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The chronology of third molar mineralization in the Austrian population—a contribution to forensic age estimation

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Abstract

The aim of the present study was to determine the chronology of third molar mineralization and to establish Austrian reference data. Therefore, a cross-sectional study was undertaken by evaluating 610 panoramic radiographs in order to assess the mineralization status of the mandibular third molars of Austrian male and female individuals (275 males and 335 females) between the ages of 12 and 24.

The evaluation was carried out using the eight grade scheme of Demirjian et al. (1973). Mean ages, standard deviations, standard errors and percentile distributions are presented for each stage of development. Significant differences between the left and right mandibular third molars were not found. Males reach the developmental stages earlier than females, statistically significant differences were noted in stages E and F. Both mandibular third molars were observed in the majority of the individuals of the Austrian sample (477 individuals, 78.2%). For medicolegal purposes the likelihood of whether an Austrian individual is older than 18 years or not was determined.
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1. Introduction

In recent years, the research area of forensic age estimation has gained increasing importance as shown by rapidly rising numbers of age assessment procedures in the German language region [1,2]. A forensic age diagnosis is a combination of methods which can be used for verification of age to determine if legal age for criminal responsibility has been reached or not. It is applicable in cases of persons without valid identification documents.

Austrian law defines the 18th birthday of an individual as the relevant age limit for reaching adult status. According to the recommendations of the interdisciplinary Study Group on Forensic Age Diagnostics, age estimation of living persons involved in criminal proceedings should include a physical examination, an X-ray of the left hand, a recording of the dental status and an evaluation of a panoramic radiograph.

Radiographic assessment of the degree of third molar formation is a major part for forensic age estimation of adolescents and young adults. Due to the fact that all other permanent teeth have finished their development in this age group [3], third molars represent the only teeth still in development. Previous findings showed that the mineralization of the wisdom teeth is a population specific process and does not occur in every ethnic group at the same age [4,5]. Therefore, it is crucial to use population specific reference data in forensic age estimation of living people.

Third molars are the teeth with the highest variability concerning anatomy, agenesis and age of eruption [3,6–8] and therefore its significance as developmental marker has been questioned. Age estimation for medicolegal purposes by means of third molar development is used in absence of other biological parameters during late adolescence and early adulthood. It should be kept in mind, that the results of some

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studies should be analyzed critically because of heterogeneous samples, small sample sizes or uncalibrated observers.

In the past, a number of methods were used to evaluate dental mineralization [9–12]. A comparison of these methods is difficult because of different design, number of evaluated teeth and stages. The eight grade scheme of Demirjian et al. [6] was developed for dental age estimation of children based on the first seven teeth. The authors proposed a scoring system which has been subject to critical considerations [13–17].

Only a few studies are available on third molar mineralization in late adolescence; Demirjian's stages are for reasons of accuracy [18] and practicability frequently used [4,5,19–23].

The aim of the present study was to establish Austrian reference data on third molar mineralization evaluated according to the eight stages proposed by Demirjian et al. [6]. In order to estimate the frequency of wisdom teeth, the prevalence of third molars in both of the lower quadrants was assessed. From a medicolegal perspective, we determined the likelihood of whether an Austrian individual is at least 18 years old, which indicates adult status in Austria.

2. Materials and methods

The cross-sectional sample consisted of 610 orthopantomograms taken between 2002 and 2004 at the Bernhard Gottlieb University Dental Clinic, Vienna. The radiographs of 335 females and 275 males between the ages of 12 and 24 years (Table 1) were collected randomly over a period of 3 months. In the present study, it was focused on analyzing a sample which is representative for the Austrian population. Therefore, individuals with foreign surnames were excluded in order to get a homogenous Austrian sample. The individuals treated at the University Dental Clinic are of different social classes and live in various regions of Austria. The anamnesis sheet of each individual was copied, and, if required, parts of the medical history. From the medical data, possible diagnostical findings, medications, orthodontic treatment and oral surgeries were recorded. Because of the satisfying data for each individual, it was decided not to make further exclusions in order to get information about possible outliers.

From each orthopantomogram, three digital pictures with different exposure times were made to compensate for the unequal brightness of the radiographs.

