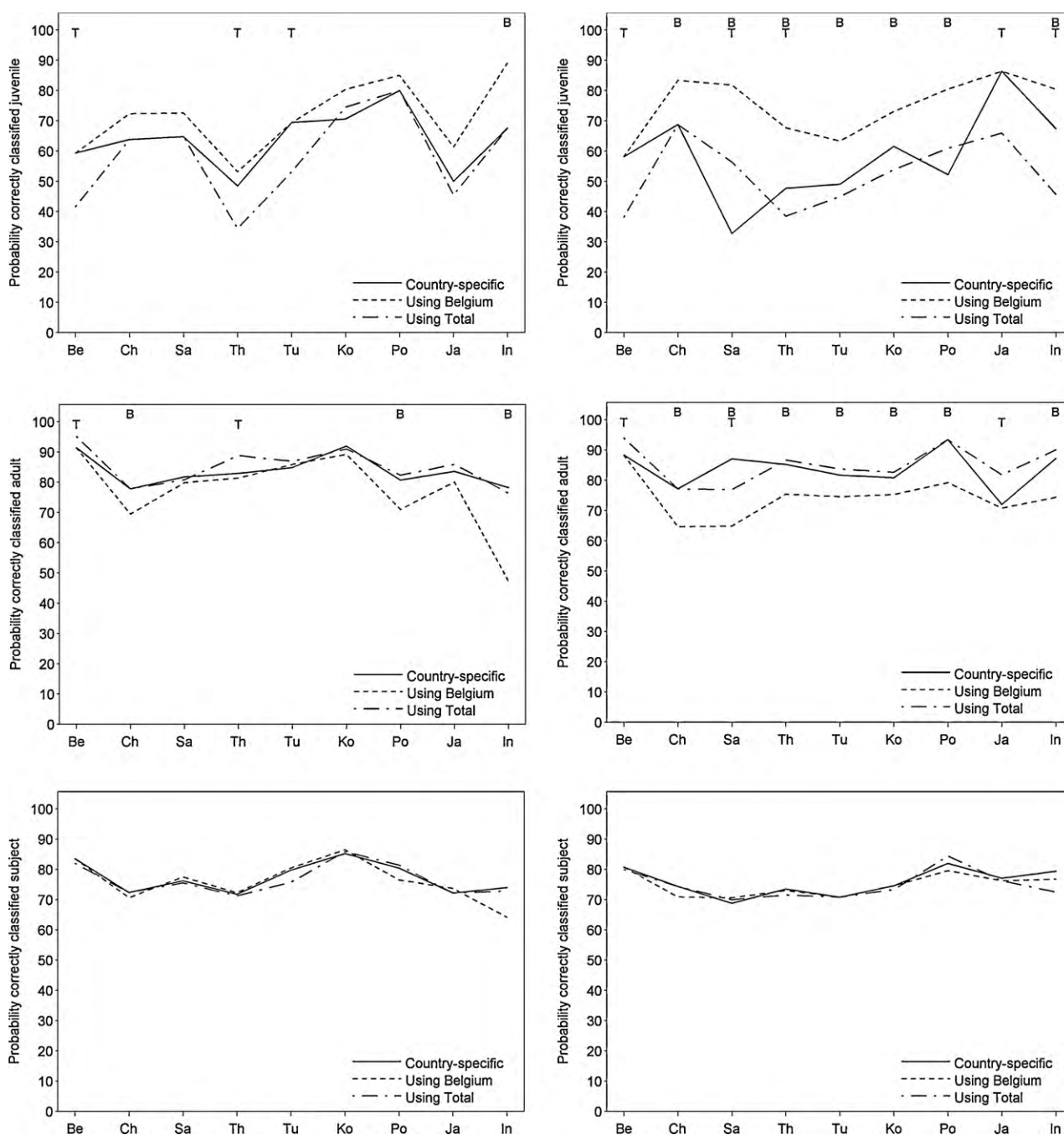


Fig. 2. Percentage of correctly identified juveniles, percentage of correctly identified adults, and percentage correctly identified subjects, based on country specific information, information from Belgium and information from all countries pooled (total). Males (left panel) and females (right panel). Be: Belgium, Ch: China, Ja: Japan, Ko: Korea, Po: Poland, Th: Thailand, Tu: Turkey, Sa: Saudi-Arabia, In: South-India. T = significant ($p < 0.05$, McNemar test) difference between percentage obtained when using total dataset compared to country specific information. B = significant ($p < 0.05$, McNemar test) difference between percentage obtained when using Belgian dataset compared to country specific information. Compared to information used of the own country and the total dataset, information obtained from Belgium results for all countries in more correctly classified juveniles and less correctly classified adults. These observations are less explicit for males compared to females. The percentage correctly classified subjects are for each gender and for the three different approaches highly overlapping.