The mineralization of both mandibular third molars was evaluated following the eight grade scheme proposed by Demirjian et al. [6]. All ratings were assessed by the same observer (A.M.).

Intra- and inter-observer reliability was tested by reexamining 70 radiographs after several months. The orthopantomograms were chosen at random from the total sample and reevaluated under blinded conditions by the first observer (A.M.). The same radiographs were rated by a second observer (B.M.), who passed an initial training. Statistical comparison was performed using a paired *t*-test assuming a significance level of 5%.

Statistical analysis was performed using SPSS 10.0 and 13.00 for Windows (SPSS Inc., Chicago, IL), Microsoft® Excel 2000 for Windows and InStat for Mac® (GraphPad Software Inc.). Absolute and relative numbers of mandibular third molars in the Austrian population were determined. Mean ages with standard deviation and standard error at each developmental stage were calculated. Percentile distributions for both sexes at each stage were assessed.

Table 1
Number of individuals per age group and sex

	Age (years)													Total (*n*)
	12	13	14	15	16	17	18	19	20	21	22	23	24	
Male	7	12	13	16	15	15	18	22	29	29	34	36	29	275
Female	15	11	14	19	17	23	29	30	34	33	44	39	27	335
Total	22	23	27	35	32	38	47	52	63	62	78	75	56	610

Table 2
Age of individuals by sex

	Males	Females	Total
Number of individuals	275	335	610
Minimum age	12.08	12.01	12.01
Maximum age	24.95	24.96	24.96
Mean age	19.98	19.73	19.84
95% C.I.	19.56; 20.39	19.36; 20.10	19.57; 20.12
S.D.	3.48	3.42	3.45

Additionally, the data was plotted to describe the association between score and age. For the convenience of statistical analysis, the data was subgrouped into 1-year age classes. The score was calculated by means of correspondence analysis with subsequent rescaling between 1 and 100. To demonstrate mandibular third molar mineralization at each stage, growth curves with the age as a function of attained stage in percent of the stages C-H were created. For this purpose, the following logistic equation was employed: $f(x) = 1/(1 + \mathrm{Exp}(a + b \times x))$. To determine the coefficient of determination (R^2) of each fit, the ratio of the difference between the corrected total sum of squares and the residual sum of squares was calculated. Unpaired *t*-tests were performed to evaluate developmental differences between both mandibular molars. Sex differences were determined using the Mann–Whitney *U*-test. For each stage, the likelihood that the individual was at least 18 years of age was calculated.

3. Results

Statistical analysis did not reveal significant intra-observer or inter-observer differences by repeated scoring of a subsample of 70 orthopantomograms ($P > 0.05$). Inter-examiner agreement was found in 85.0%, with no difference between two ratings exceeding more than one developmental stage.

The mean age of the 610 individuals of the analyzed sample was 19.84 ± 3.45 years, ranging from 12.01 to 24.96 years (Table 2).

Fig. 1 details the absolute and relative numbers of mandibular third molars in the Austrian sample. Both sexes were pooled for this analysis, because it was not possible to exclude individuals with previous extractions. Four hundred seventy seven (78.2%) out of 610 individuals possessed both lower molars. One mandibular third molar was recorded in 69 (11.3%) individuals; no lower molars were recorded in 64 (10.5%) cases.

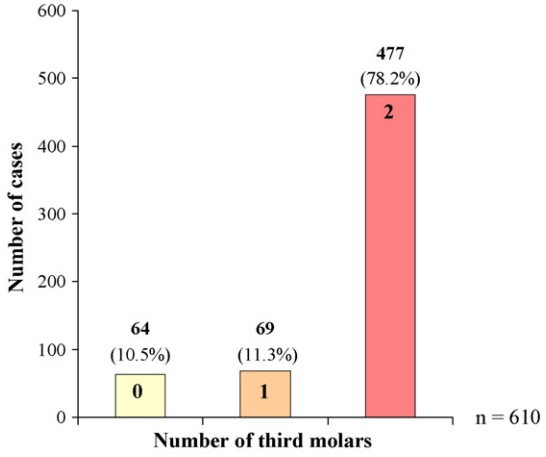

Fig. 1. Number of mandibular third molars.

Table 3
Mean ages, S.D. and S.E. at each stage for tooth 38

	Female (mean)	S.D.	S.E.	Male (mean)	S.D.	S.E.
A	12.6	–	–	–	–	–
B	12.3	0.3	0.1	12.7	0.4	0.2
C	14.6	1.6	0.4	13.7	1.0	0.3
D	15.4	1.8	0.4	16.1	2.3	0.6
E	17.8	2.5	0.5	15.6	1.8	0.4
F	18.4	2.4	0.4	17.5	2.6	0.6
G	20.3	2.1	0.2	20.1	2.1	0.3
H	22.9	1.3	0.2	22.4	1.8	0.2

Table 4
Mean ages, S.D. and S.E. at each stage for tooth 48

	Female (mean)	S.D.	S.E.	Male (mean)	S.D.	S.E.
A	12.3	0.5	0.3	–	–	–
B	12.4	0.4	0.2	12.7	0.4	0.2
C	13.8	1.3	0.4	13.5	1.0	0.3
D	15.5	2.0	0.5	15.3	1.6	0.4
E	17.2	2.8	0.6	15.1	1.6	0.4
F	18.5	2.3	0.3	17.6	2.0	0.4
G	20.5	2.2	0.2	20.1	1.9	0.3
H	22.8	1.4	0.2	22.5	1.8	0.2

Tables 3 and 4 chart mean ages, standard deviation and standard error of each developmental stage for the teeth 38 and 48, which are subdivided by gender. The correlation between chronological age and Demirjian's stages is expressed in Figs. 2 and 3.

There is a trend for earlier third molar formation in females which becomes apparent at the early crown formation stages which show a slightly advanced development in females than in males. At the developmental stage B, girls reach the indicators for this stage about 0.4 years earlier than boys. But there is a

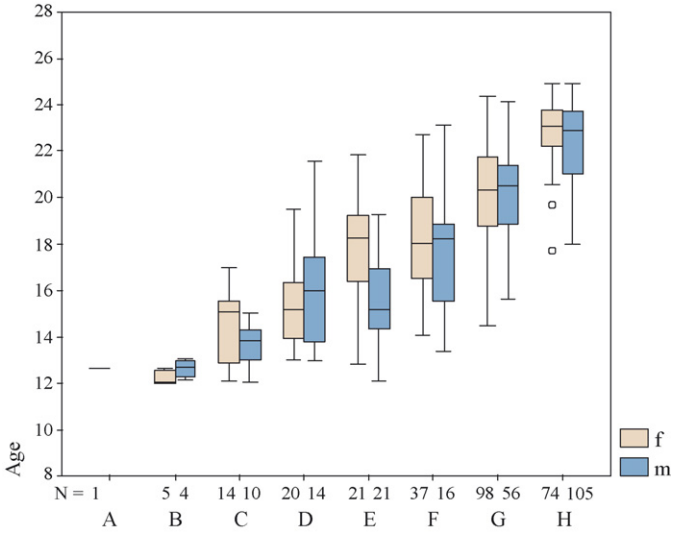

Fig. 2. Box plots of the correlation between chronological age and Demirjian's stages for tooth 38. Outliers are marked with ○.

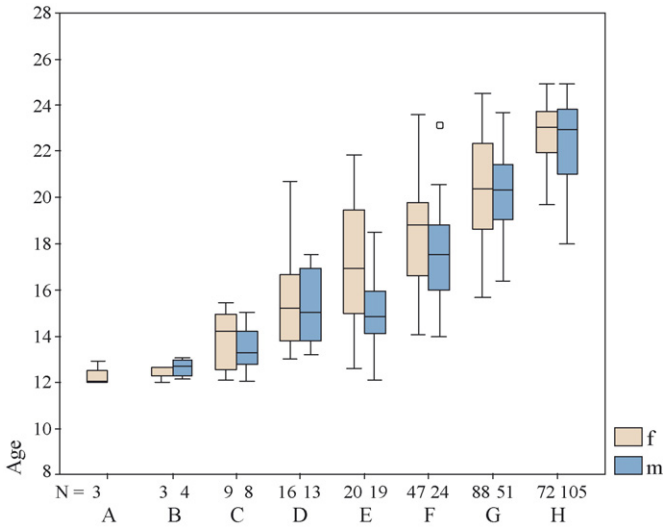

Fig. 3. Box plots of the correlation between chronological age and Demirjian's stages for tooth 48. Outliers are marked with ○.

faster rate of formation in the male individuals that becomes strongly evident at stage E with boys reaching the corresponding criteria more than 2 years earlier. This result is consistent in the following stages with males being approximately 6 months ahead of the Austrian females (Fig. 4).