adults (all subjects) between 71% and 85% (Fig. 2). There is no indication at all that not using country specific information influences the percentage of correctly identified subjects. However, using information from Belgium leads to a higher percentage of correctly identified juveniles at the price of a lower percentage correctly identified adults. Note that this phenomenon is more outspoken for females, i.e. observed differences are more clear and more often significant. The effect of the use of information from the total dataset on the percentages is less clear. In most situations, there are no significant differences between the use of the total

dataset and country specific information. In case of significant differences, these are positive as well as negative.

4. Discussion

The necessary sample size differs according to the considered research aim, meaning in this study differences between samples and related populations are sought. As an example the calculated sample size needed to detect clinically a difference of 6 months with 80% power between males from Belgium and China having

the same pattern of third molar scores would be 143 patients in each country (based on a two-sided *t*-test with $\alpha = 5\%$ and assuming a SD of 1.5 years). But the required sample size will differ according to the changing goal of the considered analysis: more Chinese subjects are needed to detect differences with Koreans than to detect differences with Belgians. Therefore, when taking into account the research aim, the planned sample size will be rather based on pragmatic limitations than on statistical considerations. Consequently in this study the pragmatic rule was applied and in each country 50 female and male subjects within each considered age range of 1 year were collected. Furthermore, based on an earlier collected database and subsequently performed statistics, the analyses in this study are restricted to subjects in the age range between 16 and 22 years [9].

During data collection a substantial difference appeared between the countries in their number of subjects and in their age distribution. Trying to perform the ideal distribution set-up which includes an equal amount of female and male subjects for each age range of 1 year, would have reduced the amount of information in most countries. Therefore all collected subjects in the age range between 16 and 22 years are included. In further research for each country the amount of subjects will be adjusted to obtain the numbers prescribed in the pragmatic rule, allowing to evaluate these results with current findings.

The evaluation based on the four repeated third molar scores renders information about all available third molars and their mutual agreement. Beside it avoids problems in analysis related to the frequent appearing agenesis of third molars [10–16]. In fact for each subject four third molar scores could be composed because only subjects with at least one third molar present were included and missing third molars received no scoring value. Moreover in the studied age category between 16 and 22 years third molar agenesis could be diagnosed because the earliest appearance is situated at the 3/4 root length maturation of the second molar [12], corresponding with a chronological age around 14 years. The finding that 9.49% third molars were absent has to be interpreted correctly in relation to the prevalence of third molar agenesis. In this study subjects with four missing third molars were excluded and no information is searched concerning the amount of subjects missing a corresponding number of third molars.

Information from Belgium compared to information used from the specific country increased the MAD maximally 1.6 months, using information from the total dataset reduces the maximally added error to 0.7 month. This denotes a relative small increase compared on the one hand to the obtained maximal country specific MAD of 1.24 years and on the other hand to the overall 7 years range between the lowest and highest detected country specific MAD. It can be concluded that the observed aging results based on country specific information do not overrule the predicted age outcomes obtained with information from Belgium or the total dataset. This implicates that if country specific information is absent, information from Belgium or combined countries can be used when an increased error of at least 1.6 months is taken in account. The constructed models allow to calculate the exact age differences to consider if information from another of the investigated countries instead of Belgium would be needed.