The score as a function of age is presented in Fig. 5. The score used here does not correspond to the maturity score originally used by Demirjian but gives an idea about the mineralization rate in each age group. According to the slope of the graph, third molar mineralization seems to occur faster in young individuals and decreases when the formation is almost finished. It can also be seen that the female mineralization, which is faster at the beginning of tooth formation, gradually decreases and stays finally at a lower level than the male one.

A statistically significant sexual dimorphism was noted for stages E ($p < 0.01$) and F ($p < 0.05$). The data is presented in Tables 5 and 6 as percentile distribution to point out the faster rate of third molar mineralization in male Austrians.

Table 5
Age distribution expressed in percentiles for tooth 38

	10	25	50	75	90
H, male	19.7	21.0	22.9	23.8	24.5
H, female	21.2	22.2	23.1	23.8	24.6
G, male	16.8	18.8	20.5	21.5	22.6
G, female	17.6	18.7	20.4	21.7	23.5
F, male	13.8	15.5	18.2	18.9	21.3
F, female	15.1	16.5	18.0	20.0	22.1
E, male	14.1	14.3	15.2	17.0	18.4
E, female	13.9	15.7	18.2	19.4	20.9
D, male	13.1	13.7	16.0	17.5	19.8
D, female	13.2	13.9	15.2	16.4	18.4
C, male	12.1	12.9	13.8	14.5	15.0
C, female	12.2	12.8	15.1	15.7	16.6

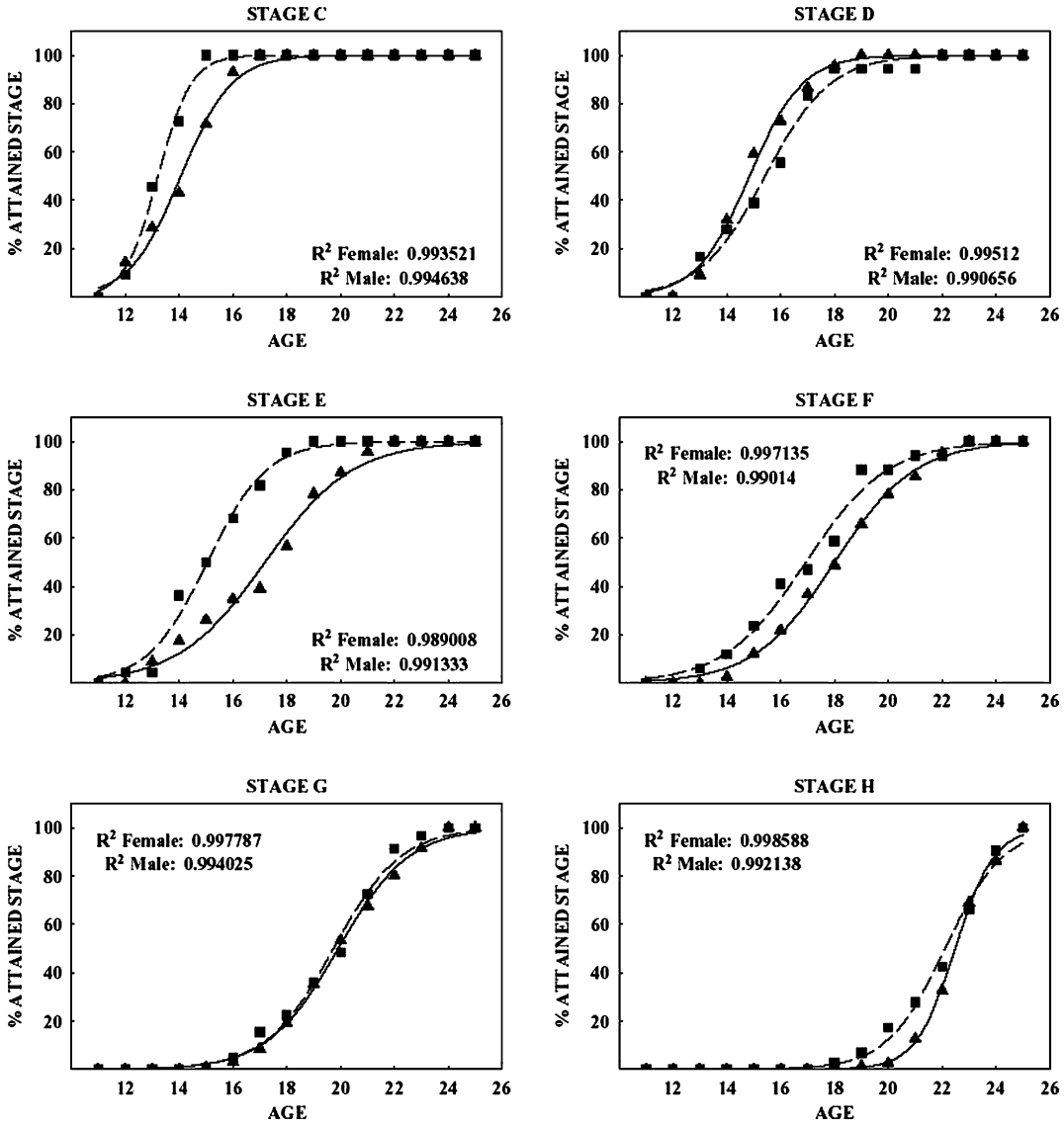

Fig. 4. Age as a function of attained stage in Austrian males (■) and females (▲) for Demirjian's stages C–H, including the coefficient of determination (R^2) of each fit.

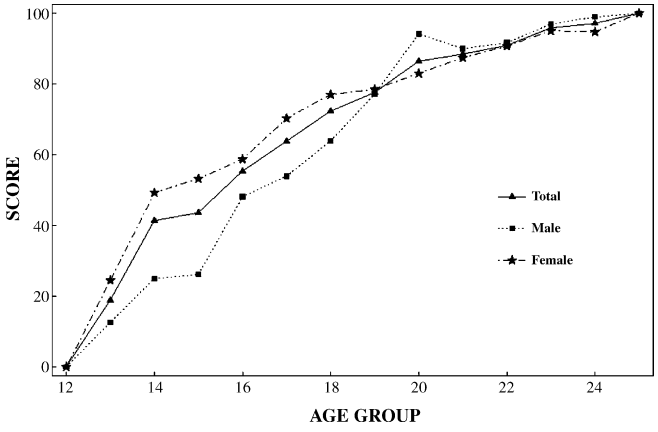

Fig. 5. Age as a function of score in Austrian males, females and total values of fourteen age groups using values derived from Correspondence Analysis. Rescaled.

Table 6
Age distribution expressed in percentiles for tooth 48

	10	25	50	75	90
H, male	20.0	21.0	22.9	23.9	24.5
H, female	20.8	21.9	23.0	23.8	24.7
G, male	17.0	19.0	20.3	21.6	22.4
G, female	17.5	18.6	20.4	22.4	23.3
F, male	15.3	15.9	17.5	18.8	19.9
F, female	15.1	16.6	18.8	20.0	21.3
E, male	13.0	14.1	14.9	16.1	18.3
E, female	12.9	14.9	17.0	19.5	21.5
D, male	13.3	13.7	15.0	17.0	17.3
D, female	13.1	13.8	15.2	16.9	18.7
C, male	12.1	12.6	13.3	14.2	15.1
C, female	12.1	12.5	14.2	15.1	15.5

Table 7
Likelihood of an Austrian individual being over 18 years of age based on Demirjian's stage H

	Male	Female
48	100.0	100.0
38	99.1	98.7
Mean	99.5	99.3

With completed mineralization of the mandibular third molars at stage H, 90% of the individuals are 18 years of age or older. Seventy five percent of male and female individuals are already 16 years old when they reach the developmental stage D.

The development of the right and left side mandibular third molars was compared using unpaired *t*-tests. Statistically significant differences between the two sides were not found.