Liversidge et al. [17] found, based on a meta analysis of earlier published data from eight countries (Australia, Belgium, Canada, England, Finland, France, South Korea, Sweden) collecting information of the development of all (left) mandibular permanent teeth (except third molars), that there is a lack of consistent population difference in the timing of dental formation. Braga et al. [18] collected three geographic population samples (European, Asian, African) together with a sample of French children (having one or more of their grandparents not originating from Europe) and

studied the influence of geographic specific standards on the quality of Bayesian age predictions. Their results indicate that non-adult Bayesian age predictions on the dental mineralization sequences of the seven (left) mandibular permanent teeth (except third molars) do not guarantee better quality levels for geographic specific standards. The results of previous authors are completely in line with the findings in current study. However in studies comparing different populations particularly based on third molar development Liversidge [19], Harris [20] and Blankenship et al. [21] found significant evidence of faster third molar development in black populations compared to white populations. Martin-de las Heras et al. [22] discovered slower third molar mineralization in a Spanish compared to a Magrebian population, Olze et al. [23] detected significant differences in the chronology of third molar mineralization between German and Japanese populations and Kasper et al. [24] concluded on the comparison of own findings from a Hispanic population and the results of Mincer et al. [25] on a Caucasian population that third molar development is faster in Hispanics. These differences in third molar development tend to presume that using third molar information from another country for the prediction of an individual's age would result in estimations with highly increased margins of errors. But, the performances of the test databases on country specific information render, due to the high inherent human variability of the third molar development wide and less accurate confidence intervals [9,26]. This makes the additional error made by using information from another country relatively small.

The precision of the estimated age differences is possibly affected by fluctuations in the sample size of the evaluated countries. This probably ignorable influence on current results will have to be checked after additional data collection and sample resizing in further research.

The population differences found by Liversidge [19] were described as the result of an earlier initiation and completion of third molar maturation in a Black South African population and suggests a shift in timing of initiation compared to the other investigated populations. Harris [20] reported among races unequal temporal differences between all morphological stages. Blankenship et al. [21] detected that blacks achieved the early root developmental stages much earlier than whites and described more complex variations in the final developmental stages. The analysis of Martin-de las Heras et al. [22] began at the stage of crown completion. Olze et al. [23] observed significant differences between Japanese and Germans in the stages between crown completion and root length equal to or greater than crown height. These findings show that limiting in this study the subjects to the 16–22 years age category and thus restricting the study to a part of the third molar developmental sequence, did not exclude its population related maturation differences. In fact shifts and differentiations in third molar timing appear spread over its initial as well as its accomplishing stages.

Existing age predicting studies based on third molar development searching for population influences, compare the results obtained from the modeling of their new, or from existing studies collected, population samples [19–24]. In this study country specific models are constructed and the performance of test samples is validated. This approach avoids the influence on the studied performances of a, for each country and the total data set, changing over-optimism in used age predictions. Moreover dividing the data in training- and test-sets prevented possible influences of the use of resampling techniques [18,27] on the estimated age outcomes.

The separate evaluation of the performances for female and male subjects revealed gender related differences for outcomes based on country specific, Belgium and total dataset information. No overall gender specific conclusion could be drawn, except that

to reduce the prediction errors, if available, female or male specific models should be applied. Current approach confirms this overall accepted rule in forensic age estimation. Because the diagnostic value of the evaluated performances is related to living individuals with known sex, it was not relevant to determine possible faults made by exchanging the gender. Furthermore pooling female and male subjects to establish a reference in case the sex of the examined individual is not known, was for identical reason, not investigated.

Using information from Belgium compared to country specific information results in a lower sensitivity, indeed the predicted ages are under estimated implicating that less subjects older than 18 years (adults) are detected. Related the specificity is higher because more subjects younger than 18 years (juveniles) are found in the under estimated age outcomes. Moreover the accuracy of this performance is nearly uniform to the found country specific values. When discriminating juveniles from adults specifically the Belgium information is providing an excellent judicial reference, because its lower sensitivity detects less adults and its higher specificity selects more juveniles, legally spoken an advantage of the doubt for the individual under examination. Using information from all countries together revealed, compared to country specific information, an overall sensitivity and specificity fluctuating in the nearness of the country specific proportions, providing a scientifically reliable reference.

5. Conclusion

Verified on 9 country specific databases the use of information from Belgium, or all countries together changes the difference between observed and predicted age obtained on country specific information only slightly. For the adult–juvenile discrimination, information used from Belgium provides judicially an overall better reference, information from the total dataset provides similar results compared to the outcomes based on information from the specific country.

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