Based on Demirjian's stage H, Table 7 expresses the likelihood of an Austrian being at least 18 years of age. The likelihood of an individual to have reached adult status with fully developed mandibular wisdom teeth amounts to 99.5% for males and 99.3% for females. Additionally, one individual of the male subsample (out of 105 cases) and one individual of the female subsample (out of 74 cases) were found to present complete root formation of tooth 38 before their 18th birthday. Respectively, all orthopantomograms showed a completed root formation of tooth 48 at 18 years of age or more (105 males, 72 females).

4. Discussion

Demirjian et al. [6] distinguished four crown stages and four root stages in their mineralization scheme. They used figures (A–H) instead of numbers to prevent the impression of an equal duration of each stage. Moreover, no absolute measurements have to be taken and estimations about future root lengths are not necessary. Hence, the use of Demirjian's stages in forensic age estimation is easy to implement and is practical. As seen in the literature [4,5,19–24] Demirjian's stages are used to assess third molar mineralization in adolescents and young adults.

Prieto et al. [23] analyzed 1054 orthopantomograms of a Spanish population between 14 and 21 years of age. In comparison to this study, stage C is reached by individuals of the Austrian sample about 0.8–1.3 years earlier. This slight developmental advance of Austrian subjects continuously diminishes in the following stages. At stage H (apex closure), Spanish individuals complete the wisdom teeth mineralization 2.8–3.2 years earlier than Austrians (sample size and age range of the Spanish population suggest critical observation). This finding is consistent with the study of Mincer et al. [21] and Arany et al. [19]. In relation to American individuals, as well as to Japanese subjects, Austrian individuals enter only the early stages at a younger age. Stages F to H are reached later, with an advancement of 2.0 years when compared to American subjects and 0.9–1.1 years when compared to Japanese adolescents at stage H. This finding is inconsistent when compared to data from Japanese individuals of a study performed by Olze et al. in 2004, which revealed an obvious heterogeneity when compared to the results of others [19]. This might be due to sample selection or differentially calibrated observers. Compared to individuals of South African origin [5,24], gender differences seem to become apparent. Austrian male individuals reach stages F to H up to 1.1 years earlier; women of the Austrian sample met the criteria for the same developmental stages 0.5–1.1 years later than their South African counterparts. The results of studies performed by Olze et al. [22,24] suggest a slightly faster mineralization rate in Austrian than in German individuals. The individuals evaluated by these authors were up to 1.5 years older when they reached the stages than the Austrian individuals. Only stage E was passed by female subjects of the German population about half a year earlier.

The male and female data were pooled to evaluate the frequency of mandibular third molars, because sufficient data about possible previous extractions of the individuals was not available. Therefore, it was focused on the determination of the number of individuals who can be evaluated by the presence of their mandibular wisdom teeth. Thus, 477 individuals or 78.2% of the Austrian population can be evaluated by two radiological observable mandibular third molars. Sixty nine individuals (11.31%) showed only one, 64 (10.5%) no third molar. Although the sample may include individuals with extractions, these results are in good accordance with previously reported data [25].

No significant side differences of mandibular third molar mineralization in both genders were found. This trend was confirmed by other studies [19,21–23,25–28]. Differences observed in practice may be due to coincidence and usually do not amount to more than one stage.

The results of this study show a faster development of third molars in Austrian males than females and did not differ from findings of previous studies [3,8,10,19,21,23,25,27]. This is a unique trait of third molars which expresses the sexually dimorphic character of tooth formation. Levesque et al. [25] demonstrated that Franco-Canadian males are reaching Demirjian's stages earlier than girls beginning with stage F. Prieto et al. [23] found a significant sexual dimorphism in stages E to G with males reaching the stages described by Demirjian et al. [6] earlier. In the Japanese Population investigated by Arany et al. [19], males entered the stages earlier than females; a significant gender difference was observed in the stages D, E and G. In line with these findings are reaching male individuals of the Austrian population the root formation stages (E–H) earlier than females. A significant difference was found in the stages E and F.

Many studies exclude individuals with any kind of pathology or irregular tooth development from further investigation. Insufficient space or a mutated axis of the germ do affect the eruption or inhibit this process [23–30]. Impacted third molars are thought to have delayed root formation [10]. However, a total exclusion of individuals with an impaired tooth development from reference studies has practical implications. Thus, odontological age estimation is only applicable to individuals with a regular dental status. Friedrich et al. published a study with 1053 subjects in order to evaluate the root formation of impacted third molars. The authors could

demonstrate that retained third molars are not associated with impaired root formation [7].

Schmeling et al. [31] published for the Study Group on Forensic Age Diagnostics recommendations on the estimation of living persons involved in criminal proceedings. As noted by Wedl et al. [32], the authors defined requirements on reference studies which should be the subject of critical reconsideration. Under question are the terms ''genetic-geographic origin'', ''socio-economic status'' and ''state of health'' which must satisfy the recommendations of the AGFAD. Some of the studies referred to by Schmeling et al. [31] do not fulfil these standards. A standardized quality of reference studies has to be attained. But how far are ''socio-economic status'' and ''genetic-geographic origin'' reliable in a study? First these parameters must be well-defined, second the ethical aspects of these terms should be taken into account. Another question arises when the state of health must be determined. Besides the inaccurate definition, the opinions about influencing factors on tooth development widely differ.

Factors which do influence tooth formation, development and eruption are hard to detect. Acute systemic illnesses are currently discussed just like chronic diseases such as renal insufficiency, hypocalcaemia, hypothyroidism, but also malnutrition and sexual maturity [33–36]. A different approach was proposed by Pelsmaekers et al. [37] using a longitudinal study design. The authors evaluated the root formation of monozygotic and dizygotic twins and developed an ACE-model (additive genetic, common environmental and specific environmental). Based on this model, less than 8% of variance was attributed to specific factors. Radiation therapy seems to have an impact in the sensitive phases of germ and root formation [38,39], just as an impairment of the germ by fracture [40]. Within the scope of some genetic diseases like Apert- [41], Williams- [42], Turner- [43,44] and the Fragile X-Syndrome [45], impairment in root formation has been described. The last named two diseases might be of particular importance for age estimation because an advanced root development was demonstrated. As noted by Rösing [46], a high number of affected evaluated individuals would limit the applicability on healthy individuals. On the other a hand, complete exclusion does not reflect reality and inhibits further analysis of possible influence factors.

For these reasons, it was decided to include all Austrian individuals for assessment and to take a closer look at possible outliers for further analysis. Surprisingly, none of the outliers possessed any characteristics associated with an altered growth. On the other hand, individuals with severe diseases who were estimated to be possible outliers showed no precarious findings. According to these results, the assumption is supported that tooth development underlies strong regulation mechanisms which seem hard to affect, even under pathological conditions.

According to the results of previous studies, Demirjian's developmental stage H could serve as a useful developmental marker to answer the question whether an individual is already considered as an adult. This stage marks the easy recognizable, fully mineralized tooth with apex closure. Therefore, the probability for an individual being older than 18 years was determined (Table 7). The calculated percentages indicate the degree of confidence whether a person has reached the age of 18 years. In the present sample, only two cases being younger than 18 years of age at the Demirjian's stage H were detected. The analysis showed, that the finished third molar mineralization indicates that the probability that an Austrian individual is at least 18 years old, is 99% certain.

5. Conclusion

The present investigation provides representative data on mandibular third molar mineralization in the Austrian population. It can be concluded, that in the case where two mandibular molars are present, the probability for an Austrian individual to be at least 18 years is 99.5 or 99.3% for males and females, respectively in the case were tooth mineralization is completed (Demirjian's stage H). These results indicate that Demirjian's stage H might constitute a helpful marker in age estimation for medicolegal purposes; nonetheless wisdom tooth mineralization can always only be seen as just one detail in the interplay of structural chances during human growth. One should keep in mind, that age estimation by means of third molar mineralization is always limited due to biological variance. The obtained data may not be valid in other populations; therefore future research of third molar mineralization is necessary in order to make population specific reference data accessible for practical use. Moreover, an evaluation of the combination from the AGFAD recommended three methods is essential to demonstrate the accuracy of the procedure and to provide standardized quality in forensic age estimation. Although Schmeling et al. [2] published a verification of age estimation in living persons at the hospital Charité, which was performed in line with the recommendations of the AGFAD, it is not verified yet if this method increases the accuracy of age estimation as expected.

